Design of a Monitoring Program for Ash Pond Effluents

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EPA REVIEW NOTICE

Design of a Monitoring Program for Ash Pond Effluents

by

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ABSTRACT

The objective of this research was to develop a procedure for designing a sound monitoring program for fossil-fueled power plant ash pond effluents. Those factors which influence the effluent characteristics and are of importance in designing a sound ash pond monitoring program were determined based on a review of the plant operating characteristics and ash pond effluent characteristics for the TVA fossil-fuel power plant system. A statistical procedure for determining the sampling frequency of chemical characteristics in ash pond effluents was then developed based on the following equation:

$$n = \frac{t^2 S^2}{L^2}$$

where n is the sample size,

> t is the value of "student's" t for a given significance level,
>
> L is the precision, and
>
> S is the sample standard deviation.

The precision is given by $\mu-\bar{X}$ where μ is the population mean and $\bar{X}$ is the sample mean. Two methods of determining the precision were presented. The first involves selecting a precision value in order to estimate the population mean within a given percentage. This method gives the number of samples required to estimate the population mean within some degree of certainty. The second involves calculating a precision value by subtracting an estimate of the population mean from either the ash pond effluent limitation established by EPA or a desirable water quality criterion. This method gives the number of samples required to show that the effluent is in compliance with the effluent limitation or below the water quality criteria. The method chosen to compute the precision depends on the purpose of the monitoring program.

The use of this procedure was demonstrated for two of TVA's ash pond systems. Example monitoring programs utilizing this procedure indicated that the sampling effort for trace metals in the ash pond effluent at both plants could be substantially decreased. This procedure should be a useful tool to managers in determining the resources needed for monitoring. The procedure may also be used to indicate when part of the investment in pollution control measures may be justified to offset the cost of monitoring to show compliance.

The major limitations of the procedure are that: (1) It relies on maintaining the same type of power plant and ash pond operating conditions in the future as were used during the period when the design data set was collected; (2) it depends heavily on the establishment of effluent limitations; (3) the effluent must be in compliance; and (4) it cannot be applied generically to all ash pond effluents, but must be applied individually to each effluent.

INTRODUCTION

The Tennessee Valley Authority (TVA) in conjunction with the Environmental Protection Agency initiated a study entitled "Characterization of Effluents from Coal-Fired Utility Boilers," to characterize the various effluents associated with coal-fired generating facilities. As part of that study a procedure for designing an ash pond effluent monitoring program to fulfill the requirements of the National Pollutant Discharge Elimination System was initiated and demonstrated for two of TVA's power plants. The procedure is such that it can be applied to other ash pond effluents outside of the TVA system. The information presented in this report represented conditions as they existed up to January 1978. These conditions are subject to change due to plant modifications made in an effort to achieve full compliance with NPDES permit requirements.

The Tennessee Valley Authority operates 12 coal-fired power plants which supply approximately 65 percent of the system's total power generation (28 million kilowatts). In 1975, approximately 34 million tons of coal were burned resulting in an estimated 5.3 million tons of ash material. This ash material is comprised of varying portions of pyrites, bottom ash, and fly ash depending on the method of firing, source of coal, and fly ash collection systems used at the plant. The fly ash can be further classified as mechanically collected (MC) or electrostatically hot and cold collected (ESP). The majority of this ash material is transported hydraulically from the point of production to a settling and disposal pond. A typical ash sluicing and disposal system is shown in Figure 1. The water used for sluicing the ash to the pond is then discharged back to the original receiving stream. In 1975 this resulted in an average effluent discharge of greater than 240 MGD for the total TVA system, or about 13,200 gpd per MW.

In 1967 TVA initiated a periodic sampling program of the surface water discharges from these coal-ash disposal ponds. In 1970, TVA began collecting weekly grab samples and analyzed the samples for pH, alkalinity, hardness, conductivity, total and dissolved solids, and turbidity. Quarterly grab samples collected since 1968 have been analyzed for eight additional parameters (Ca, Mg, Cl, Na, Fe, Mn, SO_4, and Si) and those quarterly samples collected since 1973 have also been analyzed for trace metals (Al, As, Ba, Be, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag, and Zn), phosphorus, ammonia nitrogen, and cyanide.

As a result of the 1972 Amendments to the Federal Water Pollution Control Act (Public Law 92-500), TVA began an ash pond effluent monitoring program for its 12 coal-fired power plants to comply with the National Pollutant Discharge Elimination System (NPDES). The requirements for this program since June 1976 are shown in Table 1. The required frequencies for some parameters have been increased at certain plants since July 1, 1977, as shown in parentheses in Table 1.

The Environmental Protection Agency (EPA) promulgated effluent limitations guidelines in 1974 for the achievement, by 1977, of best practicable control technology currently available (BPCTCA) and, by

MECHANICAL COLLECTOR

AIR INTAKE

FLY ASH HOPPER

FLY ASH INTAKE

SLUICE WATER INLET

WATER EJECTOR

VENT

AIR SEPARATOR

ELECTROSTATIC PRECIPITATOR

AIR INTAKE

FLY ASH HOPPER

FLY ASH INTAKE

SLUICE WATER INLET

WATER EJECTOR

VENT

AIR SEPARATOR

SPRAY WATER INLET

TO ASH DISPOSAL POND

BOTTOM ASH HOPPER -DRY BOTTOM

CLINKER GRINDER

HYDRAULIC SLUICE GATE CYLINDER

ASH SLUICE TRENCH

ASH PUMP

Figure 1. Typical Hydraulic Ash Sluicing System

TABLE 1. TVA STEAM PLANT NPDES MONITORING REQUIREMENTS FOR
ASH POND EFFLUENTS--EFFECTIVE JUNE 1976 TO JULY 1, 1977, AND
JULY 1, 1977, TO THE PRESENT

| | | Frequency of Monitoring[1] | | | |
Plant	Flow	pH	Oil & Grease	Susp. Solids	Metals
A	W	W	M (2M)	2M	M
B	M	W (C)	M (2M)	M (W)	M
C	C (W)	W (C)	M (2M)	2M (W)	M[2]
D	W	W (C)	M (2M)	M (2M)	M[3]
E	W	W	M	M	Q
F	W	W (C)	M (2M)	M (2M)	M
G	W (D)	W (C)	M (2M)	W	M
H[4]	W	W (C)	M (2M)	M (2M)	M
I	W	W (C)	M (2M)	M (2M)	M
J	W	W (C)	M (2M)	M (2M)	M
K	W	W	M (2M)	M (2M)	Q
L	W	W	M (2M)	M (2M)	Q

1. Parenthesis indicates revised sampling frequency after July 1, 1977.
2. Mercury sample required 2M.
3. Heavy metals, also, required at plant intake, one point in the Clinch River, and the West Knox Utility District intake.
4. Sampling required for two ash pond effluents.

Frequency Code: C - Continuous   M - Once per month
                   D - Once per day   2M - Twice per month
                   W - Once per week   Q - Once per quarter

1983, of best available technology economically achievable (BATEA) for the steam-electric power generating point source category (1). A discussion of applicable control technology may be found in reference 1. A summary of current EPA effluent guidelines for ash pond discharges from steam-electric power generating plants is shown in Table 2. The major goal of past monitoring programs was to provide an up-to-date data base from which to assess the potential for adverse environmental effects from this type of power plant discharge. An additional goal of the monitoring program today is to show that the effluent is in compliance with the effluent limitations shown in Table 2.

Ash pond effluent sampling frequencies utilized by TVA in past monitoring programs and by EPA in the proposed NPDES permit have been based on "educated guesses" without the benefit of formal study to establish adequate, statistically sound sampling frequencies. Improperly established frequencies could result in either unobserved, excessively variant parameter levels or too frequent, costly, and unnecessary sampling and laboratory analyses. The NPDES permit allows TVA with EPA concurrence to adjust monitoring frequencies if studies indicate changes are justified.

A sound monitoring program should be based on knowledge of the system and statistical analysis of the data gathered. The better these two aspects are integrated, the more meaningful the monitoring program. Therefore, the objective of this report is to develop a procedure for designing a sound monitoring program for ash pond effluents. To reach this objective, this report includes studies:

1. To determine those factors which influence the effluent characteristics and are of importance in designing a sound ash pond monitoring program.

2. To determine if some of these parameters could be omitted from sample analyses or if some parameters could be used to estimate other parameters.

3. To develop a statistical procedure for determining sampling intervals to meet standards and establish water quality trends.

4. To use this procedure to determine statistically sound monitoring programs for two of TVA's ash pond systems.

5. To indicate how this procedure could be applied to other ash pond systems.

Items 1 and 2 were accomplished by analysis of available ash pond effluent characteristics from 1970 to 1975, along with an identification of intake water quality parameters and steam plant operating characteristics which may influence the strategy used in developing a monitoring program for ash pond effluents. Item 3 was accomplished by modification of statistical methods available in the literature for determining the sample size to estimate population means at various confidence levels. Item 4 was accomplished by conducting a detailed sampling program of the ash pond effluents from two of TVA's steam plants and item 5 was accomplished by outlining how the procedure developed during this study could be applied to other power plant ash ponds.

TABLE 2.   CHEMICAL EFFLUENT GUIDELINES AND STANDARDS FOR STEAM-ELECTRIC POWER GENERATING PLANT ASH PONDS[1] [2]

	BPCTCA July 1, 1977		BATEA July 1, 1983		New Source Standards	
pH	6.0-9.0		6.0-9.0		6.0-9.0	
polychlorinated biphenyls	zero		zero		zero	
	Average Daily	Daily Maximum	Average Daily	Daily Maximum	Average Daily	Daily Maximum
Bottom Ash Transport Water						
total suspended solids	30	100	30 ÷ 12.5	100 ÷ 12.5	30 ÷ 20	100 ÷ 20
oil and grease	15	20	15 ÷ 12.5	20 ÷ 12.5	15 ÷ 20	20 ÷ 20
Fly Ash Transport Water						
total suspended solids	30	100	30	100	zero	zero
oil and grease[3]	15	20	15	20	zero	zero

1.   Taken from "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Steam-Electric Power Generating Point Source Category," U.S. Environmental Protection Agency, Report No. EPA-440/1-74-029-a, (October 1974).

2.   All units are in mg/l. Allowable discharge is the quantity obtained by multiplying 30 by the ratio of flow for sluicing to flow discharged and dividing by 12.5 or 20.

3.   For wet ash handling systems new sources must have zero discharge; however, this limitation for any runoff from the ash storage pile for the dry ash handling system was remanded by the Fourth Circuit Court of Appeals in July 1976.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions with respect to the variation of and trends displayed by the TVA ash pond effluents were observed:

1. Seven of the ash ponds exhibited yearly cycles in pH, total alkalinity, conductivity, dissolved solids, and total solids.

2. The remaining ash ponds exhibited no yearly pH cycle, but three had yearly cycles for alkalinity, dissolved solids, and total solids.

3. None of the ash ponds exhibited a yearly cycle for suspended solids, turbidity, or flow.

4. The concentration of most metals in the ash pond effluent appear to vary with time. The variation differs for each element within each effluent.

5. The pH of the ash pond effluents in the TVA system vary from acidic to alkaline.

Based on the review of the plant operating characteristics and ash pond effluent characteristics for the TVA fossil fuel power plant system, the following conclusions were derived:

1. The pH of the ash pond effluent was highly correlated with the percentage of CaO in the fly ash and the sulfur content of the coal.

2. The effluents from plants which receive coal from western Kentucky and southern Illinois (sulfur content of coal usually 2.8 to 4 percent and calcium content of fly ash usually 2.4 to 5.0 percent) are basic while those from plants which receive coal from eastern Tennessee, eastern Kentucky, and Virginia (sulfur content of coal usually 2 percent or below and calcium content of fly ash usually 2.2 percent or below) are neutral or slightly acidic.

3. The suspended solids concentration of the effluent correlated highly with the percentage of CaO in the fly ash, pH of the fly ash, and pH of the ash pond effluent.

4. The relationship between intake water quality characteristics and the ash pond effluent water quality characteristics varied for the different ash pond systems. For example, there was a significant correlation between the intake water pH and the pH of the ash pond effluent and also between the intake water dissolved solids and the pH of the ash pond effluent for Plants G, H, and J. These same plants also had a significant adverse correlation between the intake water conductivity and ash pond effluent pH. There was also a significant correlation between

intake water hardness and effluent pH for Plant J and a signifi-
cant negative correlation between intake water hardness and
effluent pH for Plants G and H. However, only Plants G and J
had significant correlations between intake water alkalinity
and effluent pH. For Plant G it is negative, while for
Plant J it is positive.

5.   More than half of the ash ponds increased the average concen-
     trations of Al, ammonia, As, Ba, Cd, Ca, Cl, Cr, Pb, Hg, Ni,
     Se, silica, sulfate, and Zn over that in the intake water.

6.   The detention time in the ash ponds is a function of the mixing
     of the pond contents. The mixing is a function of the wind
     conditions, pond geometry, and plant operating conditions such
     as the number of units operating, load capacity, and number of
     ESP units operating.

7.   Trace metals in the ash effluents are interrelated with one
     another at Plants E and J, respectively.

8.   Based on statistical regression analyses using the available
     data on operating conditions of TVA steam plants (such as ash
     content, sulfur content, coal usage, ESP and mechanical ash
     collector efficiencies, intake water characteristics and fly
     ash characteristics) and ash pond systems, there were not any
     useful relationships that could explain, predict, or control
     the ash pond effluent water quality. However, if data on the
     coal characteristics (including trace elements), intake water
     characteristics, and detailed plant operating conditions (such
     as coal load and time of sluicings) were available on a routine
     frequency over the same time frame, such relationships could
     conceivably be developed.

Conclusions related to the frequency and method of collection of
ash pond effluent samples were:

1.   Quarterly sampling for suspended solids during 1973 to 1975
     yielded approximately the same yearly average as did weekly
     sampling for the following ponds: A fly ash, A bottom ash, D,
     G, H, I, and L.

2.   Quarterly sampling for pH during 1973 to 1975 was adequate to
     predict the yearly average pH within 0.5 pH units for all
     plants except Plant B fly ash in 1973, Plant C west in 1974,
     and Plant L in 1973.

3.   Grab samples were selected over composite samples for the moni-
     toring programs recommended in this study because they were
     easier to collect. More study is needed to determine if
     composite samples would be more representative of the system.

4.   Each pond is site-specific with respect to effluent character-
     istics which require monitoring attention. Therefore, each
     pond must be studied separately in order to establish the most
     cost effective monitoring program for the entire TVA system.

Conclusions regarding the development of a procedure for statistically designing an ash pond effluent monitoring program were:

1. The procedure for determining the sampling frequency of chemical characteristics in ash pond effluents presented in this report is based on the following equation:

$$n = \frac{t^2 S^2}{L^2}$$

where   n is the sample size,

t is the value of "student's" t for a given significance level,

L is the precision, and

S is the sample standard deviation.

2. The precision is given by $\mu - \bar{X}$ where μ is the population mean and $\bar{X}$ is the sample mean. Two methods of determining the precision were discussed. The first involves selecting a precision value in order to estimate the population mean within a given percentage. This method gives the number of samples required to estimate the population mean within some degree of certainty. The second involves calculating a precision value by subtracting an estimate of the mean from the effluent limitation or water quality criteria. This method gives the number of samples required to show the effluent is in compliance with the effluent limitation or below the water quality criteria.

3. Designing a monitoring program to estimate the mean value of all parameters within the same percentage of the true mean for that parameter may lead to over-sampling for some parameters and under-sampling of others, because this approach does not take into account the significance of the concentration in the waste stream and it tends to reduce the precision value (increase the number of samples) as the concentration in the waste stream decreases.

4. Designing a monitoring program based on collecting samples of all parameters at the same frequency may lead to over-sampling for some parameters and under-sampling of others from a statistical standpoint. For example, some parameters are estimated more accurately than others, possibly making comparisons between parameters misleading.

5. Care should be exercised in establishing averaging periods for effluent limitations because the averaging period greatly affects the sampling frequency.

6. By utilizing the procedure presented in this study, the sampling effort for trace metals in the ash pond effluents at Plants E and J could be substantially decreased. For example, the sampling

program at Plant E was reduced from a total of 56 analyses per year for 12 different elements to 48 analyses per year for 9 different elements. At Plant J the reduction was from 156 analyses per year for 12 different elements to 35 analyses per year for 12 different elements.

7. The following example sampling program was developed for Plant E: once per year for Cr, Cu, Fe, Pb, Mn, pH, and Zn; twice per year for As; 4 times per year for Se; and 36 times per year for suspended solids.

8. The following example sampling program was developed for Plant J: once per year for Cu, Fe, and Mn; twice per year for As and Zn; 4 times per year for pH and selenium; and 24 times per year for suspended solids.

9. The procedure for designing a monitoring program presented here should be a useful tool to managers in determining the resources needed for monitoring.

10. The procedure may also be used to indicate when part of the investment in pollution control measures may be justified to offset the cost of monitoring to show compliance.

11. The major limitations of the procedure are: (1) It relies on maintaining the same type of operating conditions in the future as were used during the period when the design data set was collected; (2) it depends heavily on the establishment of effluent limitations; (3) the effluent should be in compliance; and (4) it cannot be applied generically to all ash pond effluents, but must be applied individually to each effluent.

12. The procedure for determining sampling frequencies presented here should be applied to the remaining TVA facilities once the plant modifications to meet environmental regulations have been completed.

13. Permission should be sought to alternate the NPDES monitoring program to reflect the results of this study and work performed in recommendation 1.

14. Less emphasis should probably be given to routine monitoring programs and more emphasis given to special or intensive studies directed at determining the effects of power plant operations on the ash pond effluent water quality and the effect of ash pond effluent water quality on the receiving stream water quality and its habitant.

SECTION 3

SUMMARY OF TVA DATA FROM 1970 TO 1975

This section summarizes the data available from 1970 to 1975 on individual ash pond effluent characteristics, the relationships between plant operating conditions and ash pond effluent characteristics, the relationships between the intake water and ash pond effluent charac- teristics, comparisons between weekly and quarterly sampling, and comparisons between grab and composite sampling.

INDIVIDUAL ASH POND EFFLUENT CHARACTERISTICS

The ash pond effluent data collected on a weekly basis at each of TVA's steam plants from 1970 through 1975 are summarized in Table 3. The maximum, average, and minimum values are given by year for flow, pH, phenolphthalein alkalinity, total alkalinity, hardness, conductivity, total solids, dissolved solids, suspended solids and turbidity. Care should be taken in comparing the values for a particular ash pond from year-to-year because of changes in the analytical procedures, the type data reported, and the ash pond location; the most important analytical change being the one used to determine the solids content. From 1970 to 1973, the effluents were analyzed for total and dissolved solids and the suspended solids concentrations were calculated by difference. Starting in 1974, the samples were analyzed for suspended and dissolved solids and the total solids concentration calculated by summation.

Plants A and B have separate ash ponds for bottom ash and fly ash while the remaining plants have ash ponds which receive both bottom and fly ash. Although the pH of the ash pond effluent varies from acidic to alkaline from plant to plant, a survey of the data in Table 3 indicates the pH of a particular ash pond is relatively constant from year-to-year. For the most part, the average pH from year-to-year for a particular plant only varies about half of a pH unit while the difference in the maximum or minimum value from year-to-year is approximately one pH unit. The fly ash pond at Plant A had yearly pH averages of 6.5 in 1970, 5.4 in 1972, and 4.0 in 1975. Except for 1971 the yearly average pH for the Plant A fly ash pond decreased with time from 1970 to 1975. The pH at Plant D was substantially lower in 1970 (average 6.5) than in the later years (average 8.5). The average pH of the effluent at Plant G increased from 5.7 in 1972 to 9.8 in 1973. Beginning in 1973 the sampling location for Plant G changed from the old pond to the new one. This change in operation along with others probably accounts for this increase. From 1973 to 1975 the pH stablized with the average pH, maximum pH, and minimum pH values being within 0.4, 0.1, and 1.6 pH units, respectively. The average pH at Plant I decreased from between 11.1 to 11.3 during 1970-1974 to 9.8 in 1975. The pH of a particular ash pond effluent within any one year can vary from 1 to 6 units. However, plants A, D, G, and I are exceptions.

The yearly average suspended solids concentration during the period 1970 to 1975 varied by more than 20 mg/l for all the ash ponds except those at Plants C, G, H, and I, with some varying by as much as 50 mg/l.

TABLE 3. SUMMARY OF WEEKLY ASH POND EFFLUENT DATA FROM 1970 THROUGH 1975

Plant A (Bottom Ash)							
Parameter		1970	1971	1972	1973	1974	1975
Flow (GPM)	Max	39500	21000	25000	22800	23000	23000
	Avg.	21233	13586	15654	17792	15415	20189
	Min.	700	8000	7800	4500	5000	13320
pH	Max	8.1	7.8	8.0	7.9	7.9	7.8
	Avg.	7.0	7.3	7.4	7.1	7.2	7.1
	Min.	5.3	5.7	6.5	4.1	4.1	6.1
Phenolphthalein	Max.						
Alkalinity	Avg.	<1	<1	<1	<1	<1	<1
(mg/l as $CaCO_3$)	Min.						
Total Alkalinity	Max.	120	155	124	120	160	110
(mg/l as $CaCO_3$)	Avg.	60	87	86	80	88	47
	Min.	10	38	42	20	49	20
Hardness	Max.	800	260	324	260	394	NA
(mg/l as $CaCO_3$)	Avg.	205	166	180	153	130	
	Min.	87	100	110	90	76	
Conductivity	Max.	1700	510	415	730	910	
(µmhos/cm)	Avg.	376	314	315	331	313	NA
	Min.	210	220	205	215	210	
Total Solids	Max.	874	743	624	1030	394	754
(mg/l)	Avg.	295	312	236	242	212	224
	Min.	106	149	109	103	99	113
Dissolved Solids	Max.	798	688	285	404	366	342
(mg/l)	Avg.	203	211	172	176	158	172
	Min.	50	111	54	69	77	70
Suspended Solids	Max.	590	359	351	657	274	412
(mg/l)	Avg.	96	100	64	66	54	51
	Min.	5	3	5	7	5	8
Turbidity	Max.	70	91	94	410	96	
(JCU)	Avg.	32	34	28	40	32	NA[1]
	Min.	15	6	0	11	10	

1. NA = data not available

TABLE 3 (continued)

Parameter		Plant A (Fly Ash)					
		1970	1971	1972	1973	1974	1975
Flow (GPM)	Max.	5000	9740	13000	10190	8700	17910
	Avg.	1250	5460	8175	6617	6219	7166
	Min.	200	300	5880	4500	3100	3000
pH	Max.	7.6	7.1	7.4	6.3	5.8	7.1
	Avg.	6.5	4.8	5.4	4.5	4.2	4.0
	Min.	3.5	3.7	4.0	3.7	3.6	3.4
Phenolphthalein	Max.	<1	<1	<1	<1	<1	<1
Alkalinity	Avg.						
(mg/l as $CaCO_3$)	Min.						
Total Alkalinity	Max.	120	60	65	70	20	35
(mg/l as $CaCO_3$)	Avg.	68	29	28	23	11	22
	Min.	25	7	5	2	3	11
Hardness	Max.	900	690	590	520	455	
(mg/l as $CaCO_3$)	Avg.	258	384	445	350	280	NA
	Min.	15	136	170	185	196	
Conductivity	Max.	2100	1500	970	1010	1125	
(μmhos/cm)	Avg.	815	846	800	809	813	NA
	Min.	245	400	300	640	615	
Total Solids	Max.	3941	1224	957	893	737	799
(mg/l)	Avg.	753	694	640	606	545	545
	Min.	150	71	293	370	253	284
Dissolved Solids	Max.	2000	1165	730	820	734	781
(mg/l)	Avg.	488	546	550	513	508	530
	Min.	25	239	200	141	241	276
Suspended Solids	Max.	1199	210	426	256	220	51
(mg/l)	Avg.	265	148	89	93	37	15
	Min.	<1	2	5	15	3	3
Turbidity	Max.	150	91	59	36	26	
(JCU)	Avg.	50	17	14	14	12	NA
	Min.	12	2	5	4	1	

TABLE 3 (continued)

Parameter		Plant B (Bottom Ash)		
		1973	1974	1975
Flow (GPM)	Max.	NA	NA	NA
	Avg.			
	Min.			
pH	Max.	9.1	9.5	8.5
	Avg.	8.2	8.0	8.0
	Min.	7.6	6.5	7.4
Phenolphthalein Alkalinity (mg/l as $CaCO_3$)	Max.	4	19	2
	Avg.	<1	14	<1
	Min.	<1	2	<1
Total Alkalinity (mg/l as $CaCO_3$)	Max.	73	72	65
	Avg.	59	54	54
	Min.	44	6	45
Hardness (mg/l as $CaCO_3$)	Max.	108	225	
	Avg.	79	106	NA
	Min.	56	60	
Conductivity (μmhos/cm)	Max.	260	490	
	Avg.	200	247	NA
	Min.	160	160	
Total Solids (mg/l)	Max.	914	501	351
	Avg.	224	219	137
	Min.	76	29	55
Dissolved Solids (mg/l)	Max.	500	474	186
	Avg.	145	152	112
	Min.	33	5	37
Suspended Solids (mg/l)	Max.	706	202	196
	Avg.	79	67	25
	Min.	7	7	6
Turbidity (JCU)	Max.	50	35	
	Avg.	43	25	NA
	Min.	<25	20	

TABLE 3 (continued)

	Plant B (Fly Ash)			
Parameter		1973	1974	1975
Flow (GPM)	Max.	NA	NA	NA
	Avg.			
	Min.			
pH	Max.	11.4	11.3	11.0
	Avg.	9.2	9.4	9.2
	Min.	6.5	5.0	5.3
Phenolphthalein	Max.	258	176	65
Alkalinity	Avg.	53	37	24
(mg/l as $CaCO_3$)	Min.	<1	5	3
Total Alkalinity	Max.	300	226	100
(mg/l as $CaCO_3$)	Avg.	119	76	58
	Min.	35	17	11
Hardness	Max.	512	505	
(mg/l as $CaCO_3$)	Avg.	354	304	NA
	Min.	195	125	
Conductivity	Max.	1800	1600	
(μmhos/cm)	Avg.	888	688	NA
	Min.	395	310	
Total Solids	Max.	1690	996	719
(mg/l)	Avg.	724	582	479
	Min.	319	122	110
Dissolved Solids	Max.	1224	812	711
(mg/l)	Avg.	624	488	461
	Min.	199	84	101
Suspended Solids	Max.	1491	470	157
(mg/l)	Avg.	100	94	18
	Min.	6	7	5
Turbidity	Max.	30	25	
(JCU)	Avg.	25	24	NA
	Min.	<25	10	

TABLE 3 (continued)

Parameter		Plant C - East					
		1970	1971	1972	1973	1974	1975
Flow (GPM)	Max.	11100	8975	9152	9475	9850	11100
	Avg.	6410	5710	6050	7090	7690	8410
	Min.	3525	3400	3400	4171	3683	5463
pH	Max.	8.2	7.9	8.2	7.6	7.8	7.7
	Avg.	7.5	7.3	7.2	7.2	7.1	7.1
	Min.	6.6	6.6	6.4	6.4	6.4	5.1
Phenolphthalein Alkalinity (mg/l as $CaCO_3$)	Max. Avg. Min.	<1	<1	<1	<1	<1	<1
Total Alkalinity (mg/l as $CaCO_3$)	Max.	169	132	118	120	140	114
	Avg.	92	90	64	72	69	71
	Min.	60	40	10	24	24	8
Hardness (mg/l as $CaCO_3$)	Max.	246	270	390	280	350	NA
	Avg.	194	188	210	203	222	
	Min.	144	126	90	68	25	
Conductivity (μmhos/cm)	Max.	576	675	670	662	713	NA
	Avg.	441	467	476	469	521	
	Min.	310	312	195	195	250	
Total Solids (mg/l)	Max.	535	572	539	527	881	628
	Avg.	360	350	358	367	409	370
	Min.	261	247	213	200	207	200
Dissolved Solids (mg/l)	Max.	412	434	488	510	524	489
	Avg.	312	304	318	324	360	343
	Min.	216	202	140	124	180	165
Suspended Solids (mg/l)	Max.	252	198	108	202	614	317
	Avg.	48	46	39	43	48	27
	Min.	4	3	5	1	5	3
Turbidity (JCU)	Max.	85	60	58	76	90	NA
	Avg.	38	31	28	30	33	
	Min.	5	5	10	20	10	

TABLE 3 (continued)

Parameter		Plant C - West					
		1970	1971	1972	1973	1974	1975
Flow (GPM)	Max.	3200	1706	2400	2467	1867	1867
	Avg.	1600	1636	1685	1704	1620	1631
	Min.	800	900	1600	1139	800	800
pH	Max.	9.2	9.6	8.9	8.5	8.7	8.6
	Avg.	7.8	7.8	7.5	7.6	7.2	7.5
	Min.	4.8	5.4	4.1	5.6	3.9	4.1
Phenolphthalein	Max.	20	22	<1	<1	<1	<1
Alkalinity	Avg.	17	14				
(mg/l as $CaCO_3$)	Min.	12	8				
Total Alkalinity	Max.	120	120	94	114	118	108
(mg/l as $CaCO_3$)	Avg.	79	81	58	68	70	69
	Min.	12	14	5	4	4	30
Hardness	Max.	160	200	180	222	272	
(mg/l as $CaCO_3$)	Avg.	123	133	124	126	132	NA
	Min.	84	82	80	68	80	
Conductivity	Max.	448	558	458	550	775	
(μmhos/cm)	Avg.	316	351	326	319	340	NA
	Min.	212	230	216	184	208	
Total Solids	Max.	311	393	338	422	641	454
(mg/l)	Avg.	231	240	226	245	259	269
	Min.	160	166	176	166	120	212
Dissolved Solids	Max.	309	374	290	402	629	447
(mg/l)	Avg.	200	218	200	202	215	234
	Min.	124	136	134	103	100	149
Suspended Solids	Max.	103	87	156	197	129	141
(mg/l)	Avg.	30	21	26	42	43	35
	Min.	2	<1	2	6	7	3
Turbidity	Max.	84	65	68	95	90	
(JCU)	Avg.	34	30	29	39	36	NA
	Min.	25	25	15	25	<15	

TABLE 3 (continued)

Parameter		Plant D					
		1970	1971	1972	1973	1974	1975
Flow (GPM)	Max.	7200	9470	15840	14000	14590	16470
	Avg.	6760	6923	5935	7983	8103	8586
	Min.	2800	2800	600	1050	820	1050
pH	Max.	8.0	9.7	9.7	9.3	9.1	9.3
	Avg.	6.5	8.4	8.5	8.6	8.4	8.4
	Min.	4.3	6.6	6.6	7.7	7.4	7.5
Phenolphthalein	Max.	<1	12	14	19	12	13
Alkalinity	Avg.		8	6	6	5	4
(mg/l as $CaCO_3$)	Min.		1	1	1	2	1
Total Alkalinity	Max.	95	137	70	97	78	104
(mg/l as $CaCO_3$)	Avg.	29	50	54	60	56	69
	Min.	3	28	37	37	35	48
Hardness	Max.	200	220	195	183	145	
(mg/l as $CaCO_3$)	Avg.	149	146	142	130	123	NA
	Min.	102	100	90	68	107	
Conductivity	Max.	605	460	385	380	304	
(μmhos/cm)	Avg.	349	298	290	259	271	NA
	Min.	215	195	200	190	233	
Total Solids	Max.	1189	299	306	455	250	279
(mg/l)	Avg.	337	192	185	168	178	183
	Min.	158	66	75	54	121	130
Dissolved Solids	Max.	457	272	300	375	223	247
	Avg.	244	171	164	143	161	168
	Min.	106	56	45	40	82	122
Suspended Solids	Max.	931	107	235	193	61	50
(mg/l)	Avg.	93	21	21	25	17	15
	Min.	4	1	2	<1	3	3
Turbidity	Max.	65	60	40	30	40	
(JCU)	Avg.	32	26	25	25	26	NA
	Min.	<25	<25	<25	<25	<25	

TABLE 3 (continued)

Parameter		OLD 1974	New 1974	1975
Flow (GPM)	Max.	6850	6650	6850
	Avg.	3400	6057	5658
	Min.	0	5650	4380
pH	Max.	12	11.5	11.5
	Avg.	10.8	11.2	11.1
	Min.	7.5	10.2	10.4
Phenolphthalein Alkalinity (mg/l as $CaCO_3$)	Max.	400	200	180
	Avg.	142	114	97
	Min.	5	26	35
Total Alkalinity (mg/l as $CaCO_3$)	Max.	490	500	240
	Avg.	176	154	128
	Min.	22	42	53
Hardness (mg/l as $CaCO_3$)	Max.	670	400	
	Avg.	266	288	NA
	Min.	80	76	
Conductivity (μmhos/cm)	Max.	2100	1150	
	Avg.	796	819	NA
	Min.	195	285	
Total Solids (mg/l)	Max.	866	535	600
	Avg.	369	393	404
	Min.	122	138	223
Dissolved Solids (mg/l)	Max.	804	522	598
	Avg.	340	381	398
	Min.	110	135	220
Suspended Solids (mg/l)	Max.	123	43	12
	Avg.	29	12	4
	Min.	3	2	<1
Turbidity (JCU)	Max.			
	Avg.	NA	NA	NA
	Min.			

Plant E (New Ash Pond Started 7-1-74)

TABLE 3 (continued)

		Plant F	
Parameter		1974	1975
Flow (GPM)	Max.	40000	35000
	Avg.	32940	28293
	Min.	23000	15000
pH	Max.	11.4	11.2
	Avg.	11.1	10.7
	Min.	10.5	9.1
Phenolphthalein	Max.	150	126
Alkalinity	Avg.	98	67
(mg/l as $CaCO_3$)	Min.	21	8
Total Alkalinity	Max.	173	140
(mg/l as $CaCO_3$)	Avg.	115	78
	Min.	33	28
Hardness	Max.	400	NA
(mg/l as $CaCO_3$)	Avg.	304	
	Min.	88	
Conductivity	Max.	1250	NA
(μmhos/cm)	Avg.	915	
	Min.	450	
Total Solids	Max.	795	874
(mg/l)	Avg.	472	392
	Min.	14	111
Dissolved Solids	Max.	648	871
(mg/l)	Avg.	431	386
	Min.	12	105
Suspended Solids	Max.	182	43
(mg/l)	Avg.	40	6
	Min.	1	<1
Turbidity	Max.	25	NA
(JCU)	Avg.	14	
	Min.	1	

TABLE 3 (continued)

Parameter		OLD			NEW		
		1970	1971	1972	1973	1974	1975
Flow (GPM)	Max.				10000	10000	7500
	Avg.	NA	NA	NA	10000	7347	4826
	Min.				10000	2500	2500
pH	Max.	10.6	9.5	8.2	10.4	10.5	10.4
	Avg.	6.9	4.7	5.7	9.8	9.5	9.4
	Min.	4.0	3.2	3.3	9.1	8.2	7.5
Phenolphthalein	Max.	66	12	<1	38	44	38
Alkalinity	Avg.	4	<1		25	19	16
(mg/l as $CaCO_3$)	Min.	<1	<1		12	2	6
Total Alkalinity	Max.	85	28	60	72	66	72
(mg/l as $CaCO_3$)	Avg.	18	2	17	51	44	44
	Min.	0	0	0	36	20	22
Hardness	Max.	375	300	630	360	244	
(mg/l as $CaCO_3$)	Avg.	203	248	226	199	197	NA
	Min.	100	161	38	150	160	
Conductivity	Max.	630	870	1100	480	500	
(μmhos/cm)	Avg.	452	586	568	387	345	NA
	Min.	128	355	180	295	41	
Total Solids	Max.	492	636	1004	345	400	365
(mg/l)	Avg.	318	445	455	280	316	251
	Min.	142	228	112	227	225	182
Dissolved Solids	Max.	437	618	994	324	381	323
(mg/l)	Avg.	295	425	429	261	296	232
	Min.	135	219	79	213	210	164
Suspended Solids	Max.	137	198	93	59	64	74
(mg/l)	Avg.	22	20	26	19	20	19
	Min.	<1	1	3	1	3	5
Turbidity	Max.	NA	NA	NA	<25	<25	NA
(JCU)	Avg.				<25	<25	
	Min.				<25	<25	

Plant G (New Pond Started in 1970 Began Sampling in 1973)

TABLE 3 (continued)

Parameter		1970	1971	1972	1973	1974	1975
				Plant H			
Flow (GPM)	Max.	3400	3400	3662	3362	3362	3362
	Avg.	2926	2639	2631	3261	2583	2233
	Min.	100	324	1584	3175	25	1715
pH	Max.	9.4	8.9	8.7	9.6	9.4	9.4
	Avg.	8.4	8.1	8.0	8.8	8.3	8.7
	Min.	7.6	7.0	7.5	7.6	7.3	7.1
Phenolphthalein	Max.	20	18	5	25	20	68
Alkalinity	Avg.	10	7	4	14	9	11
(mg/l as $CaCO_3$)	Min.	2	1	3	3	1	1
Total Alkalinity	Max.	100	104	107	100	95	120
(mg/l as $CaCO_3$)	Avg.	70	75	73	78	61	64
	Min.	50	8	45	55	20	34
Hardness	Max.	260	300	150	155	140	
(mg/l as $CaCO_3$)	Avg.	133	138	103	117	114	NA
	Min.	74	80	60	80	80	
Conductivity	Max.	1300	830	490	500	480	
(μmhos/cm)	Avg.	704	517	353	395	389	NA
	Min.	380	330	280	270	220	
Total Solids	Max.	742	572	331	372	379	411
(mg/l)	Avg.	422	354	255	284	265	305
	Min.	267	235	188	210	118	190
Dissolved Solids	Max.	728	564	307	364	365	376
(mg/l)	Avg.	400	337	236	268	250	292
	Min.	7	214	169	200	100	176
Suspended Solids	Max.	295	56	71	90	103	35
(mg/l)	Avg.	21	17	19	16	15	12
	Min.	2	5	2	3	3	3
Turbidity	Max.	40	45	60	80	35	
(JCU)	Avg.	26	26	27	27	25	NA
	Min.	<25	<25	<25	<25	2	

TABLE 3 (continued)

Parameter		1970	1971	1972	1973	1974	1975
			Plant I (North Outfall)				
Flow (GPM)	Max.		5565	9021	18132	23964	
	Avg.	NA	4614	4971	5740	11124	No
	Min.		3363	3353	656	3160	
pH	Max.	12.1	12	12.3	12	10.7	
	Avg.	11.3	11.3	11.3	11.4	11.1	Discharge
	Min.	10.4	10	10.7	10.5	10.6	
Phenolphthalein	Max.	284	190	190	290	204	
Alkalinity	Avg.	128	116	119	144	108	At
(mg/l as $CaCO_3$)	Min.	45	21	51	50	55	
Total Alkalinity	Max.	290	230	215	317	225	
(mg/l as $CaCO_3$)	Avg.	151	140	140	165	134	Present
	Min.	66	70	74	70	78	
Hardness	Max.	302	293	550	420	318	
(mg/l as $CaCO_3$)	Avg.	193	181	232	231	191	
	Min.	112	115	117	30	112	
Conductivity	Max.	1400	960	1140	1400	960	
(μmhos/cm)	Avg.	735	635	653	728	570	
	Min.	320	250	375	280	365	
Total Solids	Max.	816	420	376	491	429	
(mg/l)	Avg.	396	293	278	307	285	
	Min.	237	188	202	181	163	
Dissolved Solids	Max.	800	414	349	470	409	
(mg/l)	Avg.	371	269	255	285	264	
	Min.	233	171	149	166	142	
Suspended Solids	Max.	97	123	128	75	102	
(mg/l)	Avg.	24	23	24	22	21	
	Min.	<1	<1	2	2	1	
Turbidity	Max.	<25	<25	<25	<25	25	
(JCU)	Avg.	<25	<25	<25	<25	13	
	Min.	<25	<25	<25	<25	1	

TABLE 3 (continued)

Parameter		Plant I (South Outfall)					
		1970	1971	1972	1973	1974	1975
Flow (GPM)	Max.	NA	8572	9021	17144	23518	32178
	Avg.		7409	7870	9830	13786	27000
	Min.		6149	5969	1212	2190	19791
pH	Max.	12.1	12	12.1	11.9	11.6	11.1
	Avg.	11.3	11.3	11.3	11.3	11.1	9.8
	Min.	10.3	10	10.8	10.7	10	8.9
Phenolphthalein Alkalinity (mg/l as $CaCO_3$)	Max.	280	196	200	240	193	65
	Avg.	118	114	120	140	106	27
	Min.	34	20	62	96	35	7
Total Alkalinity (mg/l as $CaCO_3$)	Max.	284	215	230	260	233	94
	Avg.	138	136	139	162	132	71
	Min.	55	55	80	105	60	32
Hardness (mg/l as $CaCO_3$)	Max.	285	295	570	320	320	
	Avg.	189	177	235	224	199	NA
	Min.	131	97	128	44	120	
Conductivity (μmhos/cm)	Max.	1197	990	1100	1120	915	
	Avg.	718	615	633	730	575	NA
	Min.	340	265	330	400	250	
Total Solids (mg/l)	Max.	836	432	403	506	547	364
	Avg.	400	284	282	301	292	240
	Min.	229	179	182	192	162	75
Dissolved Solids (mg/l)	Max.	823	412	348	443	441	345
	Avg.	380	266	249	277	277	223
	Min.	225	148	154	182	160	65
Suspended Solids (mg/l)	Max.	83	116	114	63	275	78
	Avg.	20	18	33	24	15	18
	Min.	<1	<1	<1	1	<1	2
Turbidity (JCU)	Max.	<25	<25	<25	<25	25	NA
	Avg.	<25	<25	<25	<25	12	
	Min.	<25	<25	<25	<25	1	

TABLE 3 (continued)

Parameter		Plant J					
		1970	1971	1972	1973	1974	1975
Flow (GPM)	Max.	14810	19840	18320	19840	24140	28000
	Avg.	14159	13840	14841	15457	11860	14870
	Min.	8886	10960	12200	10880	3460	9700
pH	Max.	8.3	8.8	8.7	8.2	8.8	9.1
	Avg.	6.0	6.5	6.1	6.0	6.5	6.2
	Min.	3.3	3.5	3.3	3.6	3.3	3.4
Phenolphthalein	Max.	1	4	5	<1	9	13
Alkalinity	Avg.	1	2	2		5	4
(mg/l as $CaCO_3$)	Min.	1	1	1		2	1
Total Alkalinity	Max.	52	87	84	82	96	81
(mg/l as $CaCO_3$)	Avg.	25	42	41	37	47	36
	Min.	3	3	3	3	3	2
Hardness	Max.	128	135	134	151	152	
(mg/l as $CaCO_3$)	Avg.	106	96	101	104	102	NA
	Min.	73	50	62	70	2	
Conductivity	Max.	415	345	440	550	465	
(µmhos/cm)	Avg.	323	268	284	325	298	NA
	Min.	250	170	200	230	215	
Total Solids	Max.	375	262	501	341	617	719
(mg/l)	Avg.	210	193	193	233	240	206
	Min.	84	101	113	159	92	93
Dissolved Solids	Max.	362	247	235	284	294	282
(mg/l)	Avg.	197	177	168	201	193	168
	Min.	78	100	102	137	66	80
Suspended Solids	Max.	64	72	360	128	431	542
(mg/l)	Avg.	14	16	26	32	47	38
	Min.	2	<1	<1	2	1	3
Turbidity	Max.	25	31	28	95	74	
(JCU)	Avg.	22	12	8	44	11	NA
	Min.	<2	2	2	7	2	

TABLE 3 (continued)

Parameter		1970	1971	1972	1973	1974	1975
				Plant K			
Flow (GPM)	Max.		16000	35000	40500	37500	37000
	Avg.	NA	13184	16323	18172	25859	23311
	Min.		8000	1500	4500	18000	18000
pH	Max.	11.8	11.7	12.5	11.4	11.4	11.2
	Avg.	11.2	11.4	11.4	11.0	11.0	10.3
	Min.	10.0	11.1	11.0	10.5	9.4	8.9
Phenolphthalein	Max.	304	330	358	151	115	102
Alkalinity	Avg.	139	160	153	81	69	40
(mg/l as $CaCO_3$)	Min.	37	102	50	35	15	6
Total Alkalinity	Max.	362	372	400	187	146	133
(mg/l as $CaCO_3$)	Avg.	188	191	181	112	103	84
	Min.	68	130	72	58	70	54
Hardness	Max.	380	422	460	242	231	NA
(mg/l as $CaCO_3$)	Avg.	236	264	238	175	173	
	Min.	88	212	112	132	118	
Conductivity	Max.	1650	1900	2000	720	680	NA
(μmhos/cm)	Avg.	969	967	1046	507	438	
	Min.	390	650	390	27	280	
Total Solids	Max.	653	566	508	318	427	966
(mg/l)	Avg.	405	373	320	215	288	319
	Min.	257	256	117	30	131	187
Dissolved Solids	Max.	510	564	442	310	416	404
(mg/l)	Avg.	351	370	314	203	272	268
	Min.	179	253	116	23	106	172
Suspended Solids	Max.	374	20	66	37	59	273
(mg/l)	Avg.	53	3	6	13	16	29
	Min.	2	1	1	2	2	6
Turbidity	Max.	<25	<25	<25	<25	<25	
(JCU)	Avg.	<25	<25	<25	<25	<25	NA
	Min.	<25	<25	<25	<25	<25	

TABLE 3 (continued)

Parameter		Plant L					
		1970	1971	1972	1973	1974	1975
Flow (GPM)	Max.	17222	17546	17000	18500	17000	19000
	Avg.	14189	14370	13223	15188	13698	14596
	Min.	10830	9597	10000	11000	8000	8000
pH	Max.	11.3	10.7	10.5	11.1	11.5	11.2
	Avg.	10.2	9.4	9.2	10.0	10.3	10.4
	Min.	9.1	7.2	8.0	8.0	9.1	9.4
Phenolphthalein	Max.	100	60	40	95	204	102
Alkalinity	Avg.	39	21	16	36	50	46
(mg/l as $CaCO_3$)	Min.	14	2	2	1	15	15
Total Alkalinity	Max.	135	110	95	140	214	150
(mg/l as $CaCO_3$)	Avg.	78	74	76	88	96	74
	Min.	40	36	27	53	52	40
Hardness	Max.	238	210	210	320	310	
(mg/l as $CaCO_3$)	Avg.	161	143	132	171	185	NA
	Min.	110	97	88	105	105	
Conductivity	Max.	530	380	440	710	870	
(μhos/cm)	Avg.	351	327	312	348	371	NA
	Min.	220	250	220	170	200	
Total Solids	Max.	539	496	308	320	352	288
(mg/l)	Avg.	246	244	198	222	242	217
	Min.	124	180	80	122	130	108
Dissolved Solids	Max.	296	286	290	318	338	284
(mg/l)	Avg.	210	210	185	206	223	209
	Min.	103	154	72	91	118	100
Suspended Solids	Max.	329	210	34	90	92	52
(mg/l)	Avg.	36	34	13	17	20	8
	Min.	3	<1	2	<1	4	2
Turbidity	Max.	85	45	42	41	25	
(JCU)	Avg.	29	27	26	26	21	NA
	Min.	<25	<25	<25	<25	5	

The yearly average suspended solids concentration decreased with time over the period for which data is given in Table 3 for over half of the ash ponds. Exceptions to this are the ponds at Plants G, H, I, J, and K and the west pond at Plant C where they remained constant or increased.

The yearly dissolved solids averages in a particular ash pond effluent varied from year to year by as high as 167 mg/l at Plant K to as low as 34 mg/l at the west pond at Plant C. Likewise, the yearly total solids average varied from as high as 245 mg/l for the fly ash pond at Plant B to as low as 35 mg/l at Plant E.

The amount of suspended solids variation from year to year due to natural background variation is hard to determine because of changes in the ash pond structures in an effort to lower suspended solids loadings from the ponds and changes in analytical procedures. However, the trend of decreasing suspended solids was probably a result of efforts to reduce the suspended solids concentrations to levels below 30 mg/l. Therefore, the decrease was not observed at Plants G, H, and I because they were already below 30 mg/l. The effluent concentrations at Plant J and K actually increased from yearly averages in the teens to yearly averages near 30 mg/l. These increases were probably associated with a decrease in the pond hydraulic detention times and an increase in the ash and dirt content of the coal.

The yearly average alkalinity for a particular ash pond did not vary by more than 40 mg/l as $CaCO_3$, except for the fly ash ponds at Plants A (57) and B (61) and the combined pond at Plant K (107). The yearly average hardness did not differ by more than 60 mg/l from year to year except for the ponds at Plants A bottom ash (75) and fly ash (187) and K (91). The average yearly conductivity varied by more than 100 μmhos/cm for the ash ponds at Plants H (351), I (165), and K (539) and the fly ash pond at Plant B (200). There is nothing significant about the values of 40, 60, and 100. They were presented only as a reference and for the sake of comparison.

The ash pond at Plant I had two distinct discharges from 1970 to 1974 (north and south). The water quality characteristics as reported in Table 3 are similar for each outfall. There is a difference in the flow rate and suspended solids concentration of the two effluents which may be affected by the detention time or flow pattern of the ash pond, but with the limited data this is hard to verify. However, the data appear to indicate that location of the outfall does not effect the water quality characteristics of the effluent provided adequate ash settling times are provided and the water within the ash pond is well mixed.

The weekly effluent data for each pond were plotted with respect to time. Examples of these plots are shown in Figures 2 and 3. The type of trends exhibited by each ash pond effluent characteristic was determined by observation of these plots. Figure 2 is representative of the trends displayed by the ponds in which there is no yearly pH cycle, while Figure 3 is representative of those with a yearly pH cycle. A summary of the type of trends exhibited by each pond is given in Table 4. The type of trend has been defined as cyclic (Yes) or noncyclic (No) within a one year period.
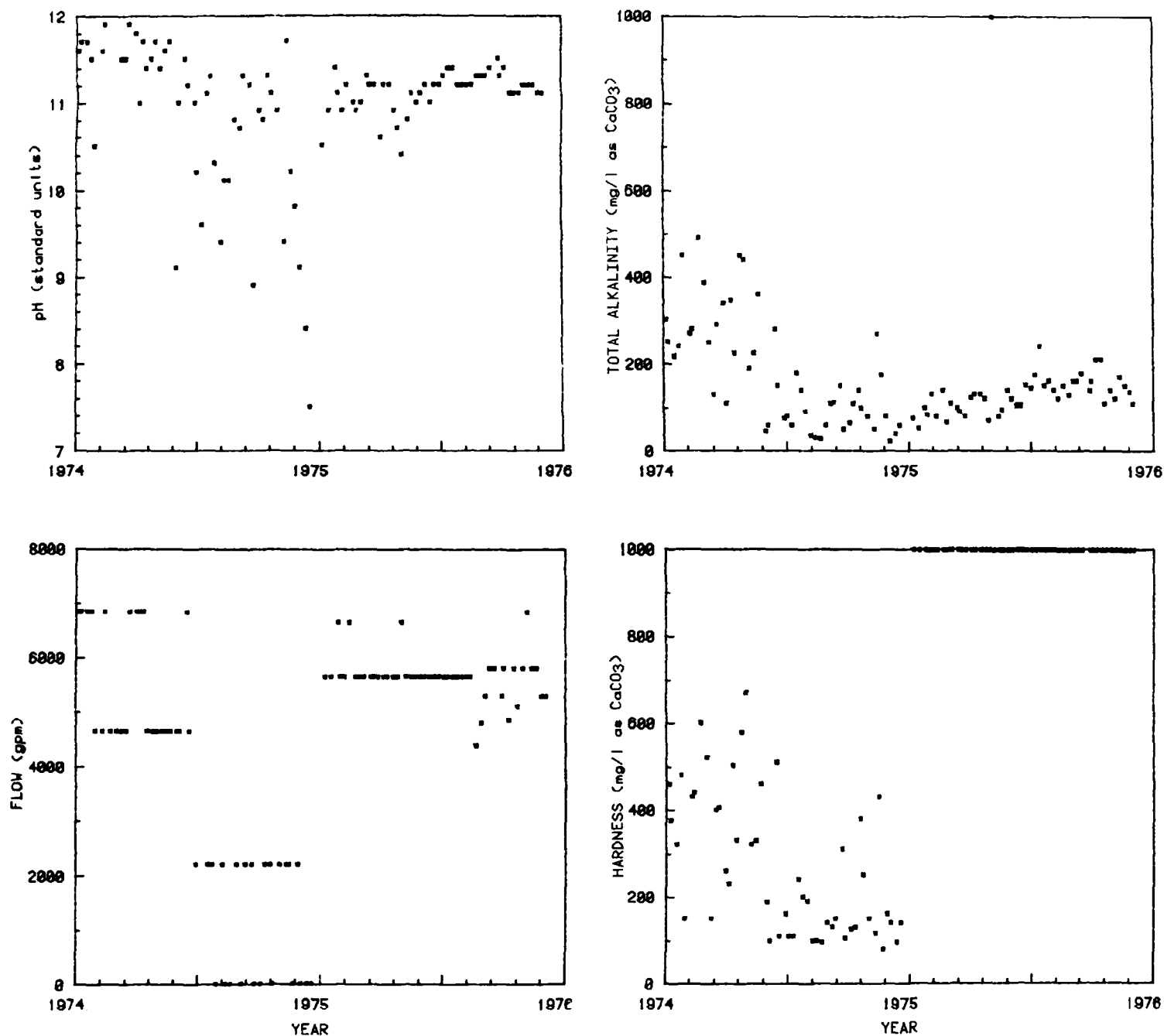
Figure 2. Variation of Plant E Ash Pond Effluent Characteristics with Time
for the Period 1974 to 1976
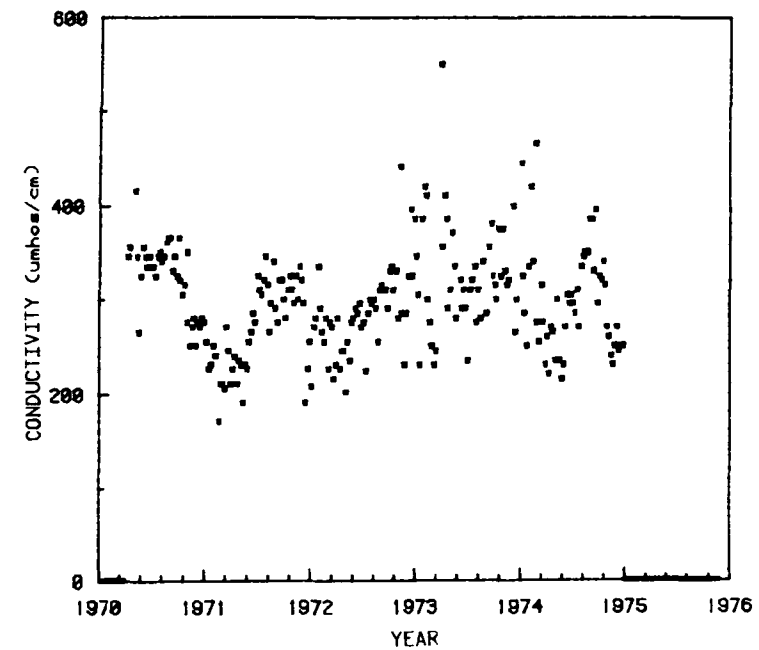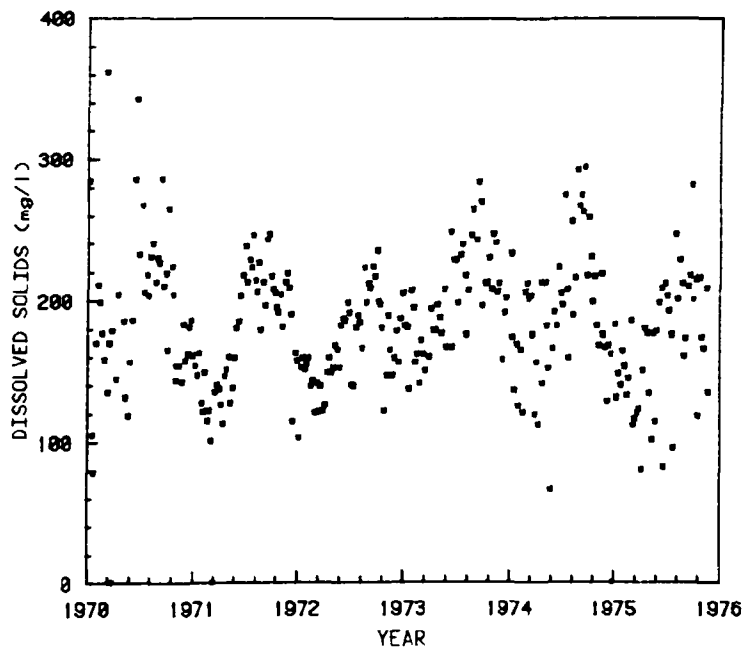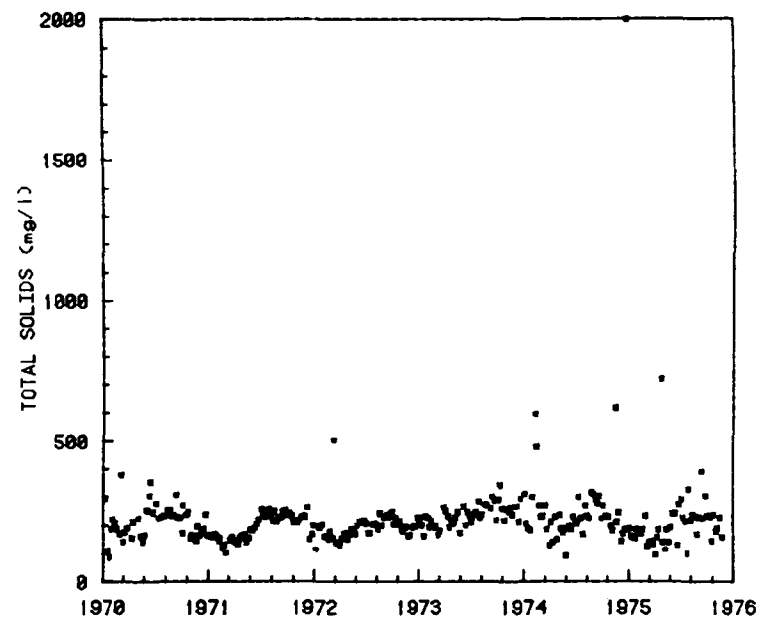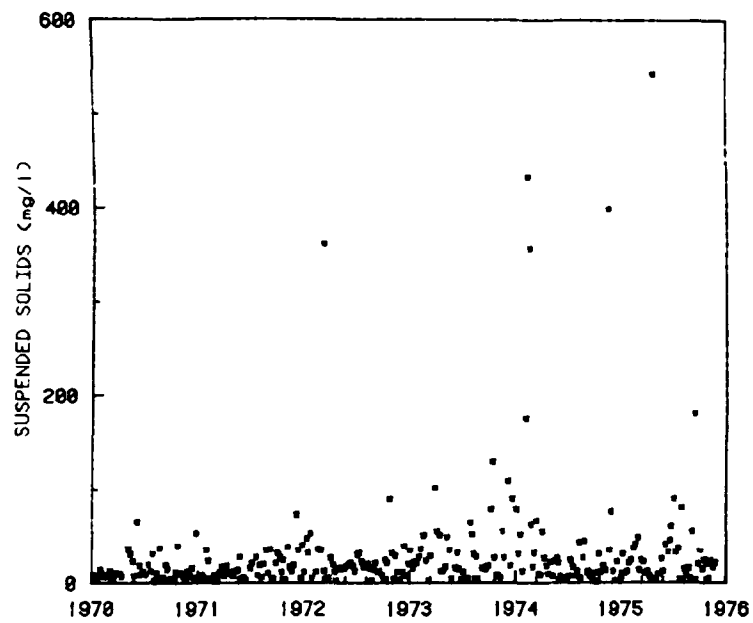
Figure 2 (Continued)
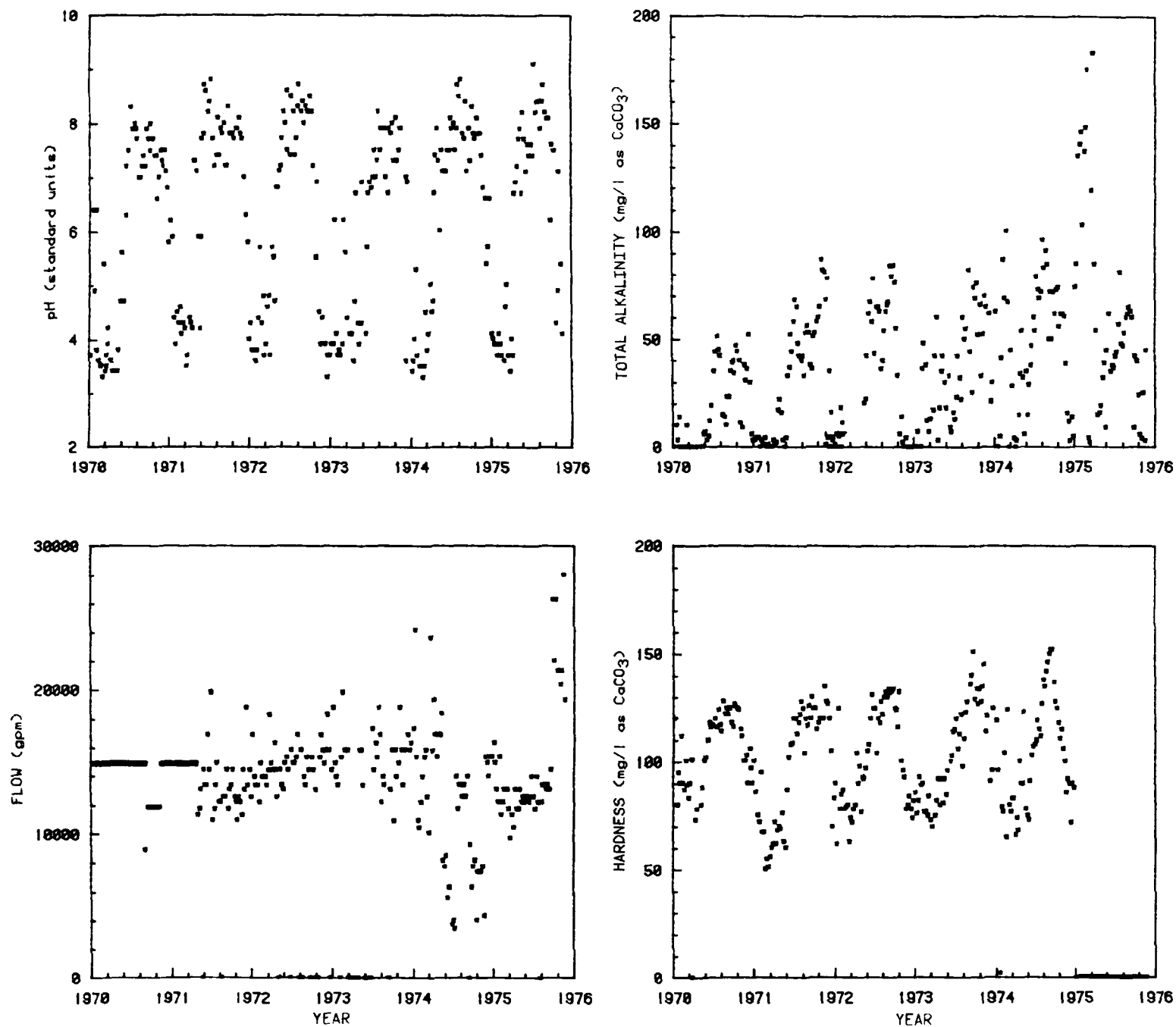
Figure 3. Variation of Plant J Ash Pond Effluent Characteristics with Time for the Period 1970 to 1976
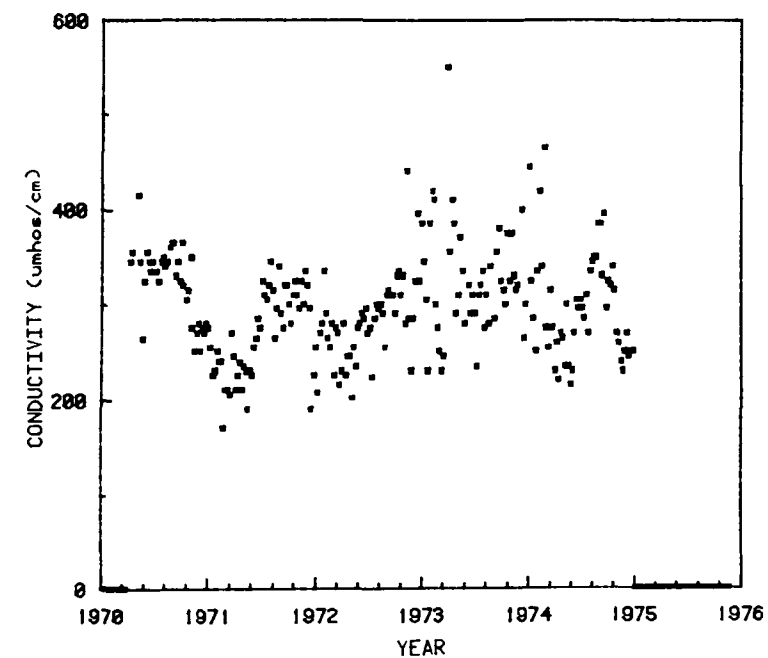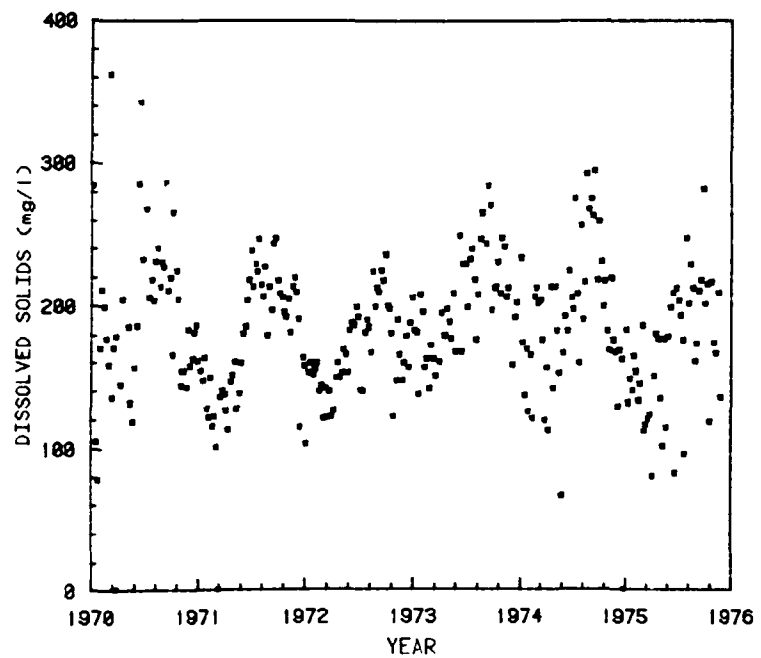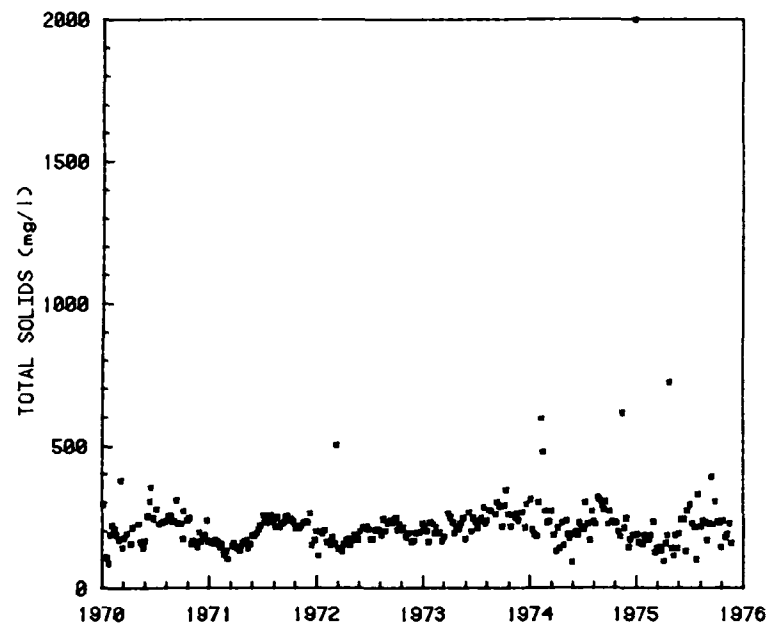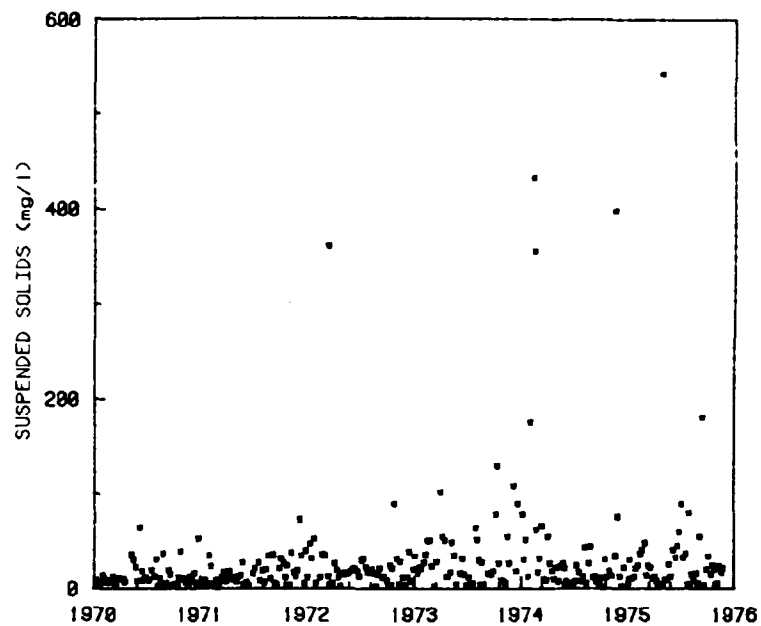
Figure 3 (Continued)

TABLE 4. TVA ASH PONDS WHICH SHOWED A YEARLY CYCLE

Parameter	Plant A		Plant B		Plant C		Plant D	Plant E	Plant F	Plant G		Plant H	Plant I		Plant J	Plant K	Plant L
	Bottom Ash	Fly Ash	Bottom Ash	Fly Ash	East	West				Old	New		North Outfall	South Outfall			
Flow	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
pH	Yes	Yes	No	No	Yes	Yes	Yes	No	No	No	No	Yes	No	No	Yes	No	No
Phenolphthalien Alkalinity	No	No	No	No	No	No	No	Yes	Yes	No	No	Yes	Yes	Yes	No	No	No
Total Alkalinity	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	No
Conductivity	Yes	Yes	-	-	Yes	Yes	Yes	-	Yes	No	No	Yes	Yes	Yes	Yes	No	No
Turbidity	No	No	No	No	No	No	No	-	No	No	No	No	No	No	No	No	No
Dissolved Solids	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No
Suspended Solids	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Total Solids	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No
Hardness	Yes	No	-	-	Yes	Yes	Yes	-	Yes	No	No	No	Yes	Yes	Yes	No	No

Yes - Indicates cycle
No - Indicates no cycle

From this summary suspended solids, flow, and turbidity showed no yearly cycle at any of the ash ponds. Seven of the ash ponds exhibited a yearly pH cycle. These same seven ash ponds exhibited yearly cycles for total alkalinity, conductivity, dissolved solids, and total solids. Five out of seven ponds also exhibited a yearly cycle for hardness. For those ash ponds which had no yearly pH cycle, only three showed yearly cycles in total alkalinity, dissolved solids, and total solids.

These plots revealed an interesting trend in the alkalinity of most of the ash pond effluents. The total alkalinity is usually approximately 50 mg/1 as $CaCO_3$ between December and April for all pond effluents. From this time on, except for the effluents from the ponds for Plant C, D, and J and the fly ash pond for Plant A, the total alkalinity either increases or remains approximately the same, rarely dropping below 50 mg/1 as $CaCO_3$. The pH normally followed the same pattern as the total alkalinity with the pH being the lowest during the later part of the year or first part of the next year. This relationship between effluent pH and effluent alkalinity is not surprising since alkalinity increases with pH.

In 1973, TVA began collecting ash pond effluent and water intake samples quarterly for trace metal and calcium, chloride and silica analyses. A summary of this data for 1973 through 1975 is given in Table 5. Discussion of these data collected prior to 1973 was excluded because it was collected at infrequent intervals. The summary consists of the average, maximum, and minimum concentrations for each element. The average was calculated by substituting a value equal to the minimum detectable amount (MDA) when the reported value was less than the MDA. Thus, the average may be biased upward if there are a significant number of reported values less than the MDA. Those parameters most likely affected are As, Ba, Be, Cd, Cr, Pb, Hg, Ni, and Se.

The average values for the ash pond effluents given in Table 5 are plotted in Figure 4 against the number of ash ponds equal to or exceeding that average concentration. For example, 7 of the 15 ash ponds have an aluminum concentration greater than or equal to 2 mg/1. Figure 4 also allows a known average concentration of a particular element in the effluent of one ash pond to be compared with the concentrations of that element in the other TVA ash pond effluents.

The average concentrations of calcium, chloride, iron, magnesium and manganese varied considerably from effluent to effluent while the average concentrations of aluminum, arsenic, silica, and sulfate varied slightly from effluent to effluent. The average concentrations of barium, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc were approximately the same in all the ash pond effluents. However, the fly ash pond at Plant A had considerably higher concentrations of aluminum, cadmium, chromium, copper, lead, nickel, silica, sulfate, and zinc than any of the other effluents. The combined ash pond effluent at Plant D had a considerably higher concentration of selenium than the rest of the effluents, while the ash pond effluent from Plant H had a considerably higher concentration of arsenic than the others. Except for the fly ash pond at Plant A (0.75 mg/1) and the combine ponds for Plant H (0.34 mg/1) and L (0.52 mg/1), the average effluent ammonia concentration was less than 0.2 mg/1. These ammonia concentrations come primarily from the intake water; however, peak concentrations may result during metal cleaning operations within the plant.

TABLE 5. SUMMARY OF QUARTERLY TRACE METAL DATA FOR ASH POND INTAKE AND EFFLUENT STREAMS

		Plant A Bottom Ash			Plant A Fly Ash			Plant B Bottom Ash			Plant B Fly Ash		
		Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
Aluminum	EFF	0.5	3.2	8.0	3.6	7.9	13	0.4	2.2	8.6	0.6	1.6	4.8
	RW	0.5	2.6	6.7	0.5	2.6	6.7	0.4	0.8	1.6	0.4	0.8	1.6
Ammonia as N	EFF	0.04	0.11	0.34	0.02	0.75	3.1	<0.01	0.07	0.31	<0.01	0.07	0.20
	RW	0.02	0.07	0.14	0.02	0.07	0.14	0.04	0.08	0.08	0.04	0.08	0.08
Arsenic	EFF	<0.005	0.007	0.015	0.005	0.011	0.035	<0.005	0.014	0.055	<0.005	0.029	0.070
	RW	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	EFF	<0.1	0.1	0.1	<0.1	0.2	0.4	<0.1	0.1	0.3	<0.1	0.1	0.2
	RW	<0.1	0.2	0.4	<0.1	0.2	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Beryllium	EFF	<0.01	<0.01	<0.01	<0.01	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	EFF	<0.001	0.001	0.002	0.023	0.038	0.052	<0.001	0.002	0.01	<0.001	0.001	0.002
	RW	<0.001	0.001	0.004	0.001	0.001	0.004	<0.001	0.004	0.01	<0.001	0.004	0.01
Calcium	EFF	23	38	67	88	126	180	17	50	200	27	152	430
	RW	21	35	48	21	35	48	17	19	20	17	19	20
Chloride	EFF	4	7	15	4	7	14	5	7	11	4	6	8
	RW	4	6	10	4	6	10	4	5	7	4	5	7
Chromium	EFF	<0.005	0.007	0.023	0.012	0.072	0.170	<0.005	0.009	0.026	<0.005	0.013	0.036
	RW	<0.005	0.010	0.024	0.005	0.010	0.024	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Copper	EFF	0.01	0.07	0.14	0.16	0.33	0.45	<0.01	0.06	0.20	<0.01	0.03	0.10
	RW	0.04	0.09	0.19	0.04	0.09	0.19	<0.01	0.02	0.02	<0.01	0.02	0.02
Cyanide	EFF	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	-	-	-	-	-	-	-	-	-	-	-	-
Iron	EFF	1.7	5.2	11	0.33	2.3	8.6	0.26	4.7	30	0.14	1.4	7.1
	RW	1.1	2.7	6.7	1.1	2.7	6.7	0.32	0.57	0.90	0.32	0.57	0.90
Lead	EFF	<0.010	0.017	0.031	<0.010	0.066	0.200	<0.010	0.018	0.048	<0.01	0.015	0.030
	RW	<0.010	0.021	0.038	<0.010	0.021	0.038	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Magnesium	EFF	0.3	6.0	9.3	9.4	14	20	4.1	6.2	21	0.2	3.6	6.8
	RW	4.1	6.1	8.0	4.1	6.1	8.0	3.6	4.3	4.7	3.6	4.3	4.7
Manganese	EFF	0.07	0.17	0.26	0.29	0.49	0.63	0.02	0.40	3.6	0.02	0.12	0.63
	RW	0.08	0.13	0.25	0.08	0.13	0.25	0.04	0.06	0.08	0.04	0.06	0.08
Mercury	EFF	<0.0002	0.0005	0.0026	<0.0002	0.0003	0.0006	<0.0002	0.0009	0.0042	<0.0002	0.0008	0.0056
	RW	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Nickel	EFF	<0.05	0.06	0.12	<0.05	0.08	0.13	<0.05	0.06	0.14	<0.05	0.05	0.08
	RW	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Selenium	EFF	<0.001	0.002	0.004	<0.001	0.002	0.004	<0.001	0.007	0.056	0.001	0.015	0.064
	RW	<0.001	0.002	0.002	<0.001	<0.002	<0.002	<0.002	0.002	0.002	<0.002	<0.002	<0.002
Silica	EFF	5.6	7.4	9.3	9.3	13	20	3.7	6.4	22	3.1	7.1	22
	RW	1.7	5.6	8.0	1.7	5.6	8.0	3.2	5.4	7.2	3.2	5.4	7.2
Silver	EFF	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.02	0.05	0.01	0.02	0.05
Dissolved Solids	EFF	140	185	260	470	593	700	110	229	710	40	458	1100
	RW	120	154	200	120	154	200	90	93	100	90	93	100
Suspended Solids	EFF	5	52	200	1	6	17	2	23	78	2	13	39
	RW	14	60	190	14	60	190	8	11	14	8	11	14
Sulfate	EFF	23	45	80	240	346	440	20	102	470	17	214	480
	RW	6	21	30	6	21	30	9	12	18	9	12	18
Zinc	EFF	0.02	0.08	0.16	0.82	1.4	2.7	0.02	0.13	0.55	0.01	0.05	0.13
	RW	0.06	0.09	0.14	0.06	0.09	0.14	0.01	0.02	0.04	0.01	0.02	0.04

NOTE: All parameters are in mg/l
   Effluent data based on years 1973-1975
   Raw water intake data based on years 1974 and 1975

TABLE 5 (Continued)

		Plant C			Plant C			Plant D			Plant E		
		Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
Aluminum	EFF	0.3	1.5	3.8	0.5	3.4	8	<0.2	1.4	3.8	1.1	2.5	3.0
	RW	0.6	4.7	15	1.3	5.2	15	0.2	0.5	0.9	1.7	2.9	4.3
Ammonia as N	EFF	0.02	0.11	0.34	<0.02	0.09	0.22	<0.01	0.06	0.15	0.03	0.06	0.09
	RW	0.03	0.14	0.33	0.03	0.16	0.29	<0.01	0.04	0.13	0.04	0.07	0.10
Arsenic	EFF	<0.005	0.013	0.05	<0.005	0.022	0.035	<0.005	0.034	0.100	<0.005	0.028	0.13
	RW	<0.005	0.008	0.026	<0.005	0.009	0.026	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Barium	EFF	<0.1	0.2	0.4	<0.1	0.14	0.3	<0.1	0.2	0.3	<0.1	0.2	0.4
	RW	<0.1	0.1	0.2	<0.1	0.14	0.2	<0.1	0.1	0.2	<0.1	0.2	0.2
Beryllium	EFF	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	EFF	0.002	0.006	0.013	<0.001	0.002	0.010	<0.001	0.001	0.002	<0.001	0.001	0.002
	RW	<0.001	0.001	0.002	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	0.001	0.002
Calcium	EFF	45	78	100	19	37	89	26	31	37	68	126	170
	RW	15	29	45	15	33	43	23	28	31	14	17	20
Chloride	EFF	7	11	16	8	11	14	2	3	5	5	6	8
	RW	7	11	16	7	11	16	2	3	4	4	5	6
Chromium	EFF	<0.005	0.006	0.008	<0.005	0.009	0.024	<0.005	<0.005	0.008	<0.005	0.017	0.022
	RW	<0.005	0.012	0.041	<0.005	0.013	0.041	<0.005	0.005	<0.005	<0.005	<0.005	<0.005
Copper	EFF	<0.01	0.05	0.10	<0.01	0.06	0.18	<0.01	0.03	0.14	0.02	0.08	0.19
	RW	0.03	0.11	0.22	0.03	0.12	0.22	0.02	0.07	0.22	0.02	0.05	0.08
Cyanide	EFF	<0.01	0.01	<0.01	<0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	-	-	-	-	-	-	-	-	-	-	-	-
Iron	EFF	0.33	1.7	4.1	0.72	6.0	27	<0.05	0.32	0.67	0.05	0.16	0.39
	RW	1.0	6.5	14	1.4	7.2	14	0.25	0.51	1.00	0.45	1.0	1.6
Lead	EFF	<0.010	0.021	0.069	<0.010	0.017	0.033	<0.010	0.016	0.046	<0.01	0.017	0.036
	RW	<0.010	0.022	0.047	<0.010	0.024	0.047	<0.010	0.012	0.018	<0.01	0.015	0.028
Magnesium	EFF	1.4	10	16	6.3	10	16	7.5	8.3	9.8	0.1	0.3	0.3
	RW	6.5	9.5	14	6.5	6.6	14	7.1	8.0	9.1	3.0	3.4	4.1
Manganese	EFF	0.13	0.20	0.34	0.05	0.18	0.66	<0.01	0.02	0.05	<0.01	0.01	0.02
	RW	0.12	0.31	0.53	0.12	0.31	0.53	0.03	0.07	0.13	0.04	0.05	0.07
Mercury	EFF	<0.0002	0.0034	0.0074	<0.0002	0.0070	0.050	<0.0002	0.0002	0.0003	<0.0002	0.0002	0.0003
	RW	<0.0002	0.0004	0.0016	<0.0002	0.0003	0.0016	<0.0002	0.0002	0.0005	<0.0002	<0.0002	<0.0002
Nickel	EFF	<0.05	0.05	0.07	<0.05	0.06	0.17	<0.05	0.06	0.19	<0.05	<0.05	<0.05
	RW	<0.05	<0.05	<0.05	<0.05	0.05	0.05	<0.05	0.08	0.27	<0.05	<0.05	<0.05
Selenium	EFF	<0.001	0.010	0.080	<0.001	0.003	0.004	<0.002	0.070	0.170	<0.002	0.007	0.014
	RW	<0.001	0.002	0.004	<0.002	0.002	0.004	<0.002	0.002	0.004	<0.002	<0.002	<0.002
Silicia	EFF	4.7	7.4	11	1.5	6.7	14	3.2	4.0	6.2	5.9	7.0	8.4
	RW	5.5	6.1	7.9	5.4	6.2	7.9	3.8	5.2	9.5	4.5	4.7	5.0
Silver	EFF	<0.01	0.01	0.03	<0.01	0.01	0.02	<0.01	0.01	0.01	<0.01	0.01	0.02
	RW	<0.01	0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dissolved Solids	EFF	260	345	460	170	239	420	100	156	200	240	368	420
	RW	160	205	240	160	197	220	110	126	140	80	93	100
Suspended Solids	EFF	3	18	37	4	31	98	3	15	45	2	4	6
	RW	11	46	150	17	51	150	1	14	55	8	18	38
Sulfate	EFF	110	158	200	35	99	280	16	57	84	100	147	210
	RW	0.07	23	52	34	49	68	13	16	20	15	20	25
Zinc	EFF	0.02	0.13	0.27	0.03	0.14	0.16	<0.01	0.03	0.07	<0.03	0.05	0.07
	RW	0.03	0.08	0.13	0.03	0.08	0.13	0.03	0.04	0.07	0.04	0.08	0.18

TABLE 5 (Continued)

		Plant F Minimum	Average	Maximum	Plant G Minimum	Average	Maximum	Plant H Minimum	Average	Maximum	Plant I Minimum	Average	South Maximum
Aluminum	EFF	0.8	1.7	3.1	0.4	1.7	2.9	0.8	1.6	2.9	0.6	1.5	2.6
	RW	<0.1	1.4	3.6	0.1	1.2	4.1	<0.2	1.0	1.6	0.8	1.6	3.0
Ammonia as N	EFF	0.03	0.17	.42	<0.01	0.12	0.62	0.03	0.34	2.60	0.01	0.07	0.31
	RW	0.02	0.08	0.26	0.01	0.04	0.08	0.06	0.23	0.49	0.08	0.05	0.10
Arsenic	EFF	<0.005	0.008	0.040	<0.005	0.030	0.070	<0.005	0.123	0.360	<0.005	0.036	0.160
	RW	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.006	0.010	<0.005	<0.005	<0.005
Barium	EFF	<0.1	0.2	0.3	<0.1	0.2	0.4	<0.1	0.2	0.3	<0.1	0.2	0.5
	RW	<0.1	0.1	0.1	<0.1	0.1	0.1	<0.1	0.1	0.2	0.1	0.2	0.3
Beryllium	EFF	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	EFF	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001
	RW	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Calcium	EFF	67	107	160	38	73	110	34	50	67	44	84	140
	RW	19	27	35	13	20	25	22	28	35	17	19	21
Chloride	EFF	4	5	6	2	4	8	8	14	22	4	6	11
	RW	3	4	4	3	4	5	7	14	28	4	6	8
Chromium	EFF	<0.005	0.033	0.072	<0.005	0.011	0.023	<0.005	0.006	0.01	<0.005	0.017	0.030
	RW	<0.005	0.006	0.012	<0.005	0.005	0.010	<0.005	0.005	0.007	<0.005	<0.005	<0.005
Copper	EFF	<0.01	0.03	0.08	<0.01	0.05	0.12	<0.01	0.04	0.14	<0.01	0.06	0.15
	RW	<0.01	0.05	0.08	<0.01	0.07	0.16	0.02	0.07	0.15	0.01	0.07	0.12
Cyanide	EFF	<0.01	<0.01	<0.01	<0.01	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	-	-	-	-	-	-	-	-	-	-	-	-
Iron	EFF	<0.05	0.22	1.1	0.26	0.53	1.4	0.18	0.56	1.4	<0.05	0.26	0.58
	RW	0.10	1.1	2.1	0.33	1.3	4.6	0.45	1.1	1.7	0.61	1.7	3.9
Lead	EFF	<0.010	0.013	0.040	<0.010	0.014	0.036	0.010	0.015	0.036	<0.01	0.012	0.038
	RW	<0.010	0.019	0.052	<0.010	0.019	0.04	0.010	0.019	0.033	0.01	0.15	0.021
Magnesium	EFF	0.3	1.57	7.2	1.1	2.4	3.1	6.2	7.4	9.7	0.2	1.2	3.7
	RW	3.5	4.2	4.9	3.4	4.0	4.6	5.7	7.4	13.0	2.6	3.3	4.3
Manganese	EFF	<0.01	0.01	0.04	<0.01	0.02	0.04	0.02	0.06	0.10	<0.01	0.05	0.5
	RW	0.06	0.07	0.011	0.05	0.10	0.23	0.10	0.14	0.18	0.01	0.01	0.2
Mercury	EFF	<0.0002	0.0003	0.0009	<0.0002	0.0024	0.014	<0.0002	0.0004	0.0016	<0.0002	0.0003	0.0012
	RW	<0.0002	0.0006	0.0033	<0.0002	0.0049	0.0031	<0.0002	0.0003	0.0008	<0.0002	0.0002	0.0003
Nickel	EFF	<0.05	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	0.07	<0.05	0.05	0.05
	RW	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Selenium	EFF	0.006	0.014	0.028	<0.001	0.010	0.019	<0.002	0.017	0.034	<0.002	0.012	0.08
	RW	<0.002	<0.002	<0.002	<0.001	0.002	0.004	<0.001	0.002	0.006	<0.001	<0.002	<0.002
Silicia	EFF	3.9	6.0	7.6	3.4	4.4	7.1	2.7	4.9	5.6	6.0	7.1	9.1
	RW	3.5	4.5	5.4	3.5	4.4	5.4	2.7	4.9	6.6	3.2	5.4	6.4
Silver	EFF	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dissolved Solids	EFF	230	366	540	190	266	320	200	256	350	190	248	370
	RW	90	129	170	70	144	480	110	145	180	90	121	310
Suspended Solids	EFF	<1	4	20	8	19	45	4	10	19	<1	5	15
	RW	6	26	42	5	18	67	10	24	29	4	24	57
Sulfate	EFF	14	160	260	88	182	620	45	98	150	50	81	200
	RW	12	19	23	<1	17	23	16	19	22	10	21	80
Zinc	EFF	<0.01	0.05	0.14	<0.01	0.05	0.10	<0.01	0.05	0.15	<0.01	0.08	0.24
	RW	0.03	0.12	0.22	0.03	0.09	0.13	0.04	0.11	0.33	0.03	0.07	0.12

TABLE 5 (Continued)

|		Plant J			Plant K			Plant L		
		Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
Aluminum	EFF	0.4	2.6	7.6	0.5	1.8	3.1	1.3	2.0	2.6
	RW	0.3	0.7	1.4	0.6	2.0	3.4	0.3	1.2	2.8
Ammonia as N	EFF	0.01	0.05	0.08	0.02	0.06	0.16	0.06	0.52	1.40
	RW	0.01	0.04	0.23	0.04	0.09	0.24	0.04	0.06	0.08
Arsenic	EFF	0.005	0.041	0.130	0.005	0.033	0.100	<0.005	0.032	0.070
	RW	0.005	0.018	0.110	0.005	0.009	0.024	<0.005	0.006	0.010
Barium	EFF	<0.1	0.2	0.3	<0.1	0.2	0.3	<0.1	0.1	0.2
	RW	<0.1	0.2	0.4	<0.1	0.1	0.3	<0.1	0.1	0.2
Beryllium	EFF	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	EFF	<0.001	0.001	0.002	<0.001	0.001	0.002	<0.001	0.001	0.004
	RW	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Calcium	EFF	20	34	57	44	76	130	32	54	91
	RW	4	15	30	12	20	28	13	17	21
Chloride	EFF	2	5	21	6	10	19	4	6	9
	RW	2	2	4	4	7	10	4	6	8
Chromium	EFF	<0.005	0.005	0.007	<0.005	0.019	0.036	<0.005	0.009	0.018
	RW	<0.005	0.005	0.006	<0.005	0.009	0.027	<0.005	0.009	0.021
Copper	EFF	0.02	0.11	0.73	0.01	0.05	0.10	<0.01	0.06	0.14
	RW	<0.01	0.08	0.13	<0.01	0.07	0.12	<0.01	0.07	0.14
Cyanide	EFF	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	-	-	-	-	-	-	-	-	-
Iron	EFF	0.1	2.4	9.4	0.11	0.39	1.2	0.05	0.56	1.00
	RW	0.26	0.7	1.2	0.66	1.9	3.3	0.28	1.03	2.40
Lead	EFF	<0.010	0.015	0.038	0.010	0.017	0.048	0.010	0.017	0.043
	RW	<0.010	0.010	0.018	0.01	0.01	0.03	0.010	0.016	0.032
Magnesium	EFF	3.9	6.7	9.3	0.4	1.6	3.6	0.4	2.6	4.2
	RW	1.2	4.5	8.3	2.5	4.3	6.9	3.4	3.9	4.4
Manganese	EFF	0.05	0.38	0.79	0.01	0.02	0.04	0.01	0.03	0.13
	RW	0.03	0.07	0.18	0.07	0.10	0.18	0.03	0.07	0.12
Mercury	EFF	<0.0002	0.0003	0.0008	<0.0002	0.0003	0.0008	0.0002	0.0003	0.0009
	RW	<0.0002	0.0003	0.0009	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Nickel	EFF	<0.05	0.05	0.08	<0.05	0.06	0.22	<0.05	<0.05	<0.05
	RW	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Selenium	EFF	<0.001	0.004	0.008	<0.002	0.010	0.016	0.002	0.010	0.020
	RW	<0.001	0.003	0.008	<0.001	0.002	0.002	<0.001	0.002	0.002
Silicia	EFF	3.5	6.4	8.7	4.0	6.7	8.8	4.5	5.7	9.1
	RW	1.0	3.9	5.0	2.5	4.6	5.9	3.6	5.1	5.8
Silver	EFF	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dissolved Solids	EFF	140	202	250	180	240	310	140	211	260
		30	89	210	80	106	150	70	88	100
Suspended Solids	EFF	1	15	81	3	8	26	3	12	50
		5	13	35	17	29	60	4	14	43
Sulfate	EFF	56	119	180	54	83	110	6	80	110
	RW	9	22	80	12	20	31	9	13	16
Zinc	EFF	0.02	0.07	0.25	0.01	0.05	0.11	0.02	0.04	0.06
	RW	0.03	0.06	0.09	0.04	0.07	0.11	0.03	0.06	0.09
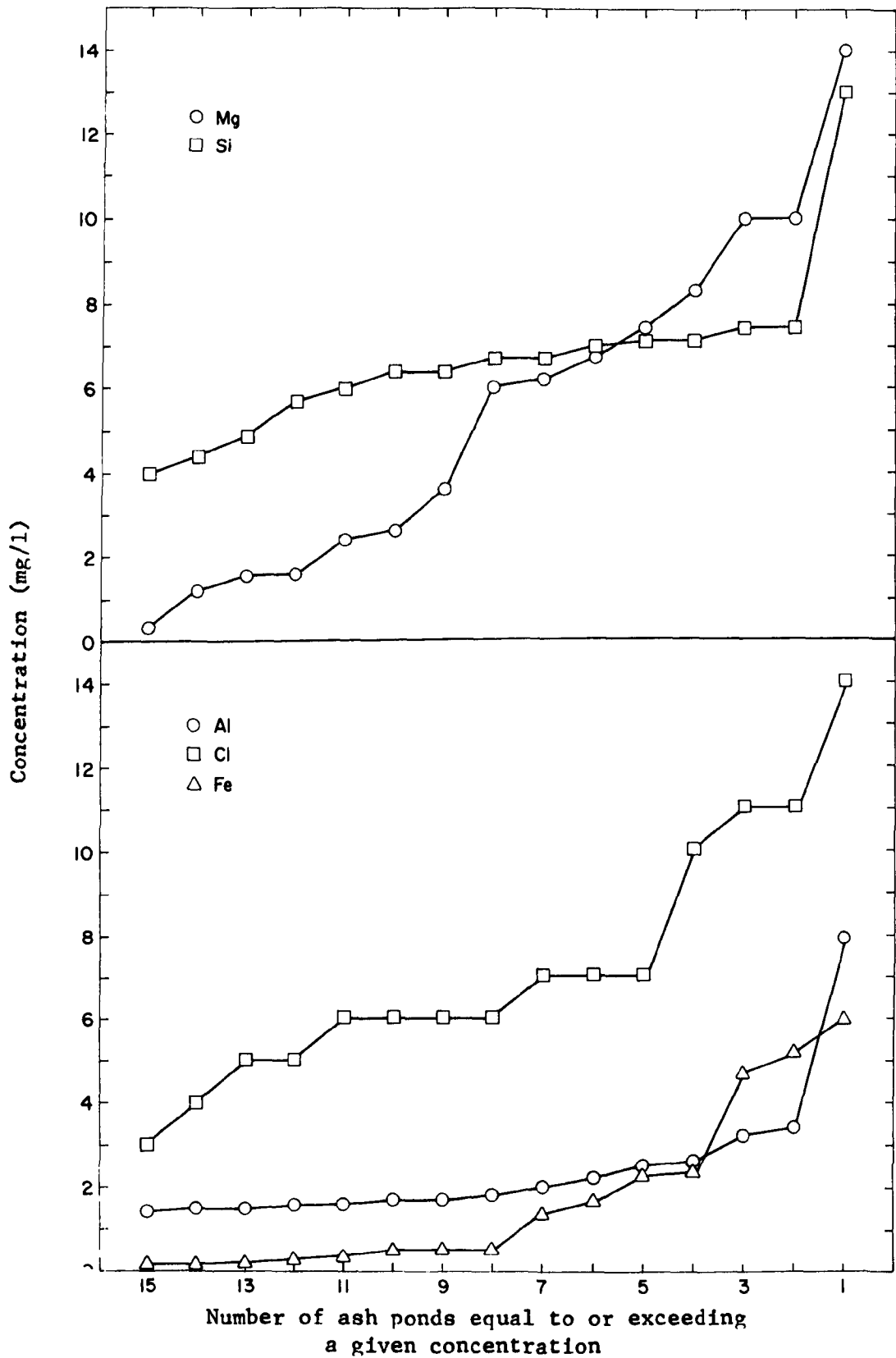
Figure 4. Number of TVA Ash Ponds Whose Average Effluent
Concentration Equals or Exceeds Various Given
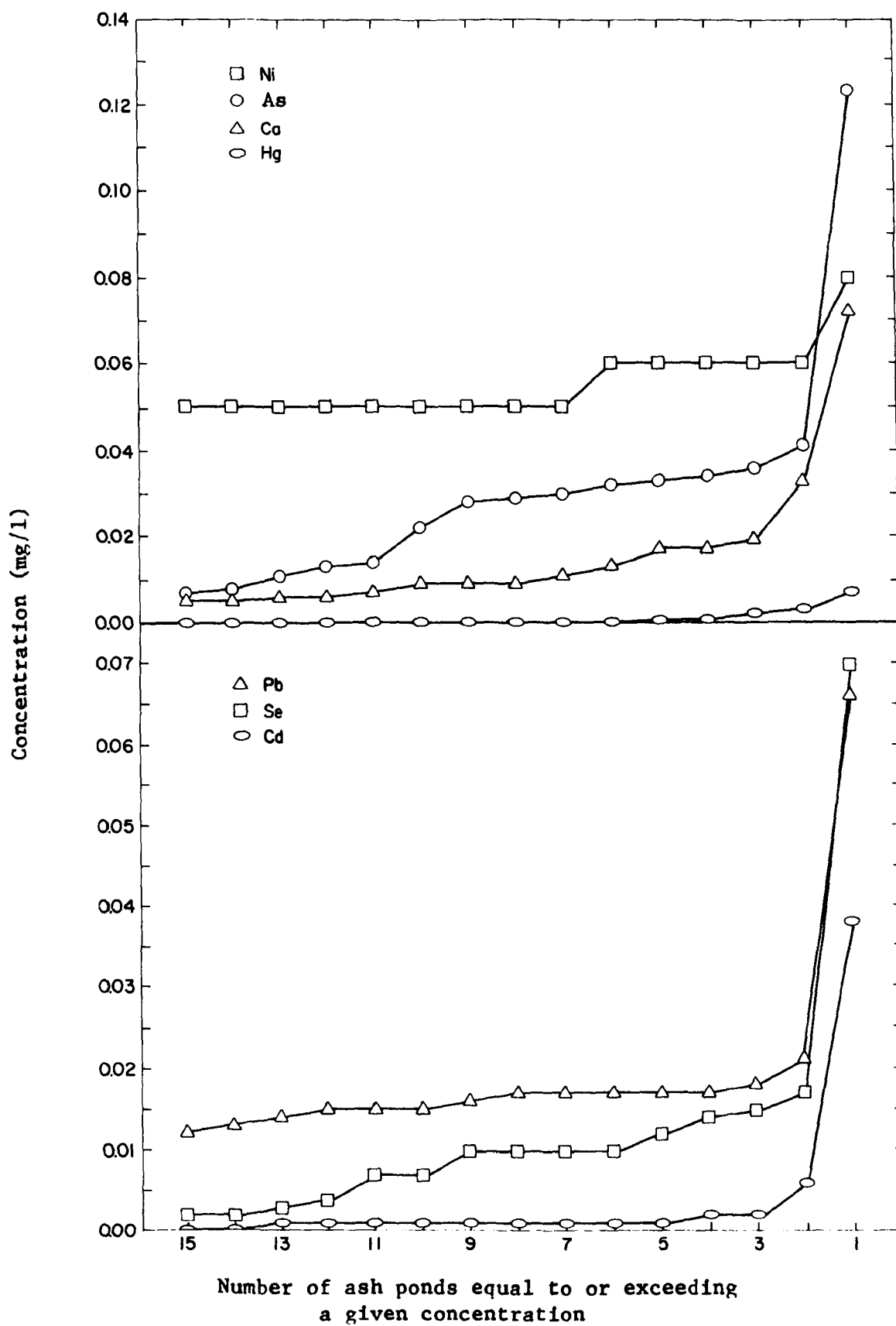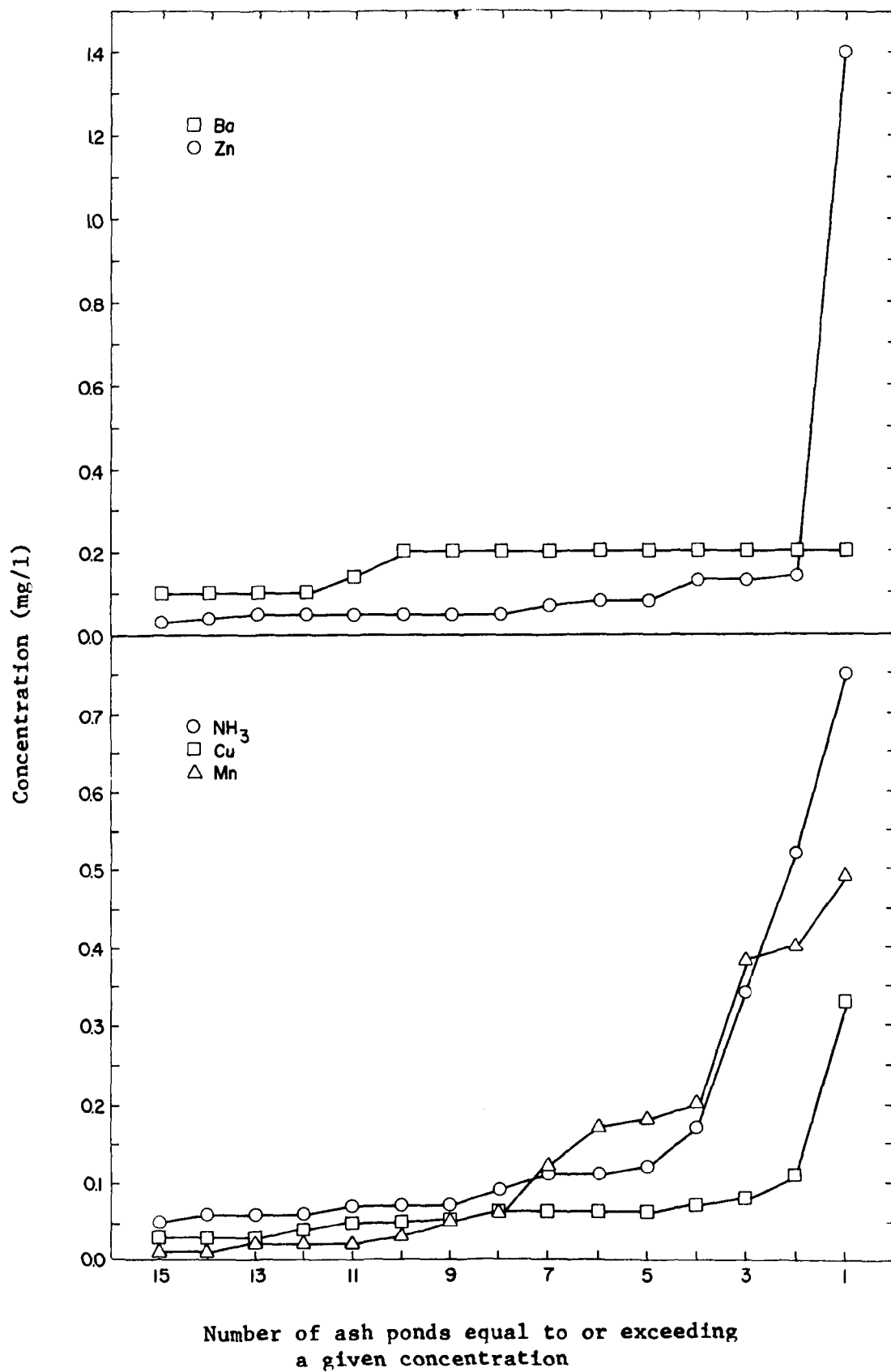Concentrations

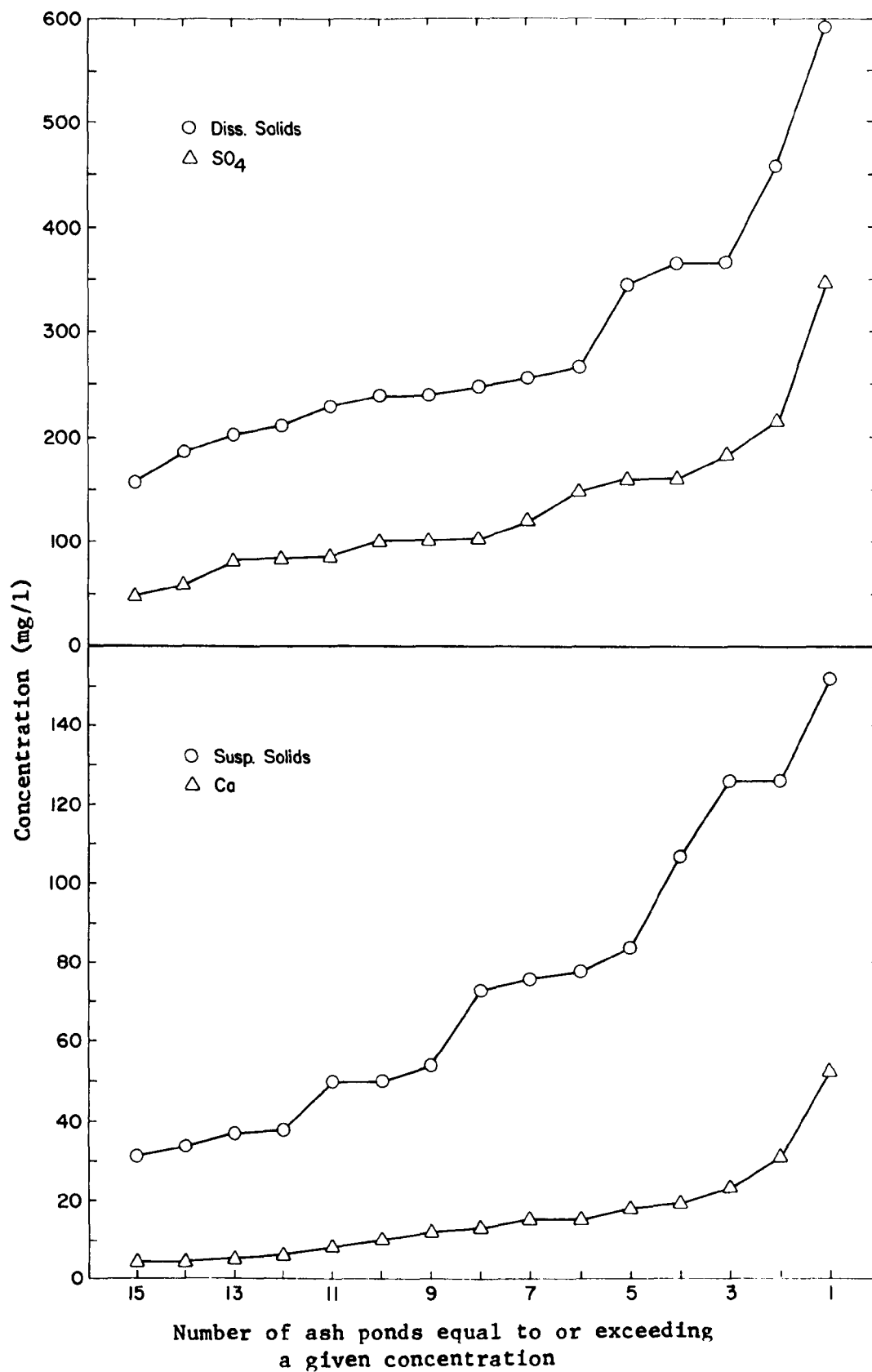Figure 4 (Continued)

Figure 4 (Continued)

Figure 4 (Continued)

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The concentrations of most metals in the ash pond effluent appear to vary with time. The amount of variation differs for each element within each effluent. This is indicated by the difference between the minimum and maximum values for each element. A more detailed statistical analysis to determine whether this variation was significant was not performed because there were insufficient data.

RELATIONSHIPS BETWEEN PLANT OPERATION CONDITIONS AND ASH POND EFFLUENT CHARACTERISTICS

Relationships between the ash pond effluent and the plant operating conditions were developed on a plant-to-plant basis in order to increase knowledge of the system and aid in developing an ash pond effluent monitoring strategy. Plant operating conditions are defined as those parameters or processes which can vary with time either with or without man's control. They include such things as coal characteristics, raw water quality characteristics, ash collector efficiencies and quantities of coal burned. A summary of the plant operating conditions, ash characteristics, and ash pond effluent characteristics at each plant are given in Table 6. These data are rough estimates and represent average values for varying time periods with a span of five years. They were obtained from various sources and most often the data were collected for other purposes. For example, the coal data were obtained from TVA Division of Power Production. The ash characteristics were obtained from routine analyis conducted by TVA's Singleton Materials Engineering Laboratory in Knoxville, Tennessee. The intake and effluent data were obtained from analysis of routine samples collected by personnel of TVA's Division of Power Production and analyzed by TVA's Laboratory Branch of the Division of Environmental Planning. The average values are also for varying periods of time within a span of five years.

Linear correlation coefficients were developed for the data shown in Table 6. The significant coefficients at the 95 percent confidence level are given in Table 7. They are based only on the data for Plants C-L. The data for Plants A and B were excluded from the correlation analysis because these two plants operate separate ash ponds for fly ash and bottom ash. The data for Plant C was included although it has cyclone boilers. Therefore the ash produced at Plant C is about 60 percent bottom ash, whereas at the other plants, which have pulverized coal boilers, the ash produced is only about 30 percent bottom ash. Unfortunately no data were available on the bottom ash characteristics.

Correlation is a measure of the degree of association between parameters and may give valuable insight into the relationships between plant operating conditions and the ash pond effluent. Even though the data in Table 6 are only estimates, the correlations can be used to group parameters that behave similarly and identify pairs of parameters that should be plotted and studied more carefully as predictors. The correlation coefficient depends primarily on the amount of variation for the parameters as well as on their measured error and the actual relation between them. In general, a large correlation coefficient between two parameters may be due not so much to a direct relationship between them as much as to their common dependence on other parameters ("lurking variables"). For example, two seasonal parameters may show a strong

TABLE 6. SUMMARY OF PLANT OPERATION CONDITIONS AND ASH POND EFFLUENT CHARACTERISTICS OF TVA COAL-FIRED POWER PLANTS

Parameters	Plant A	Plant B	Plant C	Plant D	Plant E	Plant F	Plant G	Plant H	Plant I	Plant J	Plant K	Plant L
Method of Firing	Cyclone	Circular Wall Burners	Cyclone	Tangential	Circular Wall Burners	Opposed	Tangential	Tangential	Circular Wall Burner	Tangential	Circular Wall Burner	Circular Wall Burner
Coal Source	W. Kentucky	W. Kentucky	W. Kentucky	E. Kentucky	W. Kentucky	W. Kentucky S. Illinois	W. Kentucky	Virginia E. Kentucky E. Tennessee	W. Kentucky	E. Kentucky E. Tennessee	S. Illinois W. Kentucky	W. Kentucky N. Alabama
Ash Content in Coal, %	18.8	14.8	11	15.5	15.3	16.3	15.7	15	14	19.1	15.6	16
Fly Ash of Total Ash, %	30	50	30	75	67	80	80	67	70	75	75	75
Bottom Ash of Total Ash, %	70	50	70	25	33	20	20	33	30	25	25	25
Sulfur Content in Coal, %	4.1	-	3.0	1.2	4.1	3.7	3.5	1.8	3.7	2.1	2.8	2.8
Coal Usage at Full Load (tons/day)	22901	3314	7848	8240	12897	24525	10503	8057	14460	16193	15304	17691
Number of Units	3	4	3	1	5	2	4	4	10	9	10	8
ESP Efficiency, %	-	-	-	99	74	99	60	-	75	70	60	60
Mechanical Ash Collector Efficiency, %	98	-	90-99	-	80	-	-	-	-	95	95	99
Overall Efficiency, %	98	-	-	99	95	-	98-99	99	75.5	98	98	70
Sluice Water to Ash Ratio (gal/ton)	12380[f] 9810[b]	-	23065	10770	9585	19490	12345	11425	42430	9520	17265	15370
pH of Intake Water	7.7	7.5	7.4	7.5	7.0	7.4	7.3	7.0	7.4	7.6	7.6	7.5
Suspended Solids Concentration of Intake Water (mg/l)	60	41	81	15	17	24	12	21	15	15	38	6
Alkalinity of Intake Water (mg/l as $CaCO_3$)	97	56	83	95	53	69	63	73	58	55	66	63
% SiO_2 in Fly Ash	NA	NA	47.6	NA	46.9	NA	53.7	52.5	58.7	50.4	NA	45.3
% CaO in Fly Ash	NA	NA	1.72	NA	4.66	NA	2.36	2.19	3.17	1.92	NA	4.91
% Fe_2O_3 in Fly Ash	NA	NA	11.3	NA	14.9	NA	9.6	10.2	10.7	11.6	NA	17.0
% Al_2O_3 in Fly Ash	NA	NA	22.7	NA	18.6	NA	26.4	25.5	23.9	25.2	NA	27.0
% MgO in Fly Ash	NA	NA	0.93	NA	1.33	NA	1.12	1.42	1.24	1.29	NA	1.22
% SO_3 in Fly Ash	NA	NA	2.2	NA	1.5	NA	1.09	1.9	1.2	0.54	NA	1.16
% Moisture in Fly Ash	NA	NA	1.04	NA	0.32	NA	0.37	0.63	0.22	0.21	NA	0.87
pH of Fly Ash	NA	NA	2.9	NA	11.8	NA	4.5	3.6	4.6	4.0	NA	6.5
Ash Pond Effluent pH	4.4[f] 7.2[b]	9.8[f] 8.0[b]	7.1[c]	8.4[c]	11.1[c]	11.1[c]	9.5[c]	8.7[c]	11.0[c]	7.5[c]	10.8[c]	10.1[c]
Ash Pond Effluent Suspended Solids (mg/l)	25[f] 55[b]	85[f] 64[b]	30[c]	19[c]	<10[c]	10[c]	20[c]	19[c]	19[c]	25[c]	17[c]	15[c]

[f] Fly ash pond only
[b] Bottom ash pond only
[c] Combined bottom and fly ash pond

NOTE: Intake water characteristics based on 1974 and 1975 weekly samples.
Ash pond effluent characteristics based on 1970-1975 weekly samples.

TABLE 7. LINEAR CORRELATION COEFFICIENTS SIGNIFICANT AT THE 95%
LEVEL OF CONFIDENCE FOR PLANT OPERATING CONDITIONS

Parameter	Parameter	Correlation Coefficient
Ash Pond Effluent pH	Suspended Solids in the Ash Pond Effluent	-0.856
Ash Pond Effluent pH	Sulfur Content of Coal	0.649
Ash Pond Effluent pH	CaO Content of Ash %	0.792
Suspended Solids Ash Pond Effluent	CaO Content of Ash %	-0.859
Suspended Solids Ash Pond Effluent	Fly Ash pH	-0.840
Mechanical Ash Collector Efficiency %	Al_2O_3 Content of Ash %	0.951
CaO Content of Ash %	Fe_2O_3 Content of Ash %	0.863
CaO Content of Ash %	Fly Ash pH	0.812
Ash Content of Coal %	SO_3 Content of Ash %	-0.863

association as they fluctuate together over time. Lurking variables in addition to time are to be found when looking at relationships from plant to plant. A significant correlation at the 95 percent level of confidence is one greater than 0.632 for all correlations except those involving the fly ash characteristics. Significant correlations with the fly ash characteristics are represented by an R value greater than 0.754. These values were obtained from Freund 1967 (2) and are based on the number of data points used to determine R. As the number of data points increases, the R value for the 95 percent level of confidence decreases.

Not all correlations with R values greater than 0.632 or 0.754 represent meaningful relationships. For example, the R value for the comparison of the pH of the intake water used for sluicing with the efficiency of the mechanical ash collector was 0.903, but there is no logical reason these two parameters should correlate. Therefore, this coefficient represents a meaningless relationship. One reason that a high coefficient was obtained was that coincidentally the lowest pH value and the lowest mechanical ash collector efficiency occurred at the same plant representing one sixth of the data.

Table 7 indicates that the pH of the ash pond effluent is mainly influenced by the calcium content of the fly ash (R = 0.792) and the sulfur content of the coal (R = 0.649). Since the sulfur content of coal varies with its source the following generalization can be made. The effluents from plants which receive coal from western Kentucky and southern Illinois (sulfur content usually 2.8 to 4 percent) are basic while those from plants which receive coal from eastern Tennessee, eastern Kentucky, and Virginia (sulfur content usually 2 percent or below) are neutral or slightly acidic. An exception to this is the effluents from the separate ponds at Plant A and the combined pond at Plant C.

Suspended solids in the effluent exhibited significant (with a 95 percent confidence coefficient) negative correlations with the percent of CaO in the fly ash and pH of the fly ash. There was also a significant negative correlation between the effluent pH and the effluent suspended solids which can not be explained. In addition, the pH of the fly ash correlated significantly with the percent of CaO in the ash.

RELATIONSHIP BETWEEN THE CHARACTERISTICS OF THE INTAKE WATER AND ASH POND EFFLUENT

In 1974 and 1975 weekly samples of the intake water used for sluicing at each plant were collected at approximately the same time as the ash pond effluent samples and analyzed for pH, alkalinity, dissolved solids, and suspended solids. A summary of this data is given in Table 8. These weekly data were combined with the corresponding weekly ash pond effluent data for 1974 and 1975 and linear correlation coefficients developed for the four plants: E, G, H, and J. The R values for these correlations are shown in Table 9 for these four plants. An R value greater than 0.205 indicates a significant correlation of at least the 95 percent confidence level for Plants G, H, and J, while an R value of 0.273 indicated a significant correlation of at least the 95 percent confidence level for Plant E.

TABLE 8. SUMMARY OF WEEKLY ASH POND INTAKE WATER DATA FOR 1974 AND 1975

Parameter		Plant A 1974	Plant A 1975	Plant B 1974	Plant B 1975	Plant C 1974	Plant C 1975	Plant D 1974	Plant D 1975
pH	Max	8.1	8.2	8.6	8.5	7.8	7.9	8.5	8.6
	Avg	7.7	7.6	7.5	7.6	7.4	7.4	7.8	7.8
	Min	7.4	7.1	7.0	7.0	6.8	6.9	7.5	7.3
Phenolphthalein	Max	<1	<1	<1	<1	<1	<1	9.0	6.0
Alkalinity	Avg							1.2	0.7
(mg/l as $CaCO_3$)	Min							1.0	<1
Total Alkalinity	Max	130	130	71	64	150	144	120	120
(mg/l as $CaCO_3$)	Avg	97	97	56	54	83	92	95	98
	Min	74	68	28	35	50	56	63	64
Hardness	Max	150		80		196		142	
(mg/l as $CaCO_3$)	Avg	110	NA	57	NA	111	NA	114	NA
	Min	75		55		70		91	
Conductivity	Max	340		200		438		298	
(μmhos/cm)	Avg	252	NA	142	NA	266	NA	220	NA
	Min	150		70		158		180	
Dissolved Solids	Max	204	259	164	137	357	339	223	215
(mg/l)	Avg	108	137	96	94	177	229	125	137
	Min	25	60	11	34	94	177	60	90
Suspended Solids	Max	334	187	230	145	172	155	44	34
(mg/l)	Avg	60	48	41	23	81	45	15	11
	Min	7	11	1	8	9	15	2	2
Turbidity	Max	100		25		220		27	
(JCU)	Avg	34	NA	24	NA	67	NA	25	NA
	Min	12		15		<25		<25	

TABLE 8 (continued)

Parameter		Plant E 1974	Plant E 1975	Plant F 1974	Plant F 1975	Plant G 1974	Plant G 1975	Plant H 1974	Plant H 1975
pH	Max	8.3	7.8	8.2	8.2	7.8	8.0	8.4	8.6
	Avg	7.4	7.3	7.8	7.7	7.5	7.6	7.0	7.9
	Min	7.0	7.0	7.4	6.8	7.3	7.4	7.6	7.5
Phenolphthalein	Max	<1	<1	<1	<1	90	<1	5	<1
Alkalinity	Avg					2		<1	
(mg/l as $CaCO_3$)	Min					<1		<1	
Total Alkalinity	Max	90	58	94	90	90	90	90	100
(mg/l as $CaCO_3$)	Avg	53	47	69	66	63	56	73	82
	Min	34	34	38	42	52	40	8	60
Hardness	Max	160		243		140		95	
(mg/l as $CaCO_3$)	Avg	80	NA	108	NA	72	NA	80	NA
	Min	52		84		62		60	
Conductivity	Max	200		280		230		396	
(μmhos/cm)	Avg	157	NA	205	NA	184	NA	256	NA
	Min	115		165		115		195	
Dissolved Solids	Max	190	187	587	224	156	136	250	360
(mg/l)	Avg	106	102	128	107	116	91	190	173
	Min	64	34	33	12	79	32	122	122
Suspended Solids	Max	50	184	68	87	81	175	64	72
(mg/l)	Avg	17	22	24	19	24	18	21	19
	Min	4	3	9	2	5	2	5	3
Turbidity	Max	60		150		59		90	
(JCU)	Avg	27	NA	56	NA	31	NA	30	NA
	Min	<22		22		25		<25	

TABLE 8 (continued)

Parameter		Plant I		Plant J		Plant K		Plant L	
		1974	1975	1974	1975	1974	1975	1974	1975
pH	Max	7.9	8.1	8.6	8.4	8.3	9.9	8.3	8.0
	Avg	7.8	7.5	7.6	7.4	7.9	7.9	7.8	7.6
	Min	7.4	7.1	6.5	6.0	7.6	7.6	7.5	7.4
Phenolphthalein	Max	<1	<1	1	2	<1	<1	<1	<1
Alkalinity	Avg			<1	<1				
(mg/l as $CaCO_3$)	Min			<1	<1				
Total Alkalinity	Max	74	62	108	96	96	68	80	67
(mg/l as $CaCO_3$)	Avg	58	54	52	44	66	56	68	57
	Min	53	15	7	3	50	42	38	37
Hardness	Max	79		98		135		83	
(mg/l as $CaCO_3$)	Avg	68	NA	54	NA	86	NA	70	NA
	Min	60		8		64		53	
Conductivity	Max	200		225		320		170	
(μmhos/cm)	Avg	144	NA	133	NA	185	NA	148	NA
	Min	120		43		90		125	
Dissolved Solids	Max	287	223	218	183	237	227	162	272
(mg/l)	Avg	98	105	91	79	125	136	93	89
	Min	23	25	10	12	15	68	14	10
Suspended Solids	Max	25	117	43	42	176	127	36	58
(mg/l)	Avg	15	22	15	13	38	32	6	11
	Min	4	3	2	1	9	9	2	2
Turbidity	Max	78		25		80		70	
(JCU)	Avg	24	NA	9	NA	54	NA	22	NA
	Min	10		3		45		1	

The R values in Table 9 indicate that there are several significant relationships between several intake water quality characteristics and the pH of the ash pond effluent for Plants G, H, and J. However, these relationships varied for the different plants. For example, there was a significant correlation between the intake water pH and the ash pond effluent pH and also between the intake water dissolved solids and the ash pond effluent pH for Plants G, H, and J. These same plants also had a significant negative correlation between the intake water conductivity and ash pond effluent pH. There was also a significant correlation between intake water hardness and effluent pH for Plant J and a significant negative correlation between intake water hardness and effluent pH for Plants G and H. However, only Plants G and J had significant correlations between intake water alkalinity and effluent pH. For Plant G it is negative while for Plant J it is positive.

Of these correlations with the pH of the effluent, the most meaningful with respect to prediction of the pH are the ones with intake alkalinity, since alkalinity is a measure of the resistance of the system to changes in pH. Figure 5 shows this relationship for Plant J more clearly. During periods when the alkalinity is near zero, the pH drops below four, whereas, with a normal alkalinity in the range of 30-90 mg/l, the pH is approximately eight. In order to maintain a pH between six and nine at Plant J, an intake alkalinity of around 10 mg/l is needed.

There were few significant correlations between the suspended solids in the ash pond effluent and any of the intake water quality characteristics. The ash pond effluent suspended solids were negatively correlated with the hardness in the intake water at Plants J and G. The effluent suspended solids were also negatively correlated with the conductivity of the intake water at Plant J. The effluent suspended solids were negatively correlated with the alkalinity of the intake water at Plant H.

The effluent suspended solids were not significantly correlated with the intake suspended solids at any one of the four plants. However, Figure 6 indicates that suspended solids peaks in the effluent may correspond to suspended solids peaks in the intake water when lag times of one to two weeks are considered. To test this hypothesis correlation coefficients were developed for Plants E and J by incorporating a lag time of one sample period (approximately seven days) between intake and effluent samples. By lagging the data sets in this manner the detention time of the ash pond is somewhat accounted for. The results of this comparison are given in Table 10. Only the correlations for intake versus effluent characteristics are given since intake versus intake and effluent versus effluent remained the same as before. Significant correlations between intake suspended solids and effluent suspended solids were not obtained by lagging the two data sets. Furthermore, the correlation coefficients for the data in Table 9 were higher than those for the lagged data set. An exception to this at Plant E is the correlation between the ash pond effluent conductivity and the intake dissolved solids. Exceptions to this at Plant J are the correlations for intake pH with effluent dissolved solids, intake total alkalinity with effluent dissolved solids, intake hardness with effluent flowrate, intake hardness with effluent conductivity and intake conductivity with

TABLE 9. CORRELATION COEFFICIENTS FOR THE ASH POND SYSTEM AT PLANT E

	Intake pH	Intake Total Alkalinity	Intake Hardness	Intake Conductivity	Intake Dissolved Solids	Intake Suspended Solids	Intake Turbidity	Effluent Flowrate	Effluent pH	Effluent Phenolphthalein Alkalinity	Effluent Total Alkalinity	Effluent Hardness	Effluent Conductivity	Effluent Dissolved Solids	Effluent Suspended Solids	Effluent Turbidity
Intake pH	1.000															
Intake Total Alkalinity	0.460	1.000														
Intake Hardness	0.684	-0.034	1.000													
Intake Conductivity	0.159	-0.133	0.307	1.000												
Intake Dissolved Solids	0.178	0.295	0.215	-0.135	1.000											
Intake Suspended Solids	-0.257	-0.149	0.109	0.115	-0.345	1.000										
Intake Turbidity	-0.253	-0.071	-0.081	0.118	0.029	-0.059	1.000									
Effluent Flowrate	0.160	0.111	0.087	0.038	-0.026	-0.203	0.237	1.000								
Effluent pH	0.098	0.155	0.090	-0.458	0.210	0.002	0.075	0.078	1.000							
Effluent Phenolphthalein Alkalinity	0.112	0.381	-0.356	0.538	0.200	0.032	0.026	0.056	0.701	1.000						
Effluent Total Alkalinity	0.163	0.393	0.282	-0.498	0.225	0.014	-0.035	0.045	0.664	0.953	1.000					
Effluent Hardness	0.089	0.024	0.005	-0.421	0.395	-0.099	0.028	0.068	0.778	0.655	0.704	1.000				
Effluent Conductivity	-0.156	0.102	-0.255	-0.391	0.274	-0.150	0.035	0.106	0.875	0.850	0.836	0.714	1.000			
Effluent Dissolved Solids	0.153	0.328	-0.309	-0.641	0.335	0.101	0.026	-0.205	0.678	0.781	0.743	0.743	0.904	1.000		
Effluent Suspended Solids	-0.069	-0.051	-0.250	-0.129	-0.188	0.223	-0.125	0.115	0.139	0.072	0.078	0.293	0.377	0.026	1.000	
Effluent Turbidity	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

TABLE 9 (Continued). CORRELATION COEFFICIENTS FOR THE ASH POND SYSTEM AT PLANT G

	Intake pH	Intake Total Alkalinity	Intake Hardness	Intake Conductivity	Intake Dissolved Solids	Intake Suspended Solids	Intake Turbidity	Effluent Flowrate	Effluent pH	Effluent Phenolphthalein Alkalinity	Effluent Total Alkalinity	Effluent Hardness	Effluent Conductivity	Effluent Dissolved Solids	Effluent Suspended Solids	Effluent Turbidity
Intake pH	1.000															
Intake Total Alkalinity	-0.045	1.000														
Intake Hardness	-0.187	0.812	1.000													
Intake Conductivity	-0.229	0.890	0.692	1.000												
Intake Dissolved Solids	-0.093	0.504	0.574	0.579	1.000											
Intake Suspended Solids	-0.146	-0.309	-0.537	-0.581	-0.016	1.000										
Intake Turbidity	-0.361	-0.369	-0.382	-0.309	-0.398	0.775	1.000									
Effluent Flowrate	-0.092	-0.387	-0.623	-0.623	-0.055	0.382	0.459	1.000								
Effluent pH	0.391	-0.381	-0.595	-0.452	-0.313	-0.056	0.042	0.347	1.000							
Effluent Phenolphthalein Alkalinity	0.297	-0.328	-0.504	-0.429	-0.176	0.038	0.105	0.580	0.740	1.000						
Effluent Total Alkalinity	0.088	0.001	-0.227	-0.166	0.069	-0.036	0.258	0.328	0.046	0.468	1.000					
Effluent Hardness	0.202	-0.151	0.068	-0.108	-0.254	-0.054	-0.175	0.265	0.027	0.154	0.282	1.000				
Effluent Conductivity	0.239	-0.193	-0.083	-0.066	-0.225	-0.147	-0.318	0.256	0.103	0.216	0.279	0.670	1.000			
Effluent Dissolved Solids	-0.082	0.174	0.062	-0.196	0.442	-0.088	-0.384	0.333	0.025	0.196	0.207	0.784	0.513	1.000		
Effluent Suspended Solids	-0.084	-0.166	-0.209	-0.196	-0.056	0.067	0.074	-0.033	0.010	-0.073	-0.092	-0.197	0.219	-0.038	1.000	
Effluent Turbidity	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.319	0.035	-0.243	0.836	1.000

TABLE 9 (Continued).   CORRELATION COEFFICIENTS FOR THE ASH POND SYSTEM AT PLANT H

	Intake pH	Intake Total Alkalinity	Intake Hardness	Intake Conductivity	Intake Dissolved Solids	Intake Suspended Solids	Intake Turbidity	Effluent Flowrate	Effluent pH	Effluent Phenolphthalein Alkalinity	Effluent Total Alkalinity	Effluent Hardness	Effluent Conductivity	Effluent Dissolved Solids	Effluent Suspended Solids	Effluent Turbidity
Intake pH	1.000															
Intake Total Alkalinity	0.149	1.000														
Intake Hardness	-0.227	0.495	1.000													
Intake Conductivity	-0.149	0.391	0.684	1.000												
Intake Dissolved Solids	0.173	0.258	0.441	0.766	1.000											
Intake Suspended Solids	-0.105	-0.196	-0.160	-0.104	-0.167	1.000										
Intake Turbidity	-0.052	0.032	0.054	0.014	-0.077	0.688	1.000									
Effluent Flowrate	0.079	-0.161	0.023	-0.034	0.111	-0.051	0.139	1.000								
Effluent pH	0.363	-0.051	-0.328	-0.011	0.345	0.007	0.017	0.008	1.000							
Effluent Phenolphthalein Alkalinity	0.191	0.057	-0.215	0.063	0.143	-0.084	-0.167	-0.042	0.380	1.000						
Effluent Total Alkalinity	0.105	0.340	0.252	0.127	0.006	-0.061	0.025	-0.032	-0.306	0.195	1.000					
Effluent Hardness	0.415	-0.063	-0.047	0.090	0.215	0.214	0.276	0.539	0.052	-0.065	0.177	1.000				
Effluent Conductivity	0.411	-0.224	-0.315	0.002	0.197	0.193	0.119	0.365	0.286	0.085	0.000	0.777	1.000			
Effluent Dissolved Solids	0.372	0.012	-0.408	-0.017	0.491	-0.075	0.077	0.278	0.506	0.235	-0.039	0.682	0.837	1.000		
Effluent Suspended Solids	-0.137	-0.497	0.026	-0.072	-0.084	0.201	-0.096	-0.010	-0.312	-0.102	-0.132	-0.051	0.054	-0.117	1.000	
Effluent Turbidity	-0.024	-0.187	-0.116	-0.341	-0.432	-0.046	-0.017	-0.052	-0.253	-0.249	-0.069	-0.183	-0.172	-0.156	0.419	1.000

TABLE 9 (Continued). CORRELATION COEFFICIENTS FOR THE ASH POND SYSTEM AT PLANT J

	Intake pH	Intake Total Alkalinity	Intake Hardness	Intake Conductivity	Intake Dissolved Solids	Intake Suspended Solids	Intake Turbidity	Effluent Flowrate	Effluent pH	Effluent Phenolphthalein Alkalinity	Effluent Total Alkalinity	Effluent Hardness	Effluent Conductivity	Effluent Dissolved Solids	Effluent Suspended Solids	Effluent Turbidity
Intake pH	1.000															
Intake Total Alkalinity	0.840	1.000														
Intake Hardness	0.791	0.977	1.000													
Intake Conductivity	0.800	0.960	0.967	1.000												
Intake Dissolved Solids	0.705	0.753	0.720	0.729	1.000											
Intake Suspended Solids	-0.012	-0.024	0.057	0.104	0.119	1.000										
Intake Turbidity	-0.089	-0.057	-0.078	-0.091	-0.131	-0.144	1.000									
Effluent Flowrate	-0.199	-0.224	-0.401	-0.319	-0.072	0.071	-0.084	1.000								
Effluent pH	0.865	0.841	0.825	-0.805	0.689	-0.061	-0.067	-0.266	1.000							
Effluent Phenolphthalein Alkalinity	0.246	0.243	0.221	0.256	0.084	-0.082	-0.066	-0.010	0.316	1.000						
Effluent Total Alkalinity	0.835	0.830	0.842	0.847	0.671	-0.035	-0.161	-0.365	0.875	0.340	1.000					
Effluent Hardness	0.630	0.625	0.707	0.684	0.408	-0.094	-0.009	-0.223	0.620	0.387	0.781	1.000				
Effluent Conductivity	0.048	0.143	0.209	0.188	0.160	-0.180	0.034	-0.021	-0.046	0.242	0.262	0.741	1.000			
Effluent Dissolved Solids	0.471	0.464	0.565	0.561	0.392	0.026	-0.033	-0.055	0.405	0.169	0.508	0.550	0.667	1.000		
Effluent Suspended Solids	-0.182	-0.113	-0.219	-0.225	-0.088	-0.072	-0.031	-0.076	-0.121	-0.033	-0.101	-0.143	-0.172	-0.047	1.000	
Effluent Turbidity	-0.434	0.217	-0.248	-0.242	-0.115	-0.076	-0.050	0.069	-0.374	-0.124	-0.275	0.000	0.000	0.000	0.000	1.000
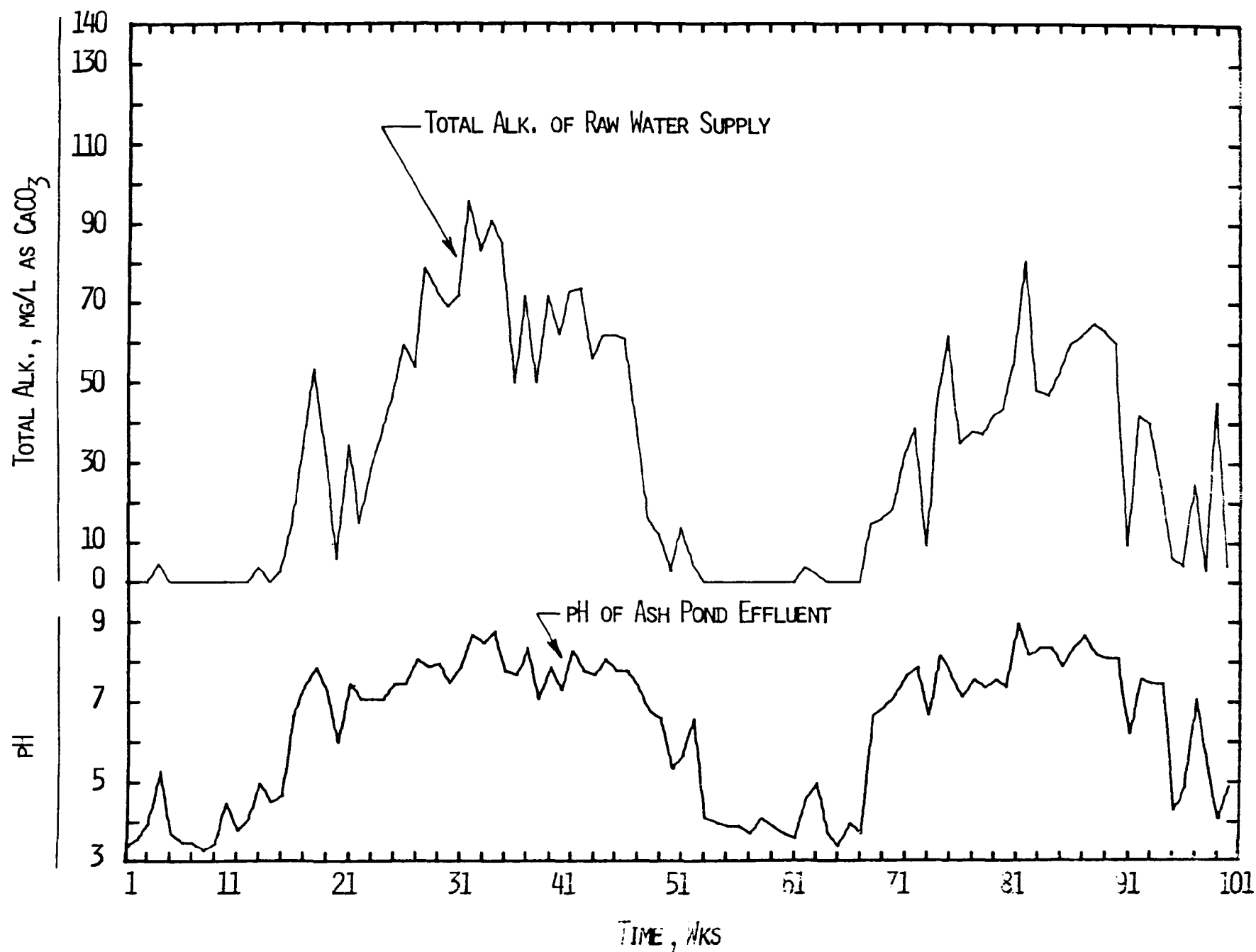
Figure 5.   Relationship of Ash Pond pH and Intake Water Alkalinity for Plant J
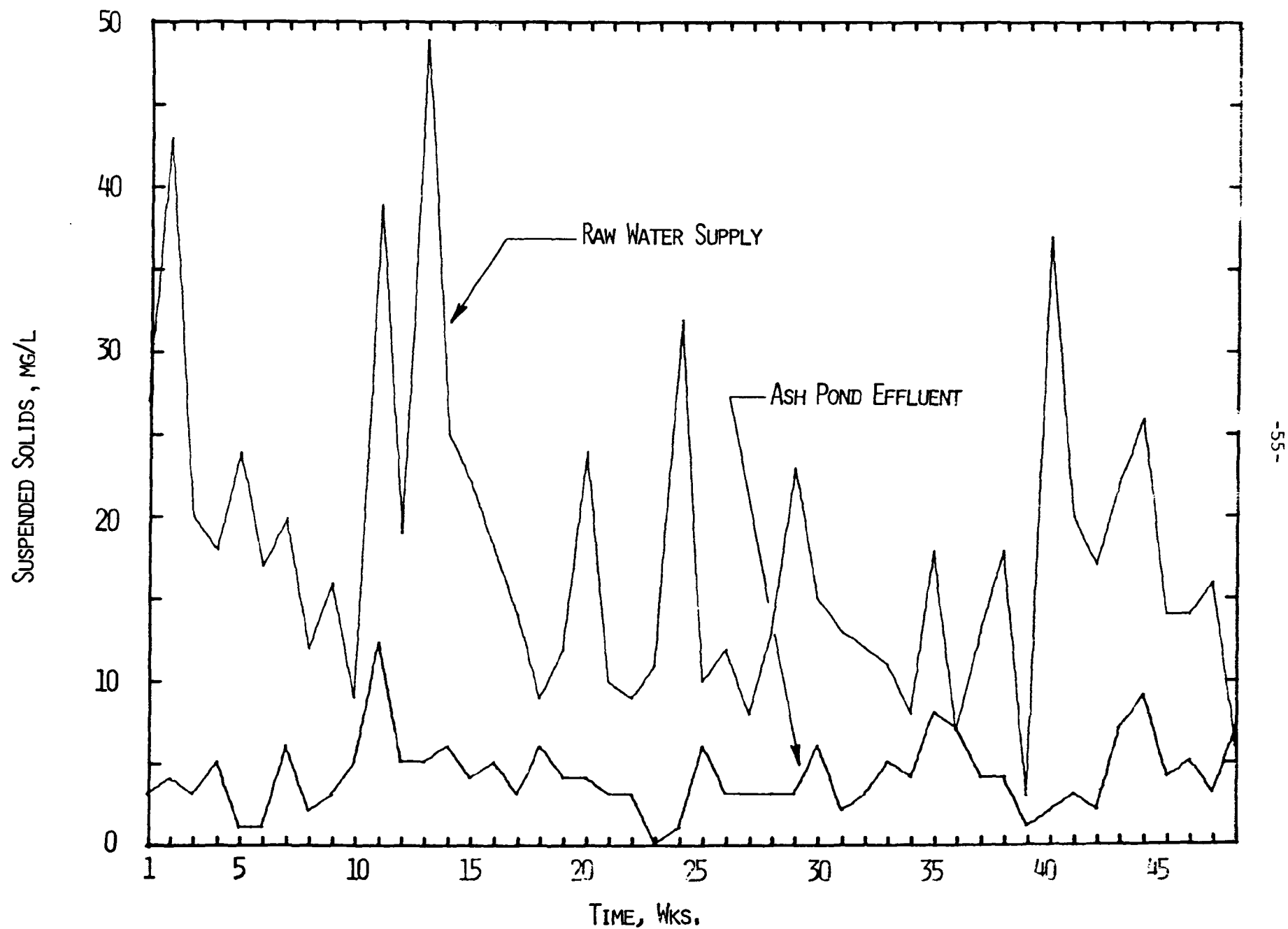
Figure 6a. Relationship of Suspended Solids in the Ash Pond Effluent and the Intake Water Supply for Plant E
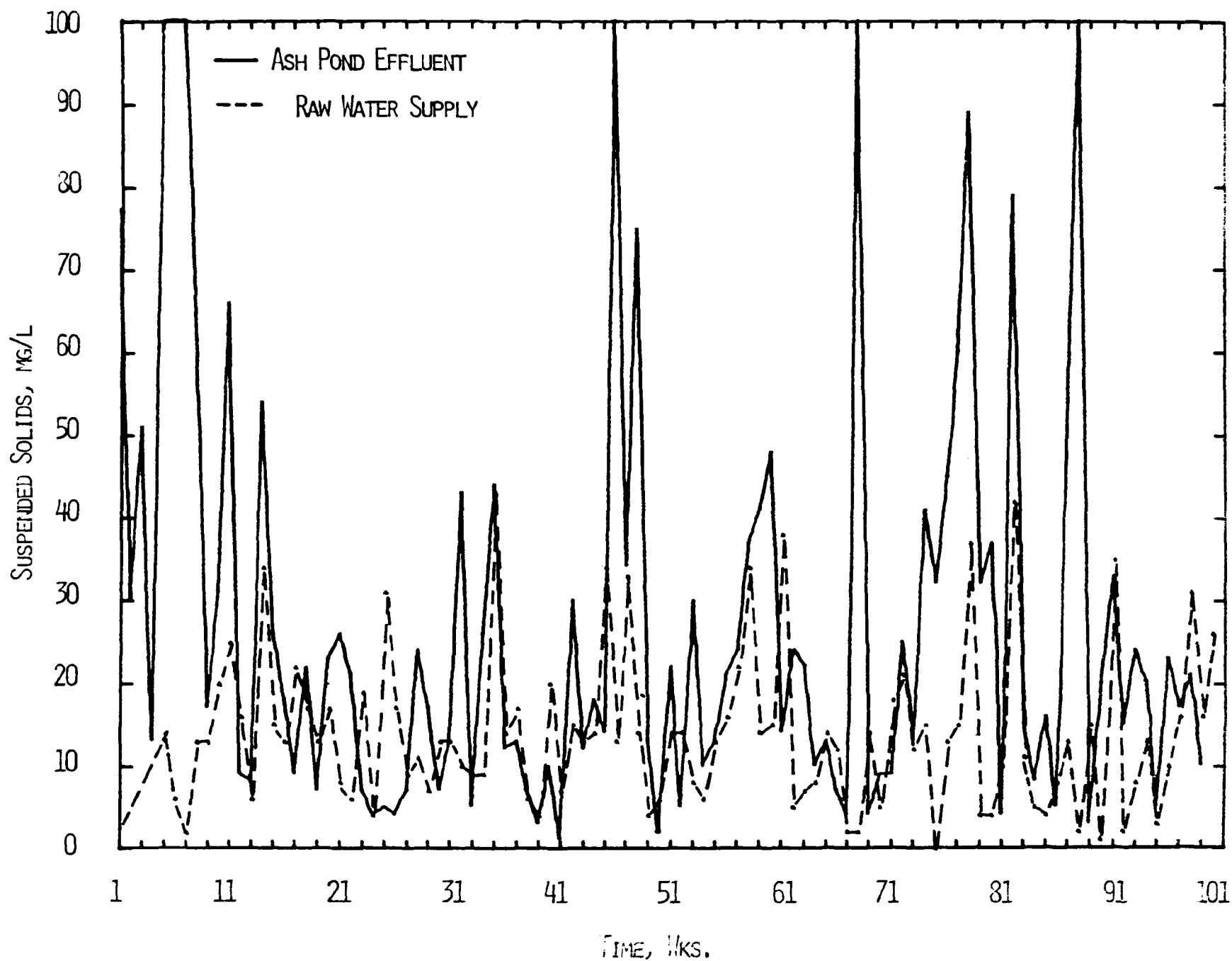
Figure 6b. Relationship of Suspended Solids in the Ash Pond Effluent and the Intake Water Supply for Plant J

TABLE 10. LAGGED CORRELATION COEFFICIENTS FOR PLANT E

	Effluent Flowrate	Effluent pH	Effluent Phenolphthalein Alkalinity	Effluent Total Alkalinity	Effluent Hardness	Effluent Conductivity	Effluent Dissolved Solids	Effluent Suspended Solids	Effluent Turbidity
Intake pH	0.171	0.061	0.129	0.137	0.015	-0.200	0.099	-0.100	0
Intake Total Alkalinity	0.032	0.204	0.350	0.384	0.050	0.044	0.175	-0.194	0
Intake Hardness	0.123	-0.123	-0.282	-0.272	-0.243	-0.323	-0.242	0.024	0
Intake Conductivity	0.024	-0.596	-0.579	-0.636	-0.498	-0.650	-0.726	-0.243	0
Intake Dissolved Solids	-0.075	0.249	0.152	0.149	0.208	0.289	0.137	0.036	0
Intake Suspended Solids	0.017	-0.038	-0.027	0.015	-0.115	-0.067	0.001	-0.091	0
Intake Turbidity	0.237	0.028	0.006	-0.001	0.004	0.035	0.015	0.203	0

LAGGED CORRELATION COEFFICIENTS FOR PLANT J

	Effluent Flowrate	Effluent pH	Effluent Phenolphthalein Alkalinity	Effluent Total Alkalinity	Effluent Hardness	Effluent Conductivity	Effluent Dissolved Solids	Effluent Suspended Solids	Effluent Turbidity
Intake pH	-0.165	0.805	0.231	0.765	0.613	0.104	0.534	-0.116	-0.273
Intake Total Alkalinity	-0.181	0.759	0.200	0.744	0.590	0.190	0.520	-0.018	-0.116
Intake Hardness	-0.524	0.769	0.217	0.783	0.640	0.243	0.479	-0.171	-0.183
Intake Conductivity	-0.493	0.766	0.241	0.784	0.646	0.249	0.487	-0.199	-0.201
Intake Dissolved Solids	-0.161	0.680	0.126	0.636	0.485	0.137	0.432	-0.065	-0.225
Intake Suspended Solids	-0.064	-0.039	-0.101	-0.052	-0.017	-0.134	-0.009	0.018	0.085
Intake Turbidity	-0.136	-0.063	-0.141	-0.110	-0.008	0.023	-0.034	0.012	-0.017

effluent flowrate. In addition, at Plant J there was a significant correlation between effluent conductivity and intake conductivity for the lagged data set which was not observed for the original comparison. Therefore, the results in Table 10 appear to have no real meaning.

The TVA ash ponds for which the weekly ash pond effluent data showed a yearly cycle were given in Table 4. The ash ponds for which the weekly intake data showed a yearly cycle were not determined because the type of trends exhibited by the parameters in the ash pond effluent are more important in determining how the data are treated statistically than the trends in the intake water. In addition, the effect of intake water quality on the ash pond effluent quality was already discussed via the linear correlation comparisons.

In general for the year 1974 and 1975 the range over which the pH in the ash pond effluent varies was larger than the range for the pH in the intake water. However, some ash ponds increased the pH while others decreased it. The dissolved solids varied over approximately the same range for both the intake and the effluent; however, the yearly average concentrations were normally higher for the ash pond effluents. The range over which the suspended solids vary is greater for the intake water than the ash pond effluent. However, the yearly average concentration for suspended solids increased from intake to effluent both in 1974 and 1975 for four effluents, while it increased either in 1974 or 1975 for an additional five effluents. The suspended solids decreased from intake to effluent for six plants in both 1974 and 1975. Table 11 gives a summary of this comparison by plant.

Also included in Table 5 was a summary of the quarterly intake data for the years 1974 and 1975. Table 12 shows the number of ash ponds which increase the various average concentrations of the intake water. Although Table 12 does not give valuable insight into the effect of variations in the concentrations of trace metals in the intake water on the variations of trace metals in the ash pond effluent it does provide information on the effect of using the intake water for ash sluicing. The extent of this effect on intake water quality is very important in designing a monitoring program for ash pond effluents. Table 12 indicates that more than half of the ash ponds increase the concentrations of Al, ammonia, As, Ba, Cd, Ca, Cl, Cr, Pb, Hg, Ni, Se, silica, sulfate, and Zn over that in the intake water. The range over which the trace metals vary in the ash pond effluent appears to be as great or greater than that in the intake water.

INDIRECT MONITORING METHODS

The previous results indicate that monitoring the ash pond effluent cannot be replaced by measurements within the operation of the power plant itself. If such an approach is to be pursued, more detailed data on variables such as the amount of coal burned, its characteristics, the quality of water used for sluicing and others will have to be collected and their relationships with the ash pond effluent characteristics determined.

TABLE 11.   COMPARISON OF WEEKLY INTAKE AND EFFLUENT
SUSPENDED SOLIDS CONCENTRATIONS FOR 1974 AND 1975
AT TVA ASH PONDS

Plant	Intake SS 1974	Intake SS 1975	Effluent SS 1974	Effluent SS 1975	Difference 1974	Difference 1975
Plant A BA	60	48	54	51	-6	+3
Plant A FA	60	48	37	15	-23	-33
Plant B BA	41	23	67	25	+26	+2
Plant B FA	41	23	94	18	+53	-5
Plant C East	81	47	48	27	-33	-20
Plant C West	81	47	43	35	-38	-12
Plant D	15	11	17	15	+2	+4
Plant E	17	18	12	4	-5	-14
Plant F	9	23	40	6	+31	-17
Plant G	12	15	20	19	+8	+4
Plant H	21	20	15	12	-6	-8
Plant I South	15	23	15	18	0	-5
Plant J	15	13	47	38	+32	+25
Plant K	38	36	16	51	-22	+15
Plant L	6	12	20	8	+14	-4

TABLE 12. NUMBER OF ASH PONDS WHOSE AVERAGE EFFLUENT
CONCENTRATIONS EXCEED THOSE OF THE INTAKE WATER

Element	No. Exceeding
Aluminum	10
Ammonia	9
Arsenic	15
Barium	7
Beryllium	1
Cadmium	7
Calcium	15
Chloride	8
Chromium	10
Copper	5
Cyanide	3
Iron	4
Lead	8
Magnesium	6
Manganese	5
Mercury	12
Nickel	10
Selenium	14
Silica	12
Silver	2
Sulfate	15
Zinc	7

COMPARISON OF WEEKLY AND QUARTERLY SAMPLING

There appears to be a discrepancy between the yearly average
suspended solids concentration calculated based on the quarterly data
and the average calculated based on the weekly data. Therefore, a
comparison of these two data sets was made. The data for this
comparison is given in Table 13. Yearly average concentrations for the
years 1973, 1974, and 1975, based on the quarterly and weekly sampling
programs are given for suspended solids. The yearly average for pH
based on weekly samples is also given. The quarterly samples (one
sample collected every three months) for all TVA ash ponds were analyzed
at the Laboratory Branch in Chattanooga. The weekly samples were analyzed
at the respective steam plant laboratories. Both sets of samples were
collected by steam plant personnel. In most cases a weekly sample was
collected at the same time as a quarterly sample.

There are two possible explanations for the differences in the
averages: the first is that for each steam plant, the same lab did not
analyze the weekly and quarterly samples; and the second is that the
average based on the quarterly samples was calculated using only four
samples while the average of weekly samples is based on approximately
52 samples. From a characterization standpoint, the more samples
analyzed, the more representative the calculated average. Therefore,
the difference could be due to having a more representative average from
the weekly samples than from the quarterly. In addition to these two
explanations, the difference in suspended solids averages in 1973 could
be the result of the different procedures used for determining the
suspended solids. The quarterly samples were analyzed directly by
weighing the quantity of suspended material removed following a filtra-
tion procedure while the weekly samples were calculated by subtracting
the dissolved solids from the total solids.

In order to determine the major reason for the discrepancy, a third
average was calculated by selecting those weekly samples which were col-
lected at the same time as the quarterly samples. This average for sus-
pended solids and pH is also given in Table 13. If the yearly average
calculated from the quarterly data and the yearly average calculated
from only four of the weekly samples are in close agreement then the
difference between the two yearly averages could be assumed to be the
result of the difference in sampling frequencies. However, if these two
averages are different by more than 10 mg/1, then the difference could
be attributed to different laboratories. The value of 10 mg/1 was
obtained from a discussion in Standard Methods (3) on the precision and
accuracy of the nonfilterable residue (suspended solids) procedure. The
discussion gives a standard deviation of ±2 mg/1 at the 15 mg/1 concentra-
tion and ±24 mg/1 at the 242 mg/1 concentration. Although a measure of
the accuracy would be more appropriate, Standard Methods (3) indicates
that there is no satisfactory procedure for determining the accuracy of
the method on wastewater samples because the true value of suspended
matter is unknown. Since most of the averages were greater than 15 mg/1
and less than 242 mg/1, a value of 10 mg/1 was chosen.

Based on the previous discussion, the differences in the yearly
average suspended solids in at least 2 out of 3 years at Plants A fly
ash, A bottom ash, B fly ash, B bottom ash, I, and J were attributed to

TABLE 13. COMPARISON OF QUARTERLY AND WEEKLY SAMPLING PROGRAMS

		Suspended Solids			pH		
		1973	1974	1975	1973	1974	1975
Plant A - Fly Ash	Q	7	5	6	-	-	-
	W	93	37	15	4.5	4.2	4.0
	QW	94	38	16	4.6	4.2	4.2
Plant A - Bottom Ash	Q	30	88	38	-	-	-
	W	66	54	51	7.1	7.2	7.1
	QW	27	40	53	7.1	7.2	6.8
Plant B - Fly Ash	Q	24	9	6	-	-	-
	W	100	94	18	9.2	9.4	9.2
	QW	43	56	16	9.1	8.6	9.6
Plant B - Bottom Ash	Q	23	33	14	-	-	-
	W	79	67	25	8.2	8.0	8.0
	QW	10	33	19	8.2	7.9	7.9
Plant C East	Q	20	20	12	-	-	-
	W	43	48	27	7.2	7.1	7.1
	QW	27	48	17	7.2	6.9	7.2
Plant C West	Q	31	20	45	-	-	-
	W	42	43	35	7.6	7.2	7.5
	QW	31	50	41	8.3	7.4	6.4
Plant D	Q	15	19	12	-	-	-
	W	25	17	15	8.6	8.4	8.4
	QW	37	13	16	8.4	8.5	8.5
Plant E (New Ash Pond)	Q	-	3	4	-	-	-
	W	-	12	4	-	11.2	11.1
	QW	-	22	4	-	11.3	11.1
Plant F	Q	6	2	6	-	-	-
	W	-	40	6		11.1	10.7
	QW	-	83	7	-	11.2	10.6
Plant G	Q	19	14	29	-	-	-
	W	19	20	19	9.8	9.5	9.4
	QW	22	17	18	9.9	9.3	9.6
Plant H	Q	10	12	8	-	-	-
	W	16	15	12	8.8	8.3	8.7
	QW	15	14	9	8.8	8.1	8.4
Plant I	Q	4	2	10	-	-	-
	W	24	15	18	11.3	11.1	9.8
	QW	26	16	10	11.2	11.2	9.9
Plant J	Q	11	26	7	-	-	-
	W	32	47	38	6.0	6.5	6.2
	QW	44	31	20	5.7	6.2	6.1
Plant K	Q	5	7	13	-	-	-
	W	13	16	29	11.0	11.0	10.3
	QW	7	14	13	11.1	11.2	10.1
Plant L	Q	7	23	6	-	-	-
	W	17	20	8	10.0	10.3	10.4
	QW	14	16	8	9.3	10.4	10.3

Note: Q - Averages based on quarterly samples analyzed by TVA Laboratory Branch.
W - Averages based on weekly samples analyzed by the respective steam plant labs.
QW - Averages based on selected weekly samples collected at or approximately the same time as the quarterly samples.

different laboratories. The difference for one year at Plants C, D, E, F, and G, was attributed to different laboratories. There did not appear to be a difference in yearly average suspended solids due to different laboratories during any of the three years for Plants H, K, and L.

If the difference in the yearly average suspended solids between laboratories is excluded the difference between the yearly average for quarterly and weekly sampling at Plants A fly ash, A bottom ash, D, G, H, I, and L was less than 4 mg/l during at least 2 of the 3 years. The difference between quarterly and weekly yearly averages was less than 4 mg/l during at least 1 year for Plants A bottom ash, B fly ash, C east, E, F, and K. For most monitoring programs a difference of 4 mg/l in suspended solids would probably be acceptable. For other monitoring programs a greater difference may be acceptable. The difference that can be tolerated depends on the goal of the monitoring program. Overall the above discussion indicates that both the sampling frequency and laboratory preforming the analysis can influence the yearly average suspended solids concentration reported for a particular plant during any given year.

A comparison of the yearly average pH of the ash pond effluent based on quarterly sampling and weekly sampling showed that except for Plant C west in 1973, Plant B fly ash in 1974 and Plant L in 1973, quarterly sampling was adequate to determine the yearly average pH within at least 0.5 pH unit.

Other than for pH and suspended solids, there were not enough data available on those parameters required by the NPDES permit to determine the influence of the sampling frequency on the calculation of the yearly average. Flow was not included in these comparisons because all ash pond effluents are equipped with continuous flow measuring and recording devices.

COMPARISON OF GRAB AND COMPOSITE SAMPLING

The two most common types of samples are grab samples and composite samples, and either may be obtained manually or automatically. Grab samples represent the waste characteristics at the time the sample is taken, while composite samples represent the waste characteristics of a mixture of several individual samples whose collection frequency or relative volume is determined based on the flow at the time of sampling. As long as the ratio of flow to individual sample volume remains the same, the compositing should be valid. A grab sample is preferred over a composite sample when the waste characteristics are relatively constant because of relative cost of collecting these two types of samples. For such wastes an occasional grab sample may be entirely adequate to establish waste characteristics.

Twenty-four hour composite samples comprised of grab samples taken every hour were collected for four consecutive days at four TVA steam plants. During at least one, and in most cases two, 24-hour sample period, three or four grab samples were collected for comparison with the composite samples. These results are shown in Figure 7. First, the

concentration of metals in the composite samples did not vary significantly over the four day period. For example, copper varied the most on a percentage basis for the four plants. The range of composite samples on the four-day periods was from 0.07 to 0.11 mg/l at Plant C, <0.01 to 0.05 mg/l at Plant J, <0.01 to 0.1 mg/l at Plant H, and <0.01 to 0.03 mg/l at Plant D. The range of grab samples is indicated by the symbol "I" in Figure 7. The grab samples appear to be as representative of the system as composite samples; however, more work is needed to statistically determine the best method of sample collection. However, only grab sampling was considered in the later sections of this report.
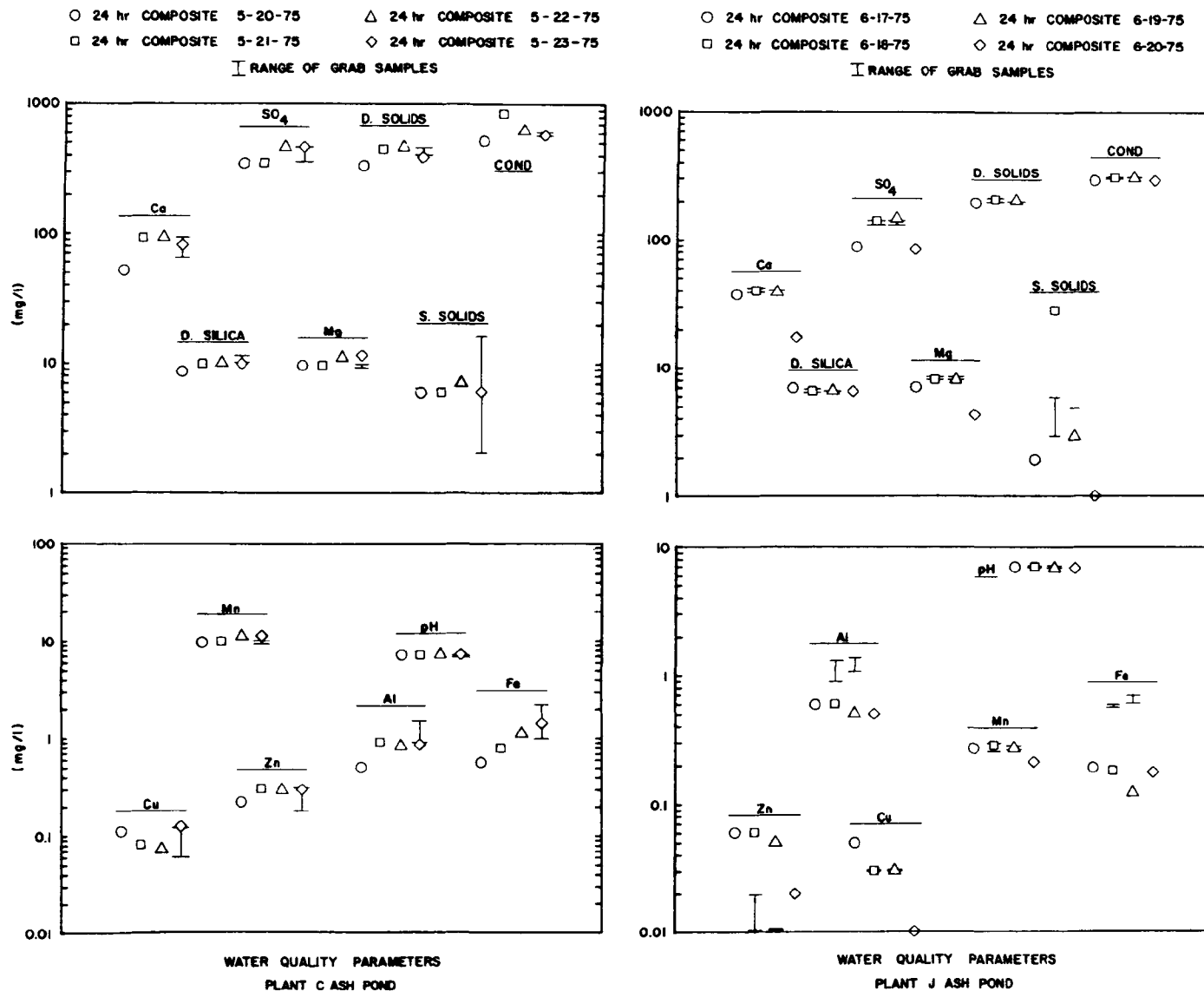
Figure 7. Comparison of Grab and Composite Samples for Four TVA Ash Pond Effluents
All parameters are in mg/l except pH (standard units) and conductivity (µmho/cm).
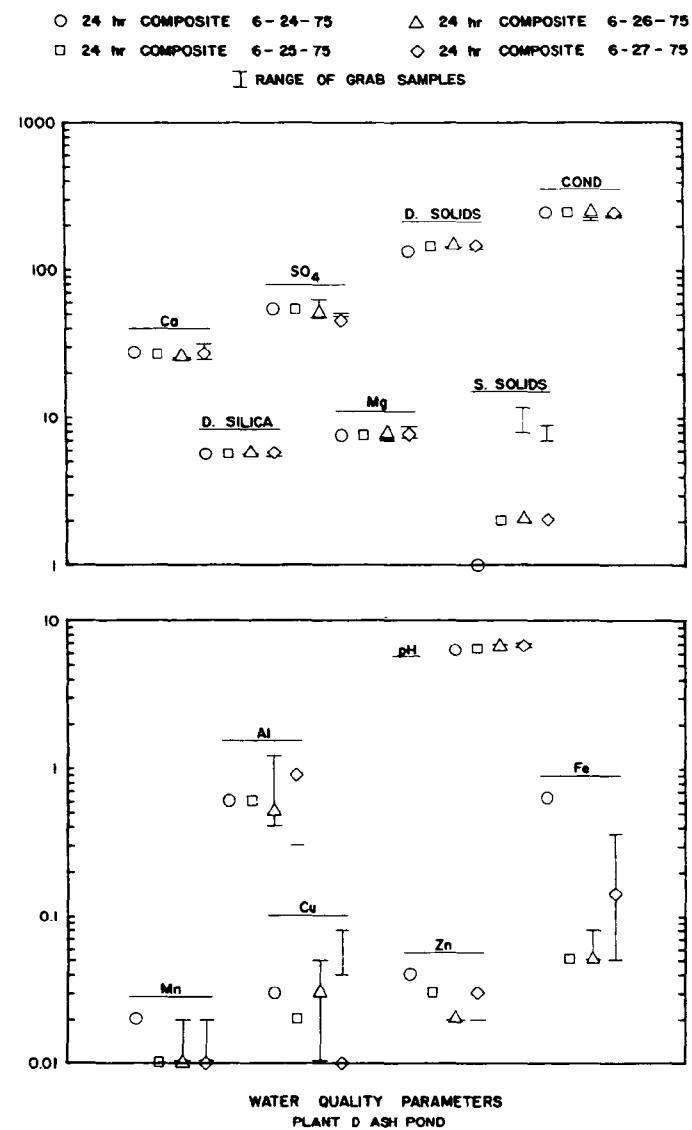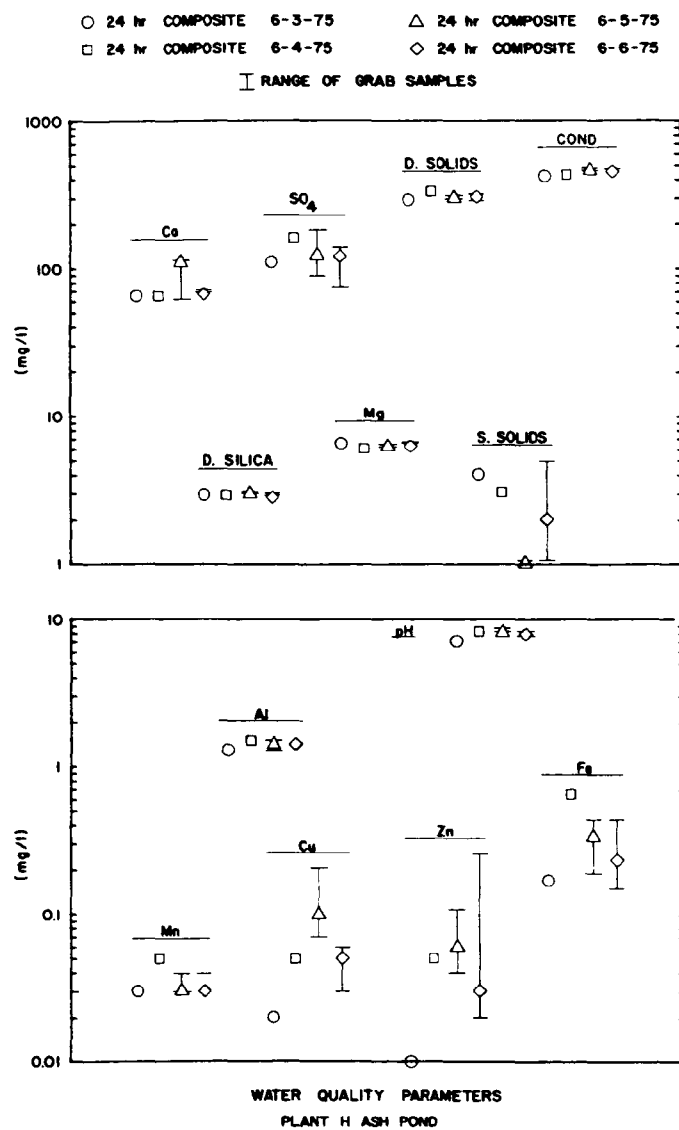
Figure 7 (Continued)

SECTION 4

PROCEDURE FOR DESIGNING AN ASH POND MONITORING PROGRAM

Since the physical understanding of the ash pond system is limited, more emphasis must be placed on statistical analysis of past effluent characteristics to design the future monitoring program. There are several statistical procedures which could be applied to determine the proper sampling frequency to ensure an accurate estimate of the ash pond effluent characteristics. The procedure discussed here requires the following: (1) a baseline data set which characterizes the effluent with a greater detail, precision, and accuracy than the data to be obtained from the monitoring program under design; (2) the variation of the baseline data with time; (3) an estimate of the statistical distribution of the baseline data; (4) the number of samples to estimate the mean as a function of the precision; and (5) an estimate of the desired precision of the monitoring program under design. The procedure assumes that the individual water quality parameters either exhibit a seasonal trend or are randomly distributed. For those parameters that are randomly distributed, that data are assumed to follow either a normal or lognormal distribution. For those exhibiting a seasonal trend, the data are divided into different sample periods which can be treated the same as a data set that is randomly distributed. The monitoring program to be designed ensures, within a specified degree of confidence, that the least number of samples is collected which shows the effluent is in compliance with a particular effluent limitation within a specified time period. Where effluent limitations have not been established, the monitoring program is designed for the collection of the minimum number of samples required to estimate the yearly mean with predetermined precision, accuracy, and confidence.

The assumption that the ash pond effluent parameters are random is not completely valid because the gross ash pond characteristics were shown to be affected by the type of coal burned. However, as long as the coal characteristics and methods of operation are not changed drastically from those used to design the monitoring program, the assumption can be considered valid. The monitoring program can be evaluated after each sampling period (the sampling period would be one year if the objective is to estimate the yearly mean) using the same procedure used to design the original monitoring program. This would be done by applying the method to either a combined data set consisting of the data set for the sample period under evaluation and the previous data sets or just the data set for the sample period under evaluation. Limiting the evaluation to the new data set would be best in the case where the data exhibits either a continuous increasing or decreasing trend from sample period to sample period while the variation within a sample period remains constant. This procedure is discussed in the following section. Application of the method to two TVA ash pond effluents will be discussed in subsequent sections.

DATA REQUIREMENTS

Before a statistically sound monitoring program can be designed, background information on the characteristics of the waste stream and the entire production process which generates this waste stream is desirable. If this information is not already available, a wastewater survey is conducted to provide this information. The balance between the use of statistical methods and evaluation based upon physical understanding is extremely important as pointed out by EPA in 1974 (4). As physical understanding increases, the use and need for statistics decreases.

Data such as that presented in Section 3 can be used to explain the system and estimate the number of samples required to provide a proper data base from which a monitoring program can be designed, or it can be used as the data set from which to design the monitoring program. The parameters which should be included in the monitoring program can also be determined from the data given in Section 3.

VARIATION OF THE DATA WITH TIME

Before a monitoring program can be properly designed, the variation of the effluent parameters with time and any periodic cycles which occur in the system must be defined. The variation of the parameters in the effluent with time can best be determined from plots of concentration versus time. The concentrations are determined from past monitoring programs or extensive waste surveys. If cycles exist within this data set, the proper sampling frequency can be predicted based on the time span of the cycle. For example, to define a weekly cycle, a sampling frequency of at least twice a week would be required. However, the cycle can be better defined by more frequent sampling. If no cycles are indicated by the data set, it can be treated as one set of random events. A statistical method can then be applied to this data set to determine the number of samples which ensures estimation of the true mean within some accuracy and precision. To estimate the true mean within some accuracy and precision for a data set which exhibits a cycle, the data set can be divided into the different phases of the cycle, thus creating individual data sets of random events. The same statistical procedure can then be applied to these individual data sets to estimate the mean within a subset, or a procedure which will be termed "stratified sampling" can be applied to estimate the mean for the entire data set (see Daniel and Terrell, 1975 (5) for a complete discussion on stratified sampling).

DISTRIBUTION OF THE DATA

Once a period of random events has been established, the probability distribution of the data within that period must be defined. The assumption as to the underlying probability distribution of a parameter is critical in designing a monitoring program. Sherwani and Moreau, 1975 (6) summarized the distribution of many water quality parameters as follows:

(1) The parameters have a finite range. They have a fixed lower physical limit, in most cases equal to zero and a variable but finite upper limit, in most cases saturation concentration;

(2) The distribution is typically positively skewed;

(3) The parameters exhibit a periodic behavior. The periodicity may be due either to the annual cycle in the meteorological and hydrological environment of the stream, or to the weekly and seasonal cycles in the waste inputs to the stream.

They found that the majority of the water quality parameters do not follow a normal distribution. However, they did find that several parameters such as flow, suspended solids, conductivity, and phosphorous followed a lognormal distribution. Berthouex and Meinert, 1977 (7) reported that surface water concentrations in the Tennessee Valley of Hg, Zn, Cu, Cd, and Pb followed lognormal distributions. For the purposes of this project, the data sets were therefore assumed to follow either a normal or lognormal distribution.

A method discussed by Miller and Freund, 1965 (8) will be used to determine whether the data are best described by a normal or lognormal distribution. The method requires that the cumulative frequency of the data be plotted on a special probability scale against the actual concentration. Data from a normal distribution will graph roughly as a straight line when such a probability scale is used. When the data graph as a straight line when the concentrations are plotted on a logrithmic scale, the data are more nearly lognormal. Logrithms to the base ten will be used for this study. These plots are called cumulative frequency plots and Figure 8 gives an example.

Additional information can be obtained from these cumulative frequency plots. For example, extrapolation below the minimum detectable amount (MDA) is reasonable, thus making it possible to estimate a geometric mean for a particular element when it is below the MDA. The concentration corresponding to 50 percent estimates the geometric mean for plots using the logarithmic scale and the arithmetic mean for plots using an untransformed scale. For lognormal distributions the logarithm of the geometric mean is equal to the mean of the logarithms of the concentrations. These plots can also be used to estimate the probability that a certain concentration, for instance an effluent limitation, will be exceeded.

ESTIMATION OF THE MEAN AS A FUNCTION OF THE PRECISION

The population mean value for a given parameter is the main interest of most monitoring programs. Therefore a method is required for ascertaining the chance that a sample statistic such as the mean deviates from the population parameters by a prescribed amount. The three components to be considered are:
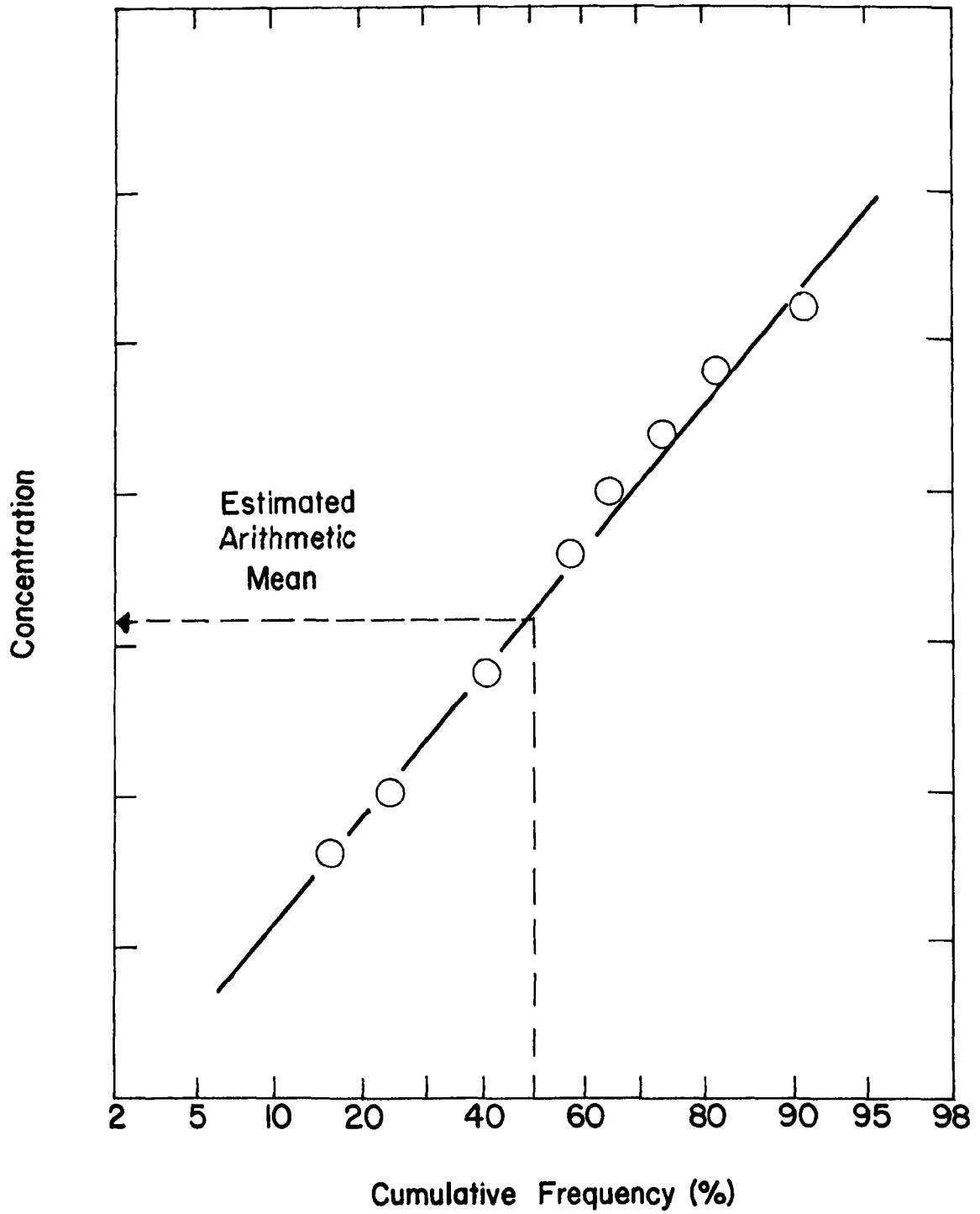
Figure 8. Example of a Cummulative Frequency Plot

1. the sample size,
2. the precision of the estimate, and
3. the significance level.

Should any two be available, the third can be calculated. For a normal distribution, the population mean, μ, is estimated by $\bar{X}$ and a confidence interval for μ is given by

$$\bar{X} \pm t \frac{S}{\sqrt{n}} \tag{1}$$

where, $\bar{X}$, S are the sample mean and standard deviation, t is the value of "student's" t for a given significance level and depends on the number of degrees of freedom of S, and n is the sample size. For a lognormal distribution $\bar{X}$ and S are the mean and standard deviation respectively of the logarithms of the concentrations.

The sample data are summarized in $\bar{X}$ and S. Both $\bar{X}$ and S are determined from past data or an extensive survey. The choice of a confidence coefficient and corresponding "student's" t value depends on the consequences of the estimate being incorrect. The 80, 95, and 99 percent significance confidence levels will be considered in this study.

The precision L may be defined as limits on either side of the true mean within which the sample mean will fall with specified probability. That is, it is desired to have a specified degree of confidence that:

$$\mu - \bar{X} < L \tag{2}$$

For the lognormal distribution μ is the logarithm of the true geometric mean and $\bar{X}$ is the mean of the logarithms of the concentrations. Given L and S, and given the value of t corresponding to the desired confidence coefficient, the required number, n, of samples is:

$$n = \frac{t^2 S^2}{L^2} \tag{3}$$

The number of samples, n, in equation 3 can be presented graphically as a function of L for any given data set as shown in Figure 9. Figures similar to Figure 9 can be used to determine the number of samples, with a given confidence coefficient, required to estimate the mean within a given precision. The sampling frequency can then be determined by dividing the number of samples by the time period over which an estimate of the mean is desired. Sampling periodically as suggested here is known as systematic sampling rather than random sampling. However, in this case both are treated as being equivalent.

To properly determine the number of samples required to estimate the mean for a data set which exhibits seasonal behavior, the following equation, according to Daniel and Terrell (5), may be used:
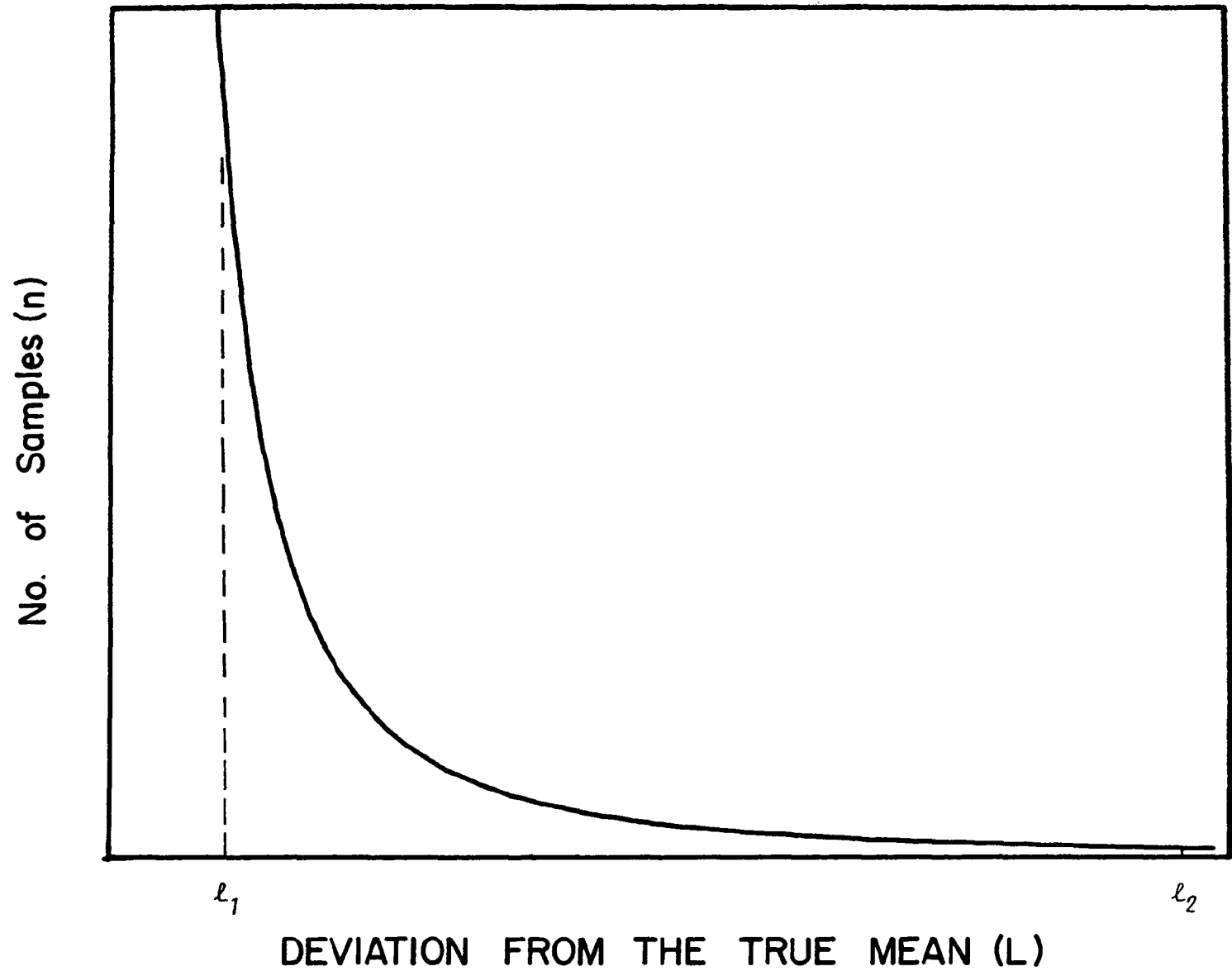
Figure 9. Example of a Plot of the Number of Samples Versus the Deviation
from the True Mean

$$n = \frac{t^2 \sum_{h=1}^{H} [(N_h/N) S_h]^2}{L^2} \qquad (4)$$

where

N_h = size of hth stratum,

N = population size, and

S_h = standard deviation of hth stratum.

H = number of strata

The allocation of the samples over the sample period can then be determined by the following equation:

$$n_h = \frac{N_h S_h}{\sum_{h=1}^{H} N_h S_h} \, n \qquad (5)$$

where n_h represents the number of samples required for the h stratum.

This method minimizes the variance of the estimate of the yearly mean. Most likely the number of samples within a stratum are not portional to the length of that stratum and, therefore, an extra step is needed to calculate the mean over the entire period. This is done by weighing the averages by the proportion of the year occupied by each stratum. That is, if $\bar{X}_h$ is the average for stratum h, the weighted average is:

$$\sum_{h=1}^{H} \frac{N_h}{N} \bar{X}_h \qquad (6)$$

Computing the standard error of the estimated mean is only slightly more complicated than for a simple random sample. See, for example, Snedecor and Cochran, 1967 (9).

ESTIMATION OF THE PRECISION

Figure 9 shows that the deviation of the sample mean from the population mean (precision) decreases with an increased number of samples, and that the incremental change in this deviation also decreases with an increased number of samples. This incremental change in the deviation is therefore the key factor in identifying the most desirable sampling frequency. This indicates that there is a critical range of values of the deviation which should be considered in the design of a monitoring program. This critical range is defined by the values between ℓ_1 and ℓ_2 in Figure 9. The value ℓ_1, is defined here as the lower limit for the range of the critical deviation but actually represents a more precise estimate than ℓ_2, while ℓ_2 is defined here as the upper limit for the range of the critical deviation. The upper limit may be defined

by the deviation produced by only one sample and the lower limit may be defined by the deviation produced by some given maximum number of samples. The given maximum number of samples may be a function of the resources available such as manpower and dollars for the monitoring program.

The strategy for selecting the precision, differs depending on the objective of the monitoring program. If the objective of the monitoring program is to determine water quality trends or means for a given period, then the deviation from the true mean may need to be very small. However, there is a point where L becomes so small that the cost for collection and analysis of the corresponding samples becomes prohibitive or impractical. In most cases a deviation of ± 10 to 20 percent of the sample mean would be acceptable. If the objective of the monitoring program is to show that the effluent is in compliance with some effluent limitation or standard, then the desired precision depends on how close the mean is to the limitation or standard. The question of such a monitoring program then become: (1) "What is the probability that an estimate of the mean would be greater than the standard when the true mean was actually less than the standard?" (The effluent is in compliance, but from an estimate of the mean, the effluent appears not to be in compliance.) and (2) "What is the probability that an estimate of the mean would be less than the standard when the true mean was actually greater than the standard?" (The effluent is not in compliance, but from an estimate of the mean, the effluent appears to be in compliance.) Both probabilities depend on the number of samples used to estimate the mean. The true mean can never be known with complete certainty, but the precision of the estimated mean can be improved by increasing the number of samples. Therefore the most efficient monitoring program to show compliance is the one with the minimum number of samples so that if the effluent is in compliance, the average of the samples shows the effluent to be in compliance.

The minimum sampling frequency necessary to determine water quality trends for a particular parameter can be determined directly from a figure similar to Figure 9 or by the use of equations 2 and 3 for a desired precision. This is done by selecting the number of samples corresponding to the desired deviation from the true mean. However, the minimum sampling frequency necessary to show compliance is obtained in a slightly different manner. The desired deviation from the mean L, is calculated as the difference between the effluent limitation and an estimate of the mean (or the logarithm of the effluent limitation and the logarithm of the estimate of the geometric mean for lognormal distributions) from a previous sampling program. The average used to determine L should be for the period over which the effluent limitation applies. The average for a given period can be used to determine L for an effluent limitation which applies over a short period as long as the data were random over the entire period. This assumes the same average would be obtained for an equal number of samples, no matter whether they were collected over a month or a year. The number of samples is then determined from a figure similar to Figure 9 or equation 3 for the L value calculated using equation 2. Division of the number of samples by the period for which the effluent limitation applies, yields the minimum sampling frequency which indicates compliance with the effluent limitation.

The procedure for selecting the best sampling frequency presented in this section is limited to determining the minimum sampling frequency for a given precision and significance level. Therefore, the procedure should be a useful tool to managers in determining the monetary resources needed for monitoring. However, the amount of money spent for monitoring is a policy decision based on available resources and priorities. In addition, the procedure showed that as the sample mean approaches the effluent limitation, the number of samples (and, therefore, the cost) required to show compliance increases. Therefore, this procedure may also be used to indicate when part of the investment in pollution control measures may be justified to offset the cost of monitoring to show compliance.

STEPWISE SUMMARY OF THE DESIGN PROCEDURE

Methods for determining the various inputs into a procedure for designing a monitoring program were described in the previous subsections. A stepwise summary of the procedure is presented below.

Step 1. Develop a physical understanding of the system.

Step 2. Develop a data set which estimates the effluent characteristics.

Step 3. Determine the variation of the data with time.

Step 4. Stratify the data set by season.

Step 5. Determine the distribution of the data in these data subsets.

Step 6. Estimate the mean as a function of the precision.

Step 7. Determine the critical range of the precision and select the desired precision for the future monitoring program.

Step 8. Determine the number of samples required to estimate the mean within the desired precision.

Step 9. Determine the maximum resources which can be allocated to the monitoring program.

Step 10. Select the monitoring frequency which best satisfies the requirements in Step 8 without exceeding the maximum resources established in Step 9.

Step 11. Repeat Steps 3 through 10 at the end of each monitoring period in order to update the program.

Step 10 cannot be accomplished without a management decision which establishes the maximum resources (Step 9) which can be allocated to the monitoring program. This decision involves a host of considerations beyond the scope of this study. Therefore, limits on the available resources will be assumed in later sections in order to demonstrate Steps 1 through 10 of the procedure. Once management has established the available resources, the results of the work presented here for Steps 1 through 8 should be easily adapted to the task of completing Steps 10 and 11.

SECTION 5

ASH POND MONITORING PROGRAM FOR PLANT E

The following section demonstrates how the procedure outlined in Section 4 was used to design a monitoring program for the ash pond effluent at TVA's Plant E.

DESCRIPTION OF PLANT E

Plant E consists of five pulverized coal-fired units with a combined full load capacity of 1.3 million kilowatts. Units 1 through 4 were placed in commercial operation in 1955 and unit 5 in 1965. Full load capacity for each of units 1-4 and unit 5 is 200,000 and 500,000 kilowatts, respectively. At full capacity the plant consumes about 13,000 tons of coal per day. The majority of the coal comes from western Kentucky and has an average sulfur content of 4.1 percent and an average ash content of 15.3 percent.

The plant also consists of eight standby gas turbine units which have a total generator nameplate rating of 475,000 kilowatts. These units are used primarily to meet system peak power loads and are used between 500 and 1,000 hours per year. These units are designed to use either natural gas or distillate fuel oil and were placed into operation in 1972. At normal full load, each unit will consume about 4,900 gallons of oil per hour; and when burning natural gas, each unit uses about 670,000 cubic feet per hour.

The coal-fired units 1 though 4 are equipped with mechanical fly ash collectors (74 percent efficiency) and electrostatic precipitators (97 percent design efficiency) while unit 5 is equipped with an electrostatic precipitator (90 percent design efficiency). The overall fly ash collection efficiency is approximately 95 percent.

Assuming operation at full load capacity, approximately 1,900 tons of ash per day would be produced by Plant E. This ash is sluiced to a 63 acre ash pond with a storage capacity of about 3.1 million cubic yards which provides settling and disposal of the ash. The ash pond effluent is discharged into the condenser cooling water discharge canal. The ash pond effluent characteristics previously discussed for Plant E and those to follow are for the ash pond effluent stream prior to discharge into the condenser cooling water discharge canal.

In addition to the ash, the ash pond also receives neutralized chemical cleaning wastes. These wastes are discharged intermittently (4 times every 3 years) and during their discharge they represent approximately 3.4 percent of the total flow from the ash pond.

MECHANICS OF THE ASH POND SYSTEM AT PLANT E

A summary of the ash pond effluent characteristics for Plant E
during 1974 and 1975 was given in Section 3. There were insufficient
data on the operating conditions of Plant E during 1974 and 1975 to
determine the relationship between the ash pond effluent and plant
operation. There were also no significant correlations between the
intake water quality and the effluent water quality except when the
detention time of the ash pond was taken into consideration by lagging
the two data sets. Therefore, two ash pond surveys were conducted in
which the physical and chemical characteristics of the ash pond and its
effluent were studied and their relationship determined. The first, a
preliminary survey, was conducted during the first week of October 1975.
The second, a more detailed survey, was conducted during the week of
February 23, 1976.

Cross-sectional profiles of the ash pond on the first two days of
the preliminary survey showed the pond to be stratified with respect to
temperature. A third pond profile on the last day of the survey showed
the pond to be completely isothermal. The reason for this destratifica-
tion was uncertain. During the second survey, two more pond profiles
were performed on February 23 and 25. The results are shown in Figure
10. During the second survey tag lines were stretched across the pond
at 5 locations and each line was marked with tape at 25 percent, 50
percent, and 75 percent distances from the left bank to indicate sampling
stations. Depth, temperature, pH, conductivity, and dissolved oxygen
were measured in situ at each station with a portable water quality
analyzer. Total alkalinity and turbidity were measured at all stations
along the tag line closest to the skimmers (skimmers are outlet devices
which prevent materials floating on the ash pond surface from being
carried out in the effluent) and at each 50 percent station. The ash
pond was again stratified with respect to temperature the first day and
completely isothermal the third day of the survey. The first day was
extremely calm while the third was windy. The stratification is believed
to be a result of the heated discharge to the pond. The temperature of
the water entering the pond is elevated by addition of the hot ash.
During calm conditions, the water entering the pond appears to spread
out over the surface of the pond and flow across it in a thin stratified
layer, whereas during windy conditions the water entering the pond mixes
with the water already in the pond. Therefore, wind conditions appear
to determine the mixing of the pond.

During the period of stratification, the difference in temperature
from top to bottom decreased as the flow approached the outlet of the
pond. This decrease was a result of both surface cooling and mixing.
Although thermally stratified the first day, the pond showed no mea-
surable difference in pH, DO, and alkalinity from top to bottom. The
conductivity was higher at the surface than at the bottom during periods
of thermal stratification. However during isothermal periods the con-
ductivity was lower at the surface than at the bottom. The turbidity
was normally constant top to bottom during isothermal conditions, while
during stratified conditions it was slightly higher at the top than at
the bottom.
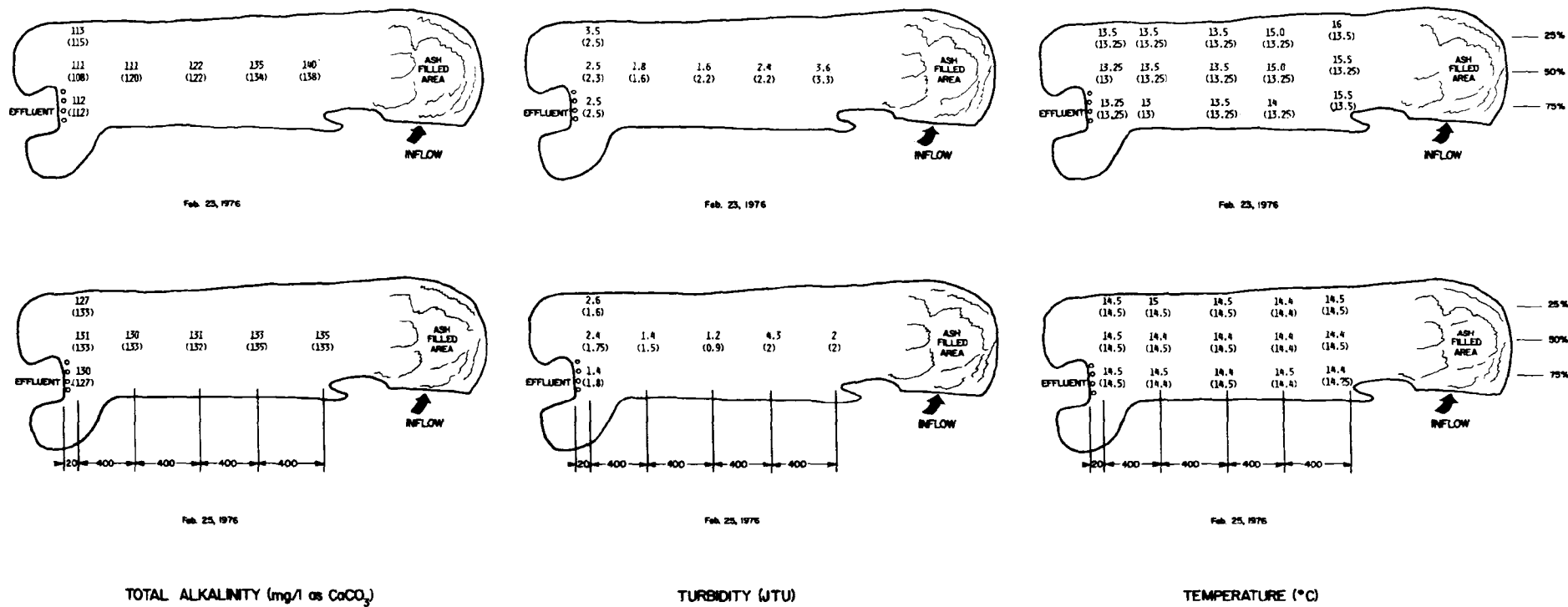
Figure 10. Vertical Profile of Ash Pond Characteristics of Plant E During Thermal Stratification and Isothermal Periods (the numbers in parenthesis represent readings approximately 1 foot from the bottom, while the other numbers represent readings just below the surface)

Feb 23, 1976 (pH)

10.9 (10.9)	11.2 (11.15)	11.1 (11.15)	11.35 (11.3)	11.2 (11.2)
10.9 (11)	11.1 (11.1)	11.1 (11.15)	11.35 (11.2)	11.2 (11.2)
11.1 (11.1)	11.1 (11.15)	11.05 (11.1)	11.2 (11.2)	11.25 (11.2)

EFFLUENT · ASH FILLED AREA · INFLOW

Feb 23, 1976 (Dissolved Oxygen)

10.5 (10)	10 (10)	10 (10)	9.9 (10)	9.8 (10)
10 (10.1)	10 (10)	10 (10)	10 (10)	9.8 (10)
10 (10)	10 (10)	10 (10)	10 (10)	9.8 (10)

Feb 23, 1976 (Conductivity)

630 (635)	630 (640)	690 (690)	780 (745)	760 (730)
635 (640)	630 (680)	675 (740)	780 (750)	780 (740)
635 (635)	615 (690)	655 (730)	715 (730)	785 (745)

25% 50% 75%

Feb 25, 1976 (pH)

11.1 (11.1)	11.05 (11.05)	11.05 (11)	11 (11)	11 (11)
11.1 (11.1)	11.1 (11.05)	11.05 (11)	11 (11)	11 (11)
11.0 (11.05)	11.0 (11.0)	11.0 (11)	11 (11)	11 (10.95)

20 400 400 400 400

Feb 25, 1976 (Dissolved Oxygen)

10 (9.9)	9.9 (9.9)	9.9 (10)	9.9 (10)	9.9 (10)
10 (10)	9.9 (10)	9.9 (10)	10 (10)	9.9 (10)
9.8 (10)	9.9 (10)	9.9 (10)	9.9 (10)	9.9 (10)

Feb 25, 1976 (Conductivity)

730 (740)	745 (740)	735 (740)	730 (738)	735 (745)
740 (740)	730 (735)	728 (735)	722 (735)	730 (735)
715 (715)	720 (720)	722 (720)	720 (728)	725 (733)

pH   Dissolved Oxygen (mg/l)   CONDUCTIVITY (μmhos)

Figure 10 (Continued)

During the preliminary survey, an unsuccessful attempt was made to determine the detention time of the ash pond using Rhodamine WT dye. The dye was injected into the sluice lines within the plant. However, the dye was adsorbed onto the fly ash and settled out with the ash making detection of the dye impossible. Therefore, during the second survey the Rhodamine WT dye was poured into the headwaters of the pond at 8:00 a.m., on February 23, 1976. Effluent samples were collected every 30 minutes and analyzed for dye concentration by a fluorometer. Dye was first detected in the effluent 7 hours after the dye was injected into the pond. The peak dye concentration occurred 12 hours after injection (see Figure 11), but dye concentrations up to 4 ppb were still detected after 43 hours. This indicates that the flow through the ash pond was plugflow with some mixing taking place.

The dye was injected into the pond during thermal stratification and thus moved across the surface of the pond reducing the detention time to approximately 12 hours. However, the morning of the 24th was fairly windy and the pond had become mixed. Therefore, the remaining dye was redistributed throughout the pond resulting in a slow decline of the dye concentration after the morning of the 24th. Had the dye been injected when the pond was completely mixed, the peak would have occurred later and been less intense than the one shown in Figure 11. Based on this dye study and the pond profiles, the detention time of the Plant E ash pond is believed to vary from approximately 12 hours to 7 days depending on the state of mixing in the pond.

During the ash pond survey in October 1975, samples of the sluice water before additions of the ash were collected by allowing a valve located in the intake pumping system to drip continuously for 8 hours during each of the three sampling days. This provided three 8-hour composite samples which represented the characteristics of the water used for sluicing. In addition, grab samples of the ash pond effluent were collected by a Circo automatic sampler at 30 minute intervals and composited every 12 hours for a 72 hour period. Both influent and effluent composite samples were analyzed for total and suspended solids and total and dissolved Al, Ca, Cr, Cu, Fe, Mg, Pb, Zn, SO_4, and Si. References for the methods used to analyze these samples are given in Appendix A. A summary of the quality control data for TVA's Division of Environmental Planning's Laboratory Branch is given in Appendix B. The results are shown in Table 14. For all elements except solids, the total and dissolved concentrations were determined analytically and the suspended concentration determined by subtraction of the dissolved concentration from the total concentration. The majority of the Cu and Fe in the effluent appears to be associated with the suspended solids. The dissolved form is the predominate form for the remaining elements. The concentration of suspended calcium for the data given in Table 14 is greater than the suspended solids concentration indicating an error or lack of precision in the analytical procedures used. The analytical procedure used to determine the suspended metal concentration is the reason for this inconsistency. The suspended Ca concentration was calculated by first analyzing for the total and dissolved concentrations and then subtracting the dissolved from the total. The suspended solids concentration was determined directly by analysis and thus is a more accurate estimate of its value than the value given for the suspended Ca concentration.
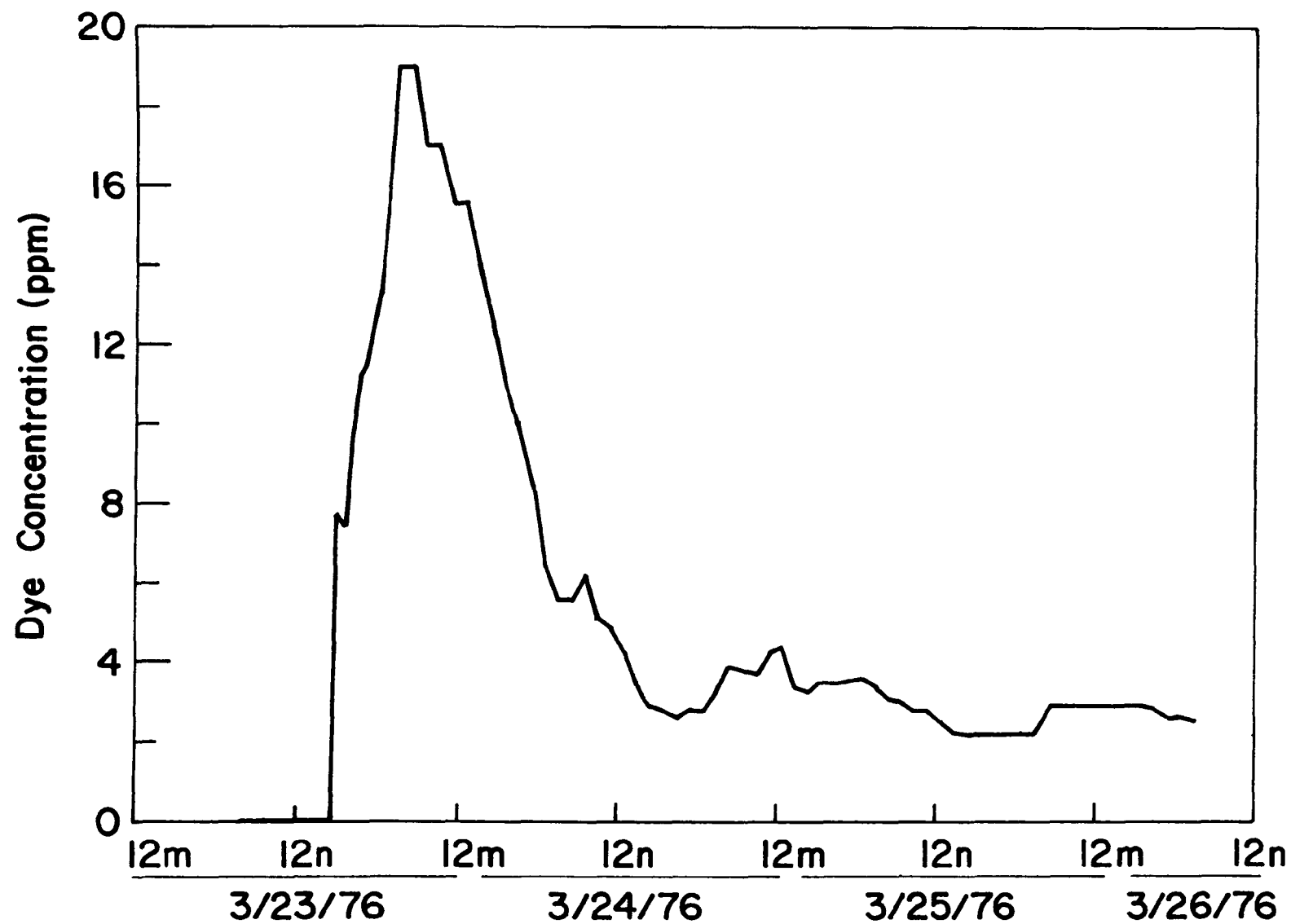
Figure 11. Concentration of Rhodomine WT Dye in Plant E Ash Pond Effluent with Time

Table 14. CHEMICAL ANALYSIS OF ASH POND EFFLUENT AND INTAKE WATER USED FOR SLUICING DURING PRELIMINARY SURVEY AT PLANT E

Elements (mg/l)		Raw Water Supply			Pond Outfall					
		9/30	10/1	10/2	9/29 Night	9/30 Day	9/30 Night	10/1 Day	10/1 Night	10/2 Day
Aluminum	Total	0.9	0.9	0.6	3.0	3.0	2.4	2.8	2.7	2.7
	Dissolved	<0.2	0.4	<0.2	2.4	2.4	2.3	2.4	2.7	2.7
Calcium	Total	34	32	32	180	180	180	180	170	180
	Dissolved	26	28	28	150	160	170	160	150	160
Chromium	Total	<0.005	<0.005	<0.005	0.023	0.031	0.03	0.026	0.034	0.04
	Dissolved	<0.005	<0.005	<0.005	<0.005	0.031	0.03	<0.005	0.012	0.006
Copper	Total	0.1	0.14	0.11	0.04	0.03	0.06	0.03	0.06	0.02
	Dissolved	0.05	0.07	0.06	0.01	<0.01	0.02	0.01	<0.01	<0.01
Iron	Total	0.36	0.27	0.34	0.43	0.35	0.15	0.11	0.14	0.10
	Dissolved	0.06	0.07	0.05	0.06	0.05	<0.05	0.05	<0.05	<0.05
Magnesium	Total	4.1	5.0	5.1	0.3	0.3	0.2	0.2	0.3	0.2
	Dissolved	4.1	4.9	5.1	0.3	0.3	0.2	0.2	0.3	0.2
Lead	Total	0.02	0.028	0.017	<0.01	<0.01	0.03	<0.01	<0.01	<0.01
	Dissolved	<0.01	0.012	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	Total	0.04	0.04	0.05	0.04	0.05	0.03	0.03	0.03	0.03
	Dissolved	0.02	0.04	0.03	0.02	0.04	a	0.03	0.03	0.02
Solids	Total	110	100	110	490	400	470	420	360	400
	Dissolved	6	2	2	22	22	4	2	11	2
Sulfate	Total	10	10	11	150	150	150	140	150	140
	Dissolved	10	10	9	150	150	150	140	150	140
Silica	Total	3.1	2.9	2.5	3.2	3.5	4.1	2.7	2.9	3.6
	Dissolved	2.1	2.8	2.0	3.0	3.5	3.0	2.6	2.9	3.4

[a]Not reported

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During the second ash pond survey, 500 milliliters of the intake and effluent samples were filtered and the residue on the filter pad analyzed for suspended metal concentrations. The intake samples were collected in the same manner as during the preliminary survey. However, the effluent samples were composited every six hours rather than twelve hours as before. In an effort to minimize laboratory costs, only four effluent samples and two intake samples were chosen for suspended metal analysis. The results of this February survey are shown in Tables 15 and 16.

The average concentrations of each element in the intake water supply and the ash pond effluent, and the difference between the two were calculated for each survey using all of the data in Table 14 and selected data (sample numbers 2, 3, 5, 7, 9, and 18) from Tables 15 and 16. The results of these calculations are shown in Table 17. The sum of suspended and dissolved values given in Table 17 may not add up to the total shown for several parameters due to round off errors and the treatment of less than values during the averaging of the original data sets. A negative sign indicates a decrease in concentration from the intake water supply to the ash pond effluent while a positive number indicates an increase in concentration.

The following conclusions were derived from Table 17.

1. Both surveys indicated that the total and dissolved aluminum concentrations increased from intake to effluent while the suspended concentration decreased.

2. The total calcium and chromium concentrations increased from the intake to the effluent with the majority of the increase being in the dissolved phase.

3. The total, dissolved, and suspended concentrations of copper and magnesium decreased from the intake to the effluent.

4. The total iron concentration decreased from the intake to the effluent. The decrease occurred both in the suspended and dissolved phases. The majority of the iron remaining in the effluent was in the suspended form.

5. Both the suspended and dissolved lead concentrations decreased from the intake to the effluent. The lead concentration in the effluent was usually near or below the minimum detectable limit.

6. The total zinc concentration decreased only slightly and the decrease was primarily in the dissolved phase.

7. The sulfate and silica concentrations increased from intake to effluent. The increases were in the dissolved form.

8. The total arsenic concentration increased from the intake to the effluent. The increase was in the dissolved form. The data for the February survey indicates that the dissolved concentration was higher than the total concentration. This is in error and is attributed either to laboratory or sampling errors.

TABLE 15. CHEMICAL ANALYSIS OF ASH POND EFFLUENT AND INTAKE WATER USED FOR SLUICING DURING THE FEBRUARY SURVEY AT PLANT E[a]

Sample Number	Date	Time	Sample Location	Solids Susp mg/l	Solids Diss mg/l	Solids Total mg/l	Diss Sulfate mg/l	Diss Silica mg/l	Chromium µg/l	Lead µg/l
1[b]	2/18/76		Intake	54	100	154	13	5.0	<5	<10
2[b]	2/19/76	9 a.m.-2 p.m.	Intake	15	90	105	12	5.0	<5	<10
3[b]	2/20/76	8 a.m.-2 p.m.	Intake	16	90	106	6	4.8	6	22
4	2/22/76		Intake	8	110	118	18		<5	<10
5[b]	2/23/76	8 a.m.-2 p.m.	Effluent	8	230	238	87	6.9	7	<10
6[b]	2/23/76	2 p.m.-8 p.m.	Effluent	4	230	234	87	7.2	19	<10
7[b]	2/23-24/76	8 p.m.-2 a.m.	Effluent	3	220	223	87	6.6	15	<10
8	2/24/76	2 a.m.-8 a.m.	Effluent	4	220	224	87	6.3	<5	<10
9[b]	2/24/76	8 a.m.-2 p.m.	Effluent	5	200	205	89	6.6	11	<10
10	2/24/76	2 p.m.-8 p.m.	Effluent	7	200	207	89	6.3	<5	<10
11	2/24-25/76	8 p.m.-2 a.m.	Effluent	4	210	214	92	6.6	10	<10
12	2/25/76	2 a.m.-8 a.m.	Effluent	3	200	203	92	6.5	7	<10
13	2/25/76	8 a.m.-2 p.m.	Effluent	3	210	213	92	6.3	23	<10
14	2/25/76	2 p.m.-8 p.m.	Effluent	2	220	222	94	6.3	17	<10
15	2/25-26/76	8 p.m.-2 a.m.	Effluent	2	210	212	92	6.3	10	<10
16	2/26/76	2 a.m.-8 a.m.	Effluent	<1	200	200	92	6.3	23	<10
17[b]	2/26/76	8 a.m.-2 p.m.	Effluent	<1	200	200	89	6.5	36	<10
18[b]	2/26/76	2 p.m.-8 p.m.	Effluent	8	210	218	94	6.4	14	<10
19	2/26-27/76	8 p.m.-2 a.m.	Effluent	<1	200	200	94	6.1	8	<10
20	2/27/76	2 a.m.-8 a.m.	Effluent	2	200	202	85	6.7	19	<10

[a]All metal concentrations are total.

[b]Chosen for suspended metal analysis.

TABLE 15[a] (continued)

Sample Number	Calcium mg/l	Copper mg/l	Iron mg/l	Manganese mg/l	Magnesium mg/l	Zinc mg/l	Aluminum mg/l	Arsenic[c] µg/l	pH[d]	TDS[d] mg/l	Temp[d] °C
1	22	0.02	1.7	0.07	3.1	0.03	2.4	<5	8.0	91	
2[b]	21	0.02	1.3	0.05	3.2	0.03	1.6	<5	7.9	85	
3[b]	21	0.24	2.2	0.33	3.2	0.14	1.6	<5	7.7	85	
4	23	0.05	0.81	0.05	3.4	<0.01	0.9	<5	8.5	90	
5[b]	93	<0.01	0.30	0.04	0.5	<0.01	1.7	5	10.95	330	
6[b]	97	<0.01	0.15	0.03	0.5	0.03	1.7	5	11.0	350	14
7[b]	110	<0.01	0.05	0.02	0.4	0.11	1.6	5	11.23	420	14.5
8	110	<0.01	0.13	0.05	0.4	0.16	1.6	10	11.2	400	13.5
9[b]	100	0.09	0.14	0.02	0.4	<0.01	1.7	5	11.3	385	14.5
10	94	<0.01	0.13	0.01	0.4	0.05	1.7	10	11.3	400	15.5
11	91	<0.01	0.09	0.01	0.4	0.08	1.9	5	11.1	385	14.5
12	95	<0.01	0.21	0.01	0.4	0.04	1.9	5	11.2	400	14.5
13	87	<0.01	0.16	<0.01	0.4	<0.01	2.0	5	11.3	400	14.5
14	92	<0.01	0.26	<0.01	0.4	0.02	2.0	5	11.3	390	15.0
15	93	<0.01	0.10	<0.01	0.4	0.02	2.0	5	11.3	410	15.0
16	98	<0.01	0.08	<0.01	0.4	<0.01	1.7	5	11.3	395	15.0
17[b]	88	<0.01	0.06	<0.01	0.4	<0.01	1.6	5	11.3	390	15.5
18[b]	87	<0.01	0.10	<0.01	0.4	<0.01	2.0	10	11.35	370	15.5
19	90	<0.01	0.09	<0.01	0.5	<0.01	1.9	20	11.3	350	15.5
20	91	<0.01	0.09	<0.01	0.5	<0.01	1.8	20	11.36	385	15.5

[a]All metal concentrations are total.

[b]Chosen for suspended metal analysis.

[c]Based on past data all intake samples were assumed to be less than the minimum detectable limit of 5 µg/l.

[d]Field measurement.

TABLE 16. SUSPENDED METALS CONCENTRATION
FOR THE FEBRUARY ASH POND SURVEY AT PLANT E

Sample Number[a]	2	3	5	7	9	18
Location	Intake	Intake	Effluent	Effluent	Effluent	Effluent
Suspended Solids (mg/l)	15	16	8	3	5	8
Chromium (μg/l)	<5	------	--------	--------	--------	--------
Lead (μg/l)[b]	<10	<10	<10	<10	<10	<10
Calcium (mg/l)	0.28	0.25	0.92	0.55	0.56	0.56
Copper (mg/l)	0.022	0.11	<0.01[c]	<0.01[c]	<0.01[c]	<0.01[c]
Iron (mg/l)	0.67	1.1	0.30	0.082	0.074	0.08
Magnesium (mg/l)	0.07	0.06	0.03	0.02	0.04	0.10
Zinc (mg/l)	0.01	0.026	0.018	0.017	<0.01[b]	<0.01[b]
Aluminum (mg/l)	0.925	0.762	0.008	0.008	0.008	0.112
Arsenic (μg/l)[c]	<5[b]	<5[b]	8	11	<5	10

[a]Sample number corresponds to sample number in Table 14.

[b]These values were assumed because the total concentrations were below the detectable limit.

[c]Values shown are for the dissolved phase because the suspended form could not be analyzed from the filter pad.

TABLE 17. AVERAGE CHEMICAL ANALYSIS OF THE ASH POND EFFLUENT AND INTAKE WATER SUPPLY DURING BOTH ASH POND SURVEYS

Element		Preliminary Survey[a]			February Survey[b]		
		Average Intake Water Supply mg/l	Average Pond Effluent mg/l	Difference mg/l	Average Intake Water Supply mg/l	Average Pond Effluent mg/l	Difference mg/l
Aluminum	Total	0.8	2.77	1.97	1.6	1.75	0.15
	Diss	0.27	2.48	2.21	0.76	1.72	0.96
	Susp	0.67	0.28	-0.39	0.84	0.03	-0.81
Calcium	Total	33	178	145	21	98	77
	Diss	27	158	131	20.7	97.3	76.6
	Susp	6	20	14	0.3	0.7	0.4
Chromium	Total	<0.05	0.031	0.031	0.0055	0.012	0.0065
	Diss	<0.05	0.022	0.022	0.0055	0.012	0.0065
	Susp	<0.05	0.0175	0.0175	<0.005	<0.005	0
Copper	Total	0.12	0.04	-0.08	0.013	0.03	-0.10
	Diss	0.06	0.012	-0.048	0.06	0.03	-0.03
	Susp	0.06	0.03	-0.03	0.07	<0.01	-0.07
Iron	Total	0.32	0.21	-0.11	1.8	0.15	-1.65
	Diss	0.06	0.052	-0.008	0.9	0.02	-0.88
	Susp	0.26	0.17	-0.09	0.9	0.13	-0.77
Magnesium	Total	4.73	0.25	4.48	3.2	0.43	-2.77
	Diss	4.7	0.25	-4.45	3.13	0.38	-2.75
	Susp	0.03	0	-0.03	0.07	0.05	-0.02
Lead	Total	0.02	0.013	-0.01	0.16	<0.01	-0.16
	Diss	0.011	0.007	-0.004	0.16	<0.01	-0.16
	Susp	0.017	0.005	-0.012	<0.01	<0.01	0
Zinc	Total	0.043	0.035	-0.008	0.09	0.035	-0.055
	Diss	0.03	0.023	-0.007	0.078	0.021	-0.057
	Susp	0.013	0.008	-0.005	0.012	0.014	0.002
Solids	Total	107	424	316	106	221	115
	Diss	104	413	308.5	90	215	125
	Susp	3	11	7.5	16	6	-10
Sulfate	Total	10.3	147	136.7	NA	NA	
	Diss	9.7	147	137.3	9	89	80
	Susp	0.6	0	-0.6	NA	NA	
Silica	Total	2.8	3.3	0.5	NA	NA	
	Diss	2.3	3.1	0.8	4.9	6.6	1.7
	Susp	0.5	0.2	-0.3	NA	NA	
Manganese	Total	NA	NA	NA	0.19	0.023	-0.167
	Diss				NA	NA	
	Susp						
Arsenic	Total	NA	NA	NA	<0.005[c]	0.008	0.063
	Diss				<0.005[c]	0.085	0.085
	Susp						

[a] Total and dissolved metal concentrations determined analytically. The suspended concentration was then calculated.

[b] Total and suspended metal concentrations determined analytically. The dissolved concentration was then calculated.

[c] Based on past data all intake samples were asumed to be less than the minimum detectable limit of 5 μg/l.

9. The total and dissolved solids concentrations increased from the intake to the effluent but the suspended solids concentration remained approximately the same, sometimes increasing and sometimes decreasing.

Other aspects of these surveys as they relate to developing an ash pond monitoring program for Plant E will be discussed in the following subsections. The results of the February survey confirmed the findings of the September survey. Because of improved sampling procedures for trace metals (collection of suspended and dissolved samples for metal analysis) a better estimate of the form in which the various metals occurred was obtained. A dye study was attempted during the first survey but the dye was injected before the majority of the ash had had time to settle out and the dye was absorbed into the ash and disappeared. During the second survey a successful dye study to determine the detention time of the ash pond was carried out by injecting the dye into the pond after the ash had settled out. The thermal stratification of the ash pond observed during the first survey was also confirmed.

SUMMARY OF THE ASH POND EFFLUENT CHARACTERISTICS AT PLANT E

A summary of the ash pond effluent characteristics based on the two ash pond surveys and the quarterly monitoring program for 1974 and 1975, is given in Table 18. The summary also includes the maximum and minimum values reported during that sample period, indicating the range over which the effluent characteristics vary. The October 1975 survey spanned 3 days while the February 1976 survey spanned 4 days. The quarterly monitoring program covered six quarters or a year and a half starting in mid-1974. The data indicate that except for Fe, Mg, and Zn, the averages for each sample period differed for each element. However, the range (the difference between the lowest and highest values) is greatest for the quarterly sampling program indicating that the effluent characteristics vary more over a period of a year rather than within a day. The weekly effluent data from 1970 to 1975 for Plant E, showed that there was no yearly cycle for flow, pH, or suspended solids but that there was a yearly cycle for alkalinity and dissolved solids. The data from the two ash pond surveys did not indicate a daily cycle for any of the elements except possibly Cu and Fe during the preliminary survey. Both Cu and Fe were consistently higher in the samples collected at night than those collected during the day. However, this was not observed during the February survey. Since the two surveys only span either 3 or 4 days, enough data is not available to ensure a weekly cycle does not exist. However, based on the data, there is no reason to believe a weekly cycle does exist.

As concluded at the end of Section 3, except for pH there is insufficient data on those parameters required by the NPDES permit for Plant E to adequately estimate the true yearly mean. Therefore, a more intensive sampling program of the ash pond effluent at Plant E was conducted from May 1976 to February 1977 to better estimate the effluent characteristics. Samples were collected on a varying workday of each week. For example, a sample may have been collected on a Thursday one week and Tuesday the following week. This was done to avoid sampling at exactly one week intervals in hopes of detecting a weekly cycle, if one exists.

TABLE 18.   SUMMARY OF THE ASH POND EFFLUENT CHARACTERISTICS AT PLANT E FOR THE
TWO ASH POND SURVEYS AND THE QUARTERLY MONITORING PROGRAM DURING 1974 AND 1975

Element	Quarterly Monitoring Program			October 1975 Survey			February 1976 Survey		
	Minimum	Avg.	Maximum	Minimum	Avg.	Maximum	Minimum	Avg.	Maximum
Aluminum (mg/l)	1.1	2.5	3.0	2.4	2.77	3.0	1.6	1.8	2.0
Calcium (mg/l)	68	126	170	170	178	180	87	95	110
Chromium (mg/l)	<0.005	0.017	0.022	0.023	0.031	0.04	<0.005	0.014	0.036
Copper (mg/l)	0.02	0.08	0.19	0.02	0.04	0.06	<0.01	0.015	0.09
Iron (mg/l)	0.05	0.16	0.39	0.10	0.21	0.43	0.05	0.13	0.30
Magnesium (mg/l)	0.1	0.3	0.3	0.2	0.25	0.3	0.4	0.43	0.5
Lead (mg/l)	<0.01	0.017	0.036	<0.01	0.01	0.03	<0.01	<0.01	<0.01
Zinc (mg/l)	<0.03	0.05	0.07	0.03	0.035	0.05	<0.01	0.04	0.16
Dissolved Solids (mg/l)	240	368	420	349	413	468	200	210	230
Suspended Solids (mg/l)	2	4	6	2	11	22	<1	4	8
Dissolved Sulfate (mg/l)	100	147	210	140	147	150	85	90	94
Dissolved Silica (mg/l)	5.9	7.0	8.4	2.6	3.1	3.5	6.1	6.5	7.2
Arsenic (mg/l)	0.03	0.06	0.09	NA	NA	NA	0.005	0.008	0.02
Manganese (mg/l)	<0.01	0.01	0.02	NA	NA	NA	<0.01	0.02	0.05

Grab samples were collected by representatives from TVA's Division of Environmental Planning and shipped to the Laboratory Branch in Chattanooga, Tennessee. The samples were analyzed for the following parameters which are required by the NPDES permit for Plant E: ph, flow, suspended solids, total arsenic, chromium, copper, iron, lead, manganese, selenium, and zinc. The NPDES permit also calls for cadmium, mercury, and nickel to be monitored, however, these elements were not included in this study because previous data (see Table 5) indicated the concentrations were at or below the miminum detectable limit. In addition, the samples were analyzed for aluminum, calcium, magnesium, dissolved silica, sulfate and dissolved solids. These elements were included because previous data indicated their presence. The samples were collected in the ash pond discharge prior to mixing with any other waste stream as required by the NPDES permit. During the sampling period the plant was operated as normal, including the discharge of routine chemical-cleaning wastes and air-preheater washdown to the ash pond.

The results of this intensive sampling program are given in Table 19. Beginning October 14, 1976, only every other sample collected was analyzed because the data did not vary substantially from week to week. A summary at the bottom of the table gives the minimum, mean, and maximum values for each element. Linear correlation coefficients were developed between elements. A significant correlation at the 95 percent significance level is represented by an R value greater than 0.325 in Table 20 (2). The following parameters were correlated significantly with pH: conductivity, calcium, dissolved solids, and dissolved silica. Copper was negatively correlated with pH. The following parameters were significantly correlated with dissolved solids: chromium, conductivity, dissolved silica, and sulfate. Turbidity was negatively correlated with dissolved solids, calcium, chromium, dissolved silica, and sulfate. Suspended solids were significantly correlated with flow, turbidity, and aluminum. Suspended solids were also negatively correlated with chromium, selenium, dissolved solids, and dissolved silica. Aluminum was significantly correlated with iron, manganese, and zinc in addition to turbidity and suspended solids. Calcium was significantly correlated with iron, manganese, selenium, and dissolved silica. Copper was significantly correlated with magnesium. In addition to aluminum and calcium, iron was significantly correlated with manganese. These correlations indicate that the heavy metals in the ash pond effluent are definitely interrelated with one another.

Several of the R values indicated relationships between parameters which may be beneficial to a monitoring program. For example, turbidity could be used as an indication of the suspended solids concentration or conductivity could be used to indicate the dissolved solids concentration. These two relationships have been used extensively by industry for automation of monitoring programs. However, the relationship between flow and suspended solids may be more beneficial to controlling suspended solids, especially if the flow could be controlled to ensure a given suspended solids concentration. Figure 12 shows the linear regression for flow versus suspended solids. According to the data in Figure 12, if the flow is maintained between 17,500 and 24,320 gallons per minute (gpm) the average suspended solids concentration should be 30 mg/l assuming a linear regression and 95 percent confidence level. It also

TABLE 19. ASH POND EFFLUENT CHARACTERISTICS FOR PLANT E

Date	Flow (gpm)	pH	Conductivity (µhos/cm)	Turbidity (JTU)	Aluminum (mg/l)	Calcium (mg/l)	Chromium (µg/l)	Copper (mg/l)	Iron (mg/l)	Lead (mg/l)	Magnesium (mg/l)	Manganese (mg/l)	Zinc (mg/l)	Selenium (µg/l)	Arsenic (µg/l)	Dissolved Silica (mg/l)	Total Sulfate (mg/l)	Dissolved Solids (mg/l)	Suspended Solids (mg/l)
5/5/76	6070	11.1	450	NA	1.4	54	10	<0.01	0.20	<10	2.9	<0.01	<0.01	18	80	3.5	58	210	6
5/13/76	4170	11.3	832	NA	1.8	32	25	<0.01	0.12	<10	3.2	<0.01	<0.01			6.5		340	1
5/17/76	4470	11.2	681	NA	2.2	4	13	<0.01	0.16	<10	0.4	0.02	0.04	17	14	7.1	72	290	2
5/28/76	6120	10.7	550	NA	1.8	76	8	0.13	0.47	<10	0.9	0.05	0.13	12	<20	5.3	130	300	6
6/01/76	4170	10.8	510	NA	1.5	65	32	0.02	0.28	<10	0.8	0.02	0.02	12	5	4.9	140	40	6
6/11/76	6320	11.0	547	1.5	1.6	120	8	0.22	0.22	<10	14	0.02	0.03	15	25	5.1	190	280	4
6/16/76	7380	11.2	667	1.1	2.5	230	40	0.04	0.26	<10	0.5	0.01	0.28	18	30	5.7	130	370	1
6/24/76	7100	11.0	630	<1.0	1.7	150	9	0.04	0.13	<10	0.4	0.02	0.59	11	9	6.4	140	300	1
6/29/76	6120	11.3	810	<1.0	2.0	140	50	0.05	0.10	<10	0.6	<0.01	<0.01	15	15	6.4	200	390	2
7/08/76	7100	11.0	645	1.6	2.5	130	42	<0.01	0.25	230	0.7	<0.01	<0.01	17	15	5.3	220	350	6
7/16/76	4850	11.1	655	1.4	2.6	120	41	<0.01	1.0	<10	0.6	0.06	<0.01	16	20	6.2	190	340	4
7/20/76	NA	NA	NA	NA	2.2	130	18	0.03	2.6	<10	1.5	0.07	0.02	17	<5	6.6	130	350	4
7/26/76	7920	11.5	1120	2.9	3.1	170	34	0.02	0.20	<10	0.2	<0.01	0.09	21	15	7.1	130	470	2
8/03/76	9950	11.2	805	2.0	3.2	130	21	0.06	0.17	<10	0.3	<0.01	0.01	21	20	5.8	180	310	10
8/12/76	10720	11.3	1070	1.4	2.6	170	24	0.11	0.56	<10	<0.1	0.11	0.02	13	15	7.0	200	460	4
8/17/76	10720	11.3	1030	1.2	3.1	140	18	<0.01	0.23	<10	0.2	0.01	0.04	19	<5	6.8	170	360	<1
8/26/76	11330	11.3	1020	2.4	6.1	140	21	0.04	16	19	0.2	0.39	0.04	15	25	5.9	160	370	9
8/30/76	10790	11.4	1070	1.2	3.2	170	25	<0.01	0.15	19	0.2	<0.01	0.06	16	20	6.4	160	370	17
9/10/76	10970	11.1	830	2.8	4.8	120	34	0.02	0.78	<10	0.8	0.04	0.02	16	15	6.2	230	430	11
9/16/76	11150	11.3	1060	11	2.9	140	34	0.02	0.29	14	0.3	0.01	0.02	5	25	6.5	8	470	2
9/20/76	4850	11.2	890	<1	2.4	19	29	0.02	0.18	11	4.1	<0.01	<0.01	4	20	6.7	8	720	3
9/30/76	5370	11.5	1165	NA	3.9	280	9	0.02	10	<10	4.5	0.28	0.06	20	<5	7.1	180	430	2
10/07/76	4420	11.3	835	3.5	3.3	160	37	0.02	0.19	<10	0.8	<0.01	0.05	25	10	6.1	200	480	6
10/14/76	5260	11.3	810	2.1	2.2	150	27	<0.01	0.38	18	0.7	0.03	0.04	20	12	5.4	220	430	8
10/28/76	10840	10.8	650	8.6	NA	120	28	0.06	0.50	<10	1.2	0.02	0.02	13	17	4.1	360	340	14
11/12/76	11530	11.3	595	<1.0	2.7	100	31	<0.01	0.33	<10	4.3	<0.01	0.02	1	15	5.4	210	430	19
11/22/76	10900	11.4	850	2.4	2.0	100	16	<0.01	0.18	<10	0.7	<0.01	<0.01	10	14	5.6	16	270	14
12/10/76	11830	11.2	757	NA	1.8	100	10	0.03	0.34	<10	0.6	<0.01	0.03	10	5	4.9	110	290	12
12/20/76	15480	11.0	580	9.4	16	100	9	0.13	1.4	<10	1.4	0.13	0.42	10	4	4.4	120	250	40
1/05/77	20650	10.9	427	13	2.6	73	<5	<0.01	2.5	<10	2.0	0.03	<0.05	10	13	5.1	93	190	45
1/20/77	28900	11.5	960	7.4	2.6	110	<5	0.02	1.8	23	0.6	0.01	0.02	17	23	4.8	160	370	39
2/03/77	15940	11.2	882	2.1	1.7	96	17	0.02	0.41	<10	0.6	<0.01	<0.01	16	12	5.3	200	370	9
2/15/77	14390	11.1	697	3.1	2.2	110	25	0.06	0.56	<10	1.0	<0.01	<0.01	11	10	4.3	180	490	10
2/25/77	14440	11.2	745	6.9	2.8	96	15	0.02	1.6	<10	0.8	<0.01	0.02	7	13	2.9	150	240	38
Minimum	4170	10.7	42	<1	1.4	35	<5	<0.01	0.1	<10	<0.1	<0.01	<0.01	5	<5	2.9	58	190	<1
Average	9570	11.2	79	3.4	3.0	124	23	0.04	1.4	20	1.4	0.04	0.06	14	17	5.7	167	366	11
Maximum	28900	11.5	116	13	16	280	50	0.22	16	230	14	0.39	0.59	25	80	7.1	360	720	45

TABLE 20. LINEAR CORRELATION COEFFICIENTS FOR THE VARIOUS ASH POND EFFLUENT PARAMETERS AT PLANT E

	Flow	pH	Conductivity	Turbidity	Aluminum	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Manganese	Zinc	Selenium	Arsenic	Dissolved Silica	Sulfate	Dissolved Solids	Suspended Solids
Flow	1.000																		
pH	0.127	1.000																	
Conductivity	0.080	0.826	1.000																
Turbidity	0.652	-0.193	-0.222	1.000															
Aluminum	0.254	-0.036	0.021	0.368	1.000														
Calcium	0.137	0.450	0.515	-0.373	0.075	1.000													
Chromium	-0.405	0.113	0.182	-0.403	-0.122	0.201	1.000												
Copper	-0.015	-0.392	-0.271	-0.028	0.268	-0.002	-0.276	1.000											
Iron	-0.128	0.192	0.287	0.134	0.369	0.311	-0.218	0.003	1.000										
Lead	-0.047	-0.128	-0.101	-0.098	-0.030	0.032	0.274	-0.125	-0.034	1.000									
Magnesium	-0.126	-0.125	-0.234	-0.055	-0.076	0.033	-0.283	0.580	0.033	0.065	1.000								
Manganese	0.001	0.154	0.305	0.025	0.426	0.374	-0.184	0.126	0.959	-0.053	0.039	1.000							
Zinc	-0.022	-0.210	-0.213	0.023	0.428	0.225	-0.210	0.244	0.015	-0.086	-0.083	0.079	1.000						
Selenium	-0.247	0.240	0.128	-0.293	-0.060	0.474	0.102	-0.068	0.087	0.105	-0.036	0.108	-0.063	1.000					
Arsenic	-0.065	-0.033	-0.231	-0.078	-0.187	-0.165	-0.042	0.006	-0.037	-0.008	0.147	-0.064	-0.125	0.089	1.000				
Dissolved Silica	-0.450	0.457	0.528	-0.403	-0.159	0.418	0.229	-0.211	0.064	-0.080	-0.117	0.172	0.005	0.327	-0.025	1.000			
Sulfate	-0.049	-0.051	0.235	-0.581	-0.054	0.200	0.452	0.089	-0.051	0.180	0.061	-0.011	0.228	0.041	-0.250	-0.146	1.000		
Dissolved Solids	-0.217	0.375	0.578	-0.332	-0.100	0.263	0.514	-0.158	-0.018	-0.159	0.199	0.027	-0.190	-0.073	-0.171	0.408	0.346	1.000	
Suspended Solids	0.812	-0.090	-0.213	0.707	0.430	-0.294	-0.418	0.009	0.101	-0.043	-0.036	-0.016	0.043	-0.317	-0.087	-0.647	-0.114	-0.399	1.000
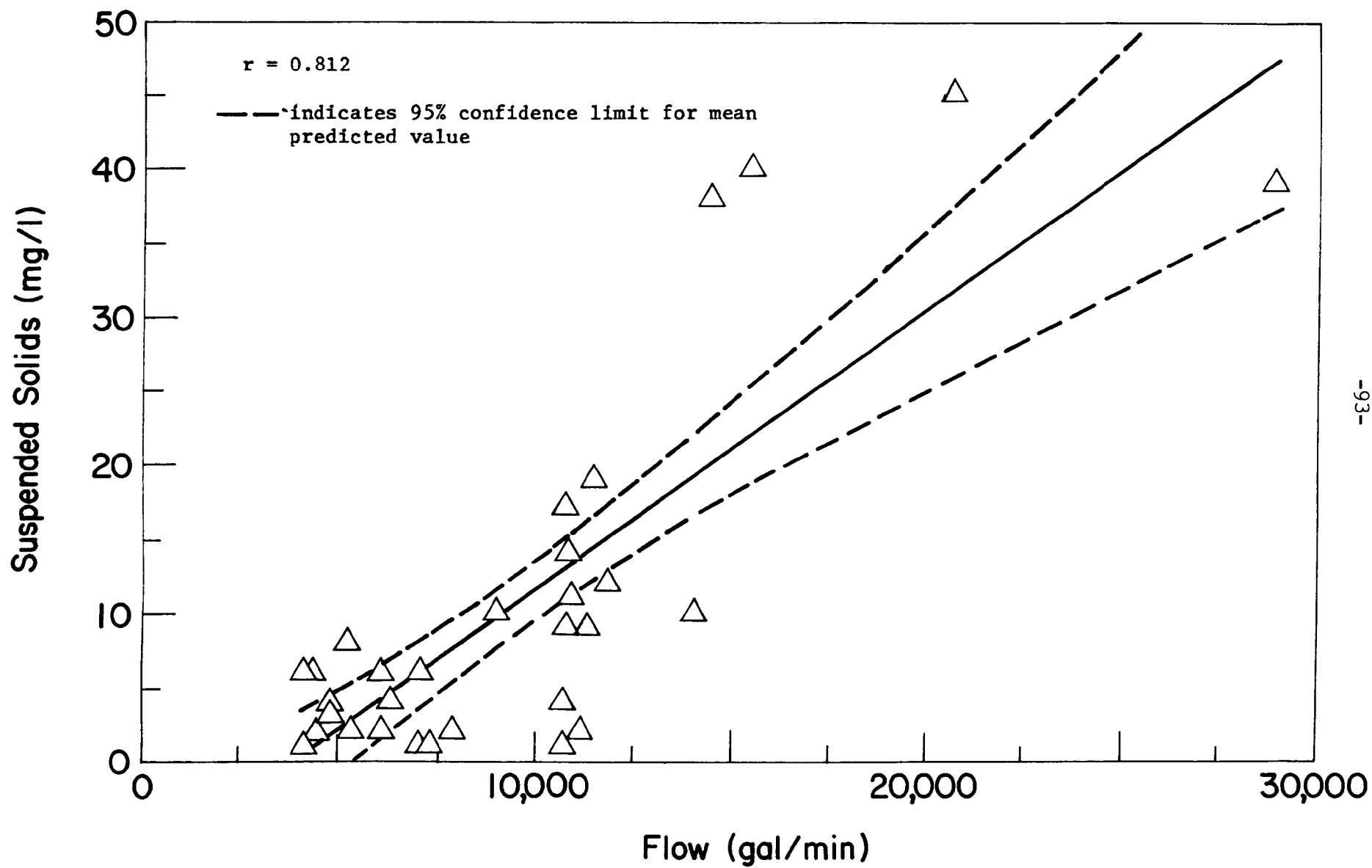
Figure 12. Relationship Between Flow and Suspended Solids in the Ash Pond Effluent at Plant E

shows that for a flow of 9,570 gpm the average suspended solids should be between 8.5 and 12.5 mg/l 95 percent of the time. This agrees with the data in Table 19. The average flow was 9,570 gpm and the average suspended solids was 11 mg/l. At flows above 12,500 gpm there is more lack of fit to a straight line in the data.

There are three possible explanations for the relationship between suspended solids and flow. The first is that the large changes in the ash pond flow correspond to the operational status of unit 5. The flow increases when unit 5 is on-line and decreases when it is off-line. The new electrostatic precipitator on unit 5 may produce an ash which differs chemically and physically from the ashes from the other units. This ash may not settle as well as the ash from the other units and thus the apparent relationship with increased flow. The second explanation is that the increased flow causes an increase in the velocity of the water spilling over the skimmers which may cause an increase in the quantity of cenospheres discharged with the effluent. The third explanation may be a reduced detention time in the pond when unit 5 is operating. However, more data at the higher flows are needed along with the settling characteristics of the different ashes from the various units, the detention time, and the effect of weir overflow rate on the discharge of cenospheres before the apparent dependency of suspended solids on flow can be properly explained.

The summary of the ash pond effluent characteristics for Plant E given in Table 19 will now be used to complete steps 3 through 8 of the design procedure summarized in Section 4.

VARIATION OF THE ASH POND EFFLUENT CHARACTERISTICS AT PLANT E WITH TIME

The variation with time of the ash pond effluent characteristics given in Table 19 for Plant E is shown in Figure 13. Except for flow and possibly suspended solids, there does not appear to be any trend or cycle over the sample period for any of the effluent constituents. Flow appears to increase in August and then again in December. This increase in ash pond flow is due to:

1. The operation of the electrostatic precipitator on unit 5 which was placed into service on June 1, 1976, resulting in an additional flow of 5.2 mgd. The time required for startup before reaching full operation may account for the 2-month lay between June and the flow increase in August.

2. Increased plant capacity factor due to increased hours of operation during extreme hot and cold weather periods resulting in more frequent and longer duration of ash sluicing.

Suspended solids also appear to exhibit an increasing trend or possibly a yearly cycle. The reason for this may be due to the previously discussed relationship of suspended solids with flow. If this is the case, then, theoretically, suspended solids is not random over a year's period. However, because previous data did not indicate a yearly cycle, the relationship with flow has not been confirmed and for ease of
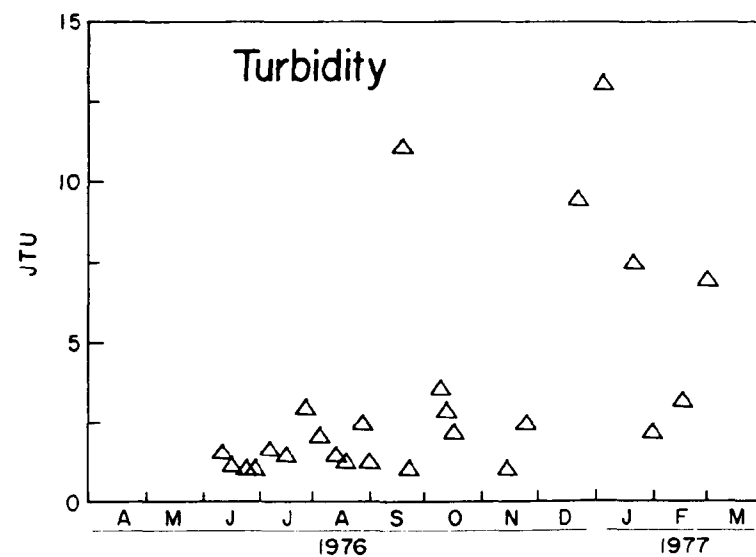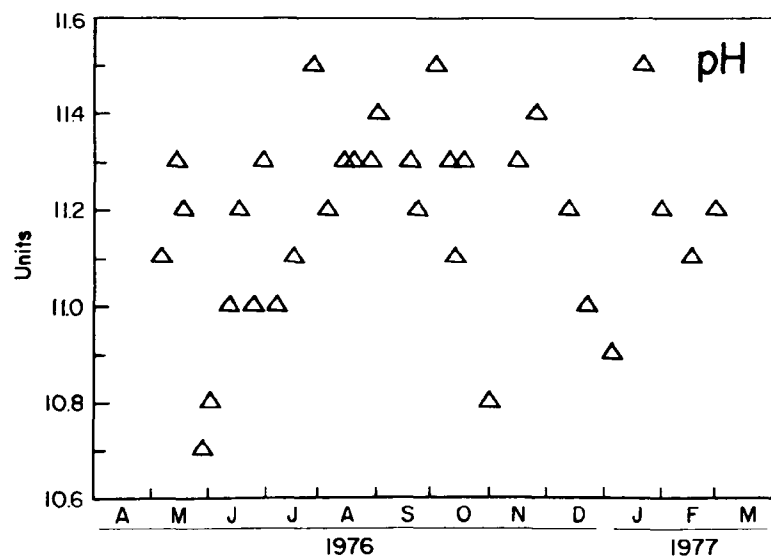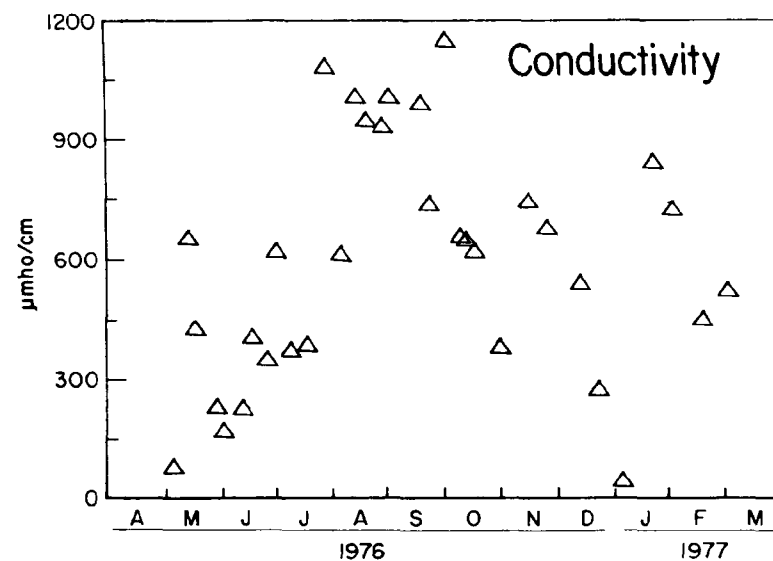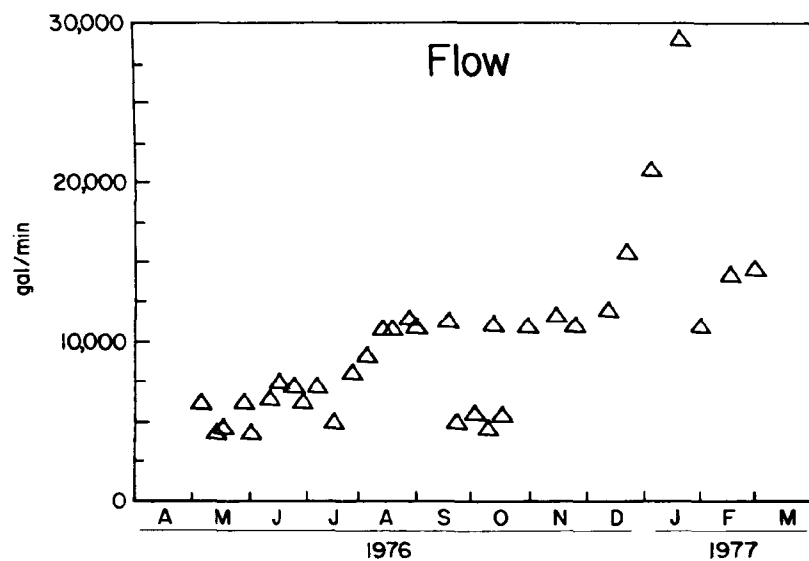
Figure 13. Variation of Ash Pond Effluent Characteristics with Time at Plant E
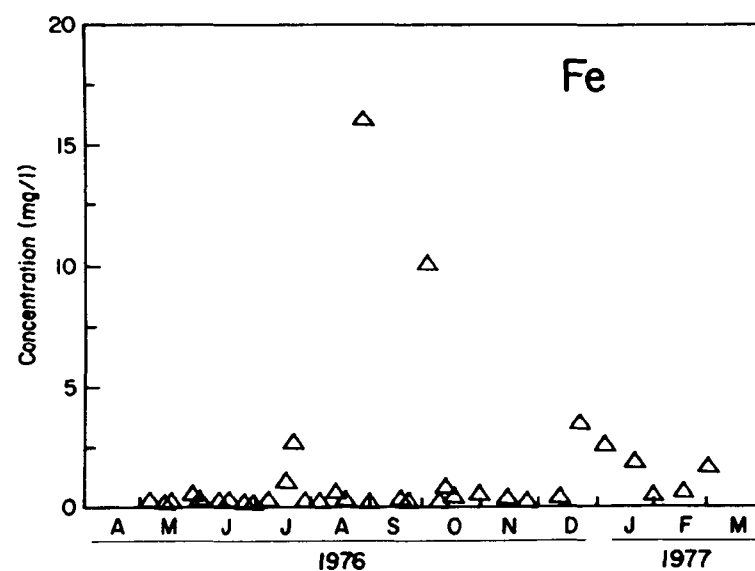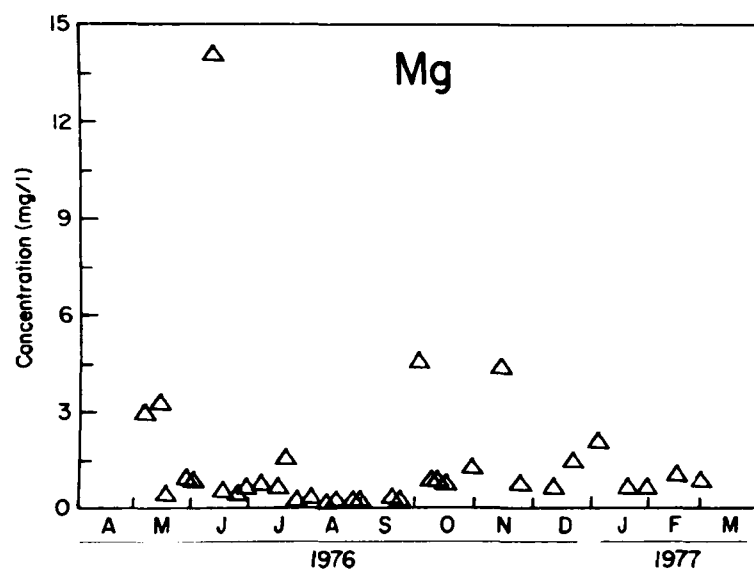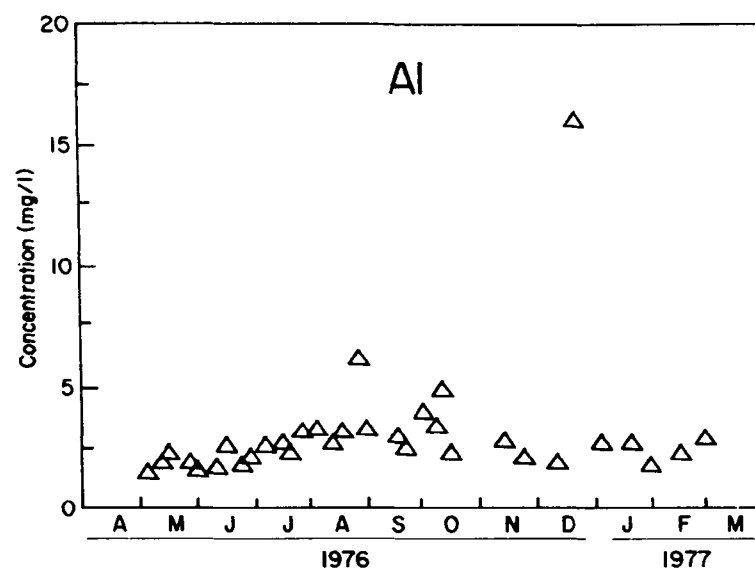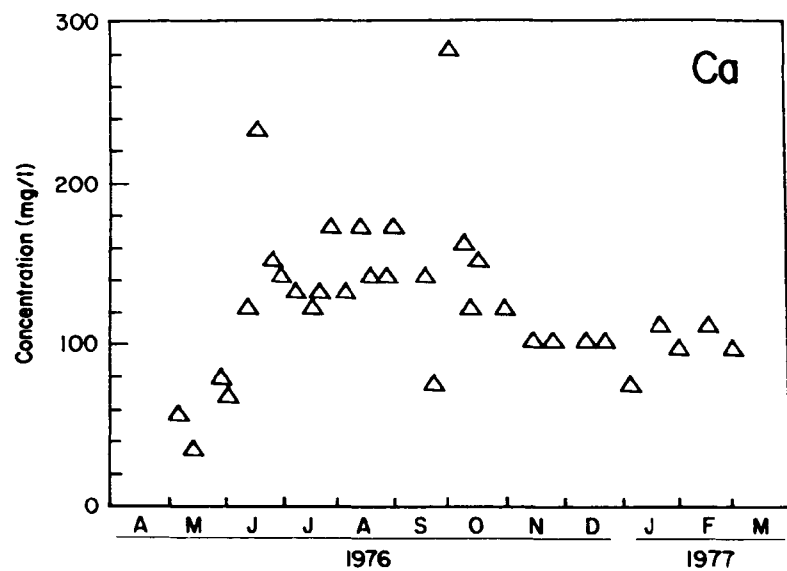
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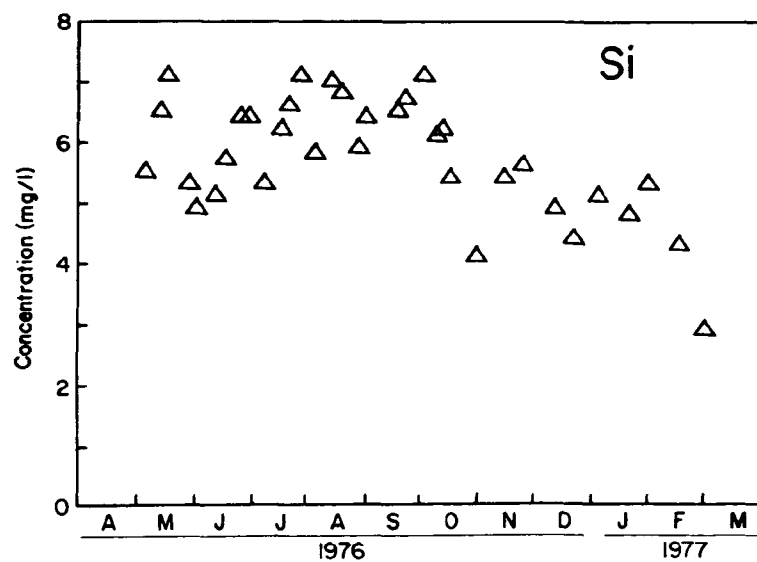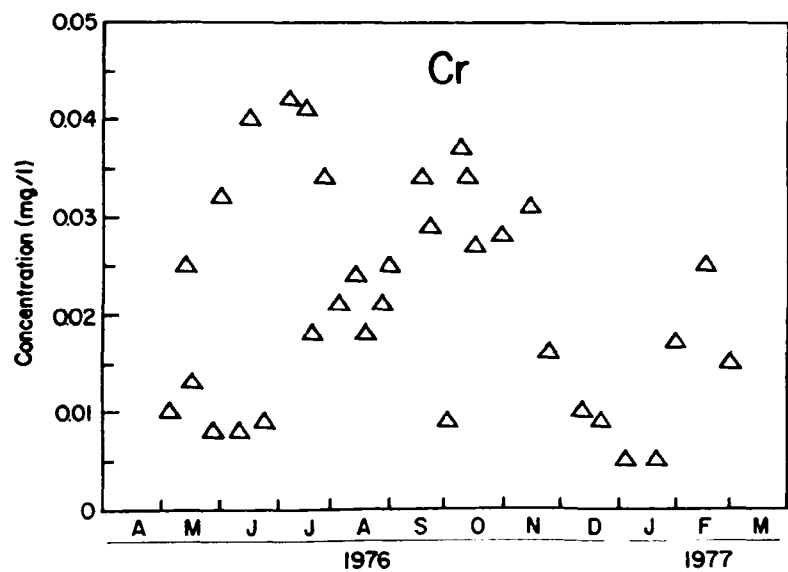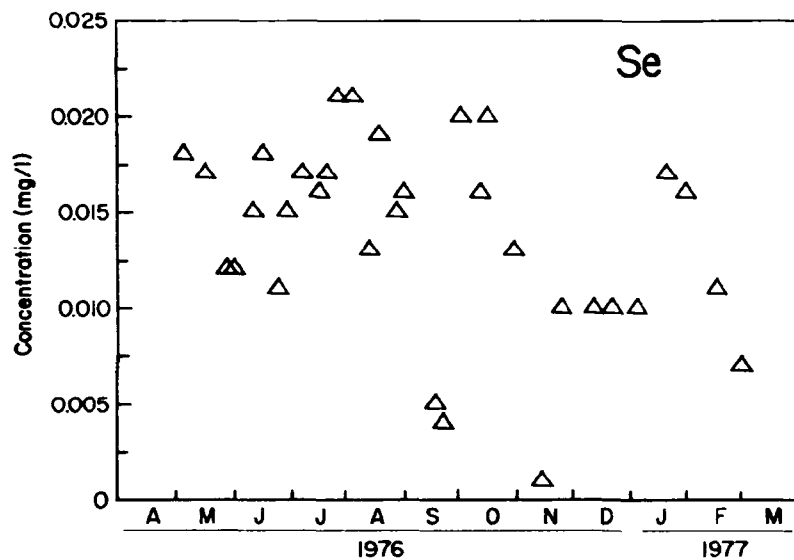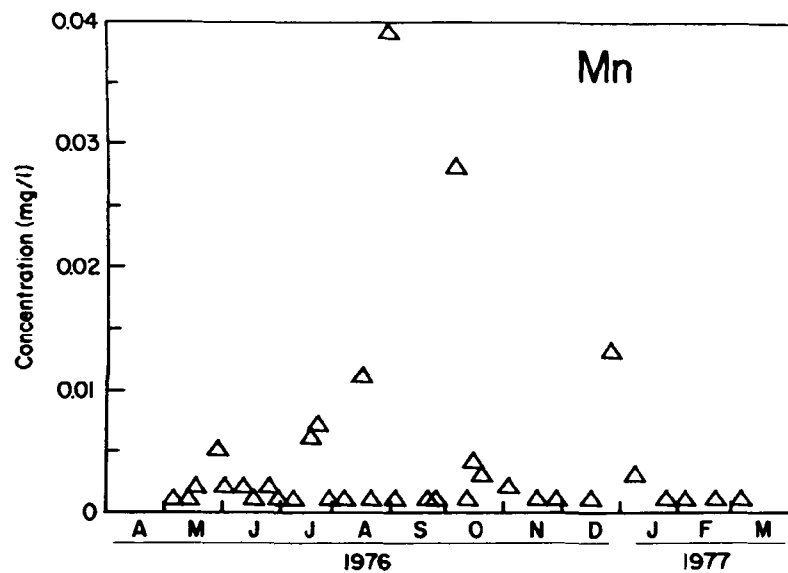
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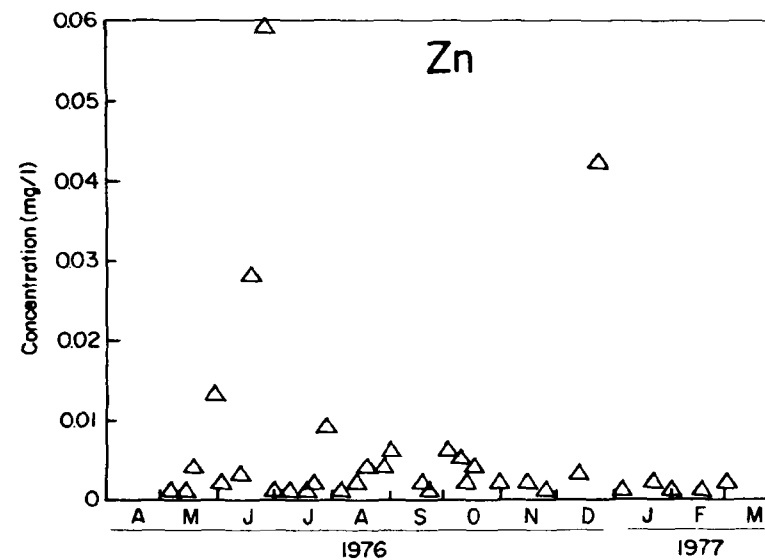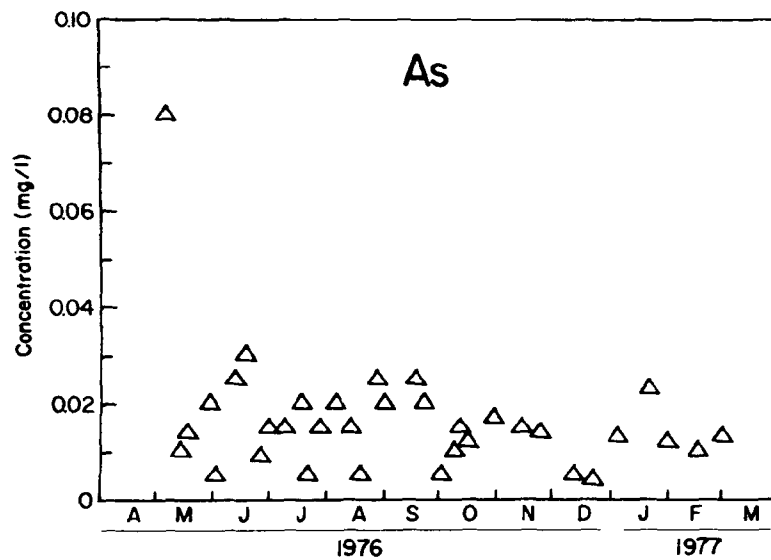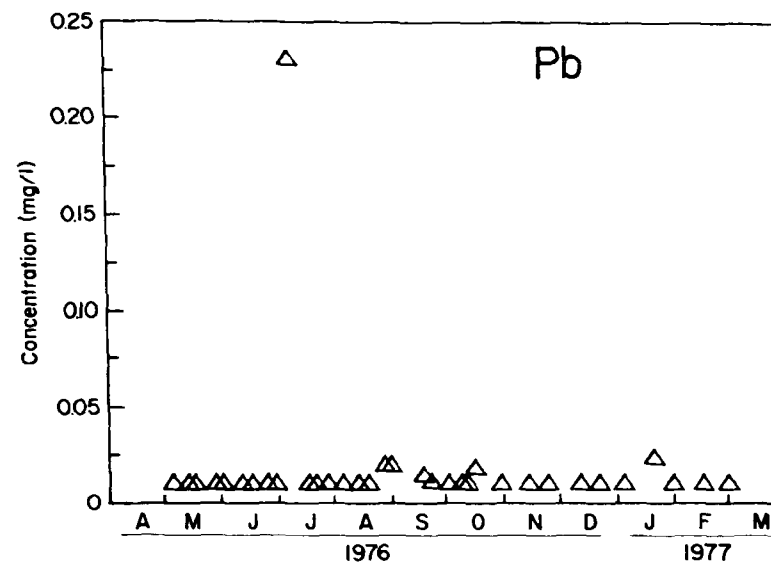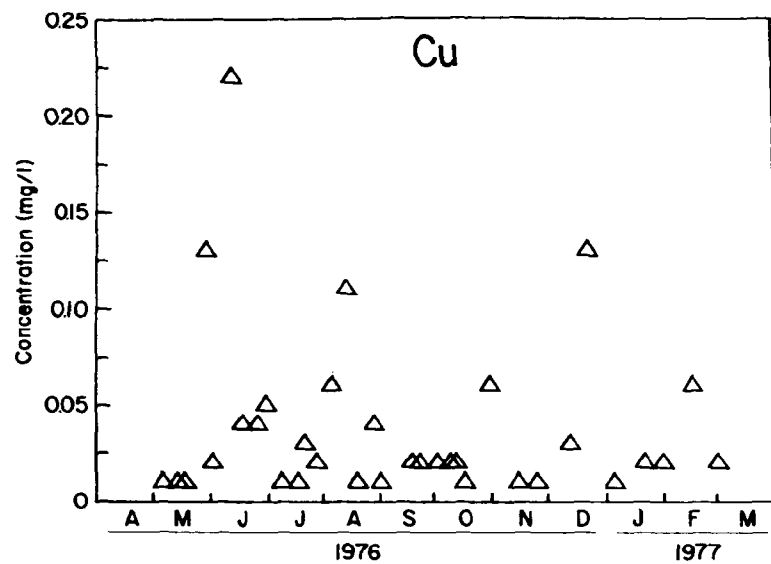
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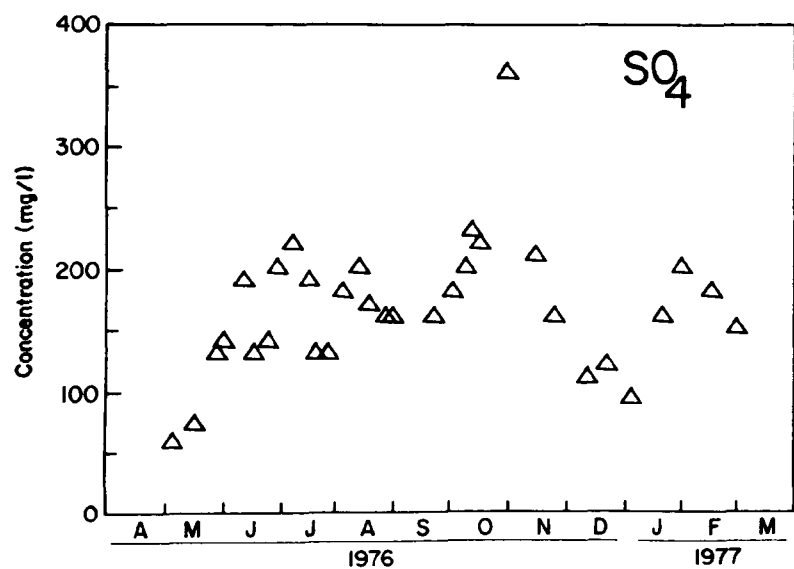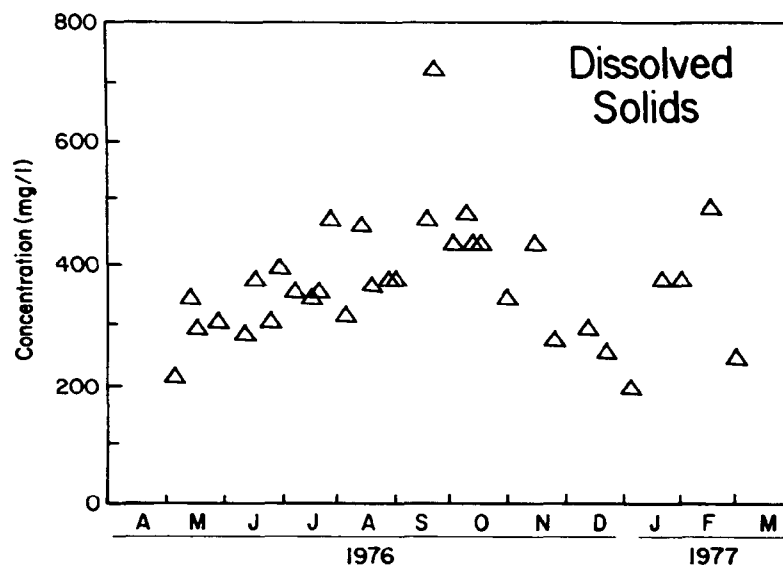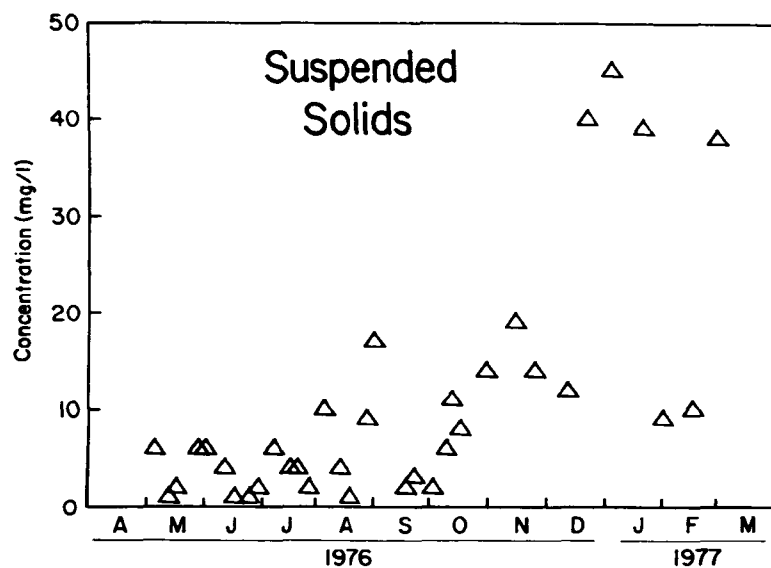
Figure 13 (Continued)

statistical analysis, the variation in suspended solids will be assumed to be random. None of the other ash pond effluent constituents appeared to be cyclic; therefore, they will also be assumed to be random.

By assuming the data to be random, the data set does not need to be divided into smaller data sets because the data can be assumed to estimate the effluent characteristics for almost any time period even though the data were collected over a 10-month period. In other words, the same statistical values, such as the mean and standard deviation, should be expected for 30 samples collected randomly over 30 days as those obtained for 30 samples collected over 365 days. This will be useful later when the objective of the monitoring program is to show compliance over a time period other than 10 months. Such is the case with suspended solids. There are, however, practical limits over the time periods for which the data set given in Table 19 should be used to estimate the effluent characteristics. For example, to use this data to estimate the daily average or 10-year average may not be wise. Other statistical procedures such as those suggested by Box and Jenkins 1970 (10) should be consulted for extrapolations of this magnitude.

STATISTICAL DISTRIBUTION OF THE EFFLUENT CHARACTERISTICS AT PLANT E

Cumulative frequency plots were prepared for the ash pond effluent data given in Table 19 according to the method outlined by Miller and Freund (8). These plots are shown in Figure 14. The best fit straight line was determined by visual placement. In the top row of Figure 14, the data are plotted to the log base ten scale while the data in the bottom row are plotted on an arithmetic scale. The two sets of plots were compared for each parameter to determine which plot of the data yielded the straightest line. This determination was made by visual inspection. If the data in the bottom row were closest to a straight line, then the parameter was assumed to follow a normal distribution. If the data in the top row was closest to a straight line, then the parameter was assumed to follow a lognormal distribution. If there did not appear to be a difference, then a normal distribution was assumed to simplify calculations. Also, for ease of calculation these were the only two distributions considered.

Table 21 lists the various parameters and the assumed distribution based on this comparison. The following parameters were assumed normal: arsenic, chromium, lead, pH, selenium, dissolved silica, and sulfate. The following were assumed lognormal: aluminum, calcium, conductivity, copper, dissolved solids, iron, magnesium, manganese, suspended solids, turbidity, and zinc. These distributions are in agreement with those reported by Berthouex and Meinert (7) for surface waters in the Tennessee Valley. An exception is lead which followed a normal distribution in the ash pond effluent while that in the surface waters in the Tennessee Valley was reported to follow a lognormal distribution. However, a considerable portion of the samples had Pb concentrations below the minimum detectable limit. Table 21 contains additional information which will be discussed in the following subsection.
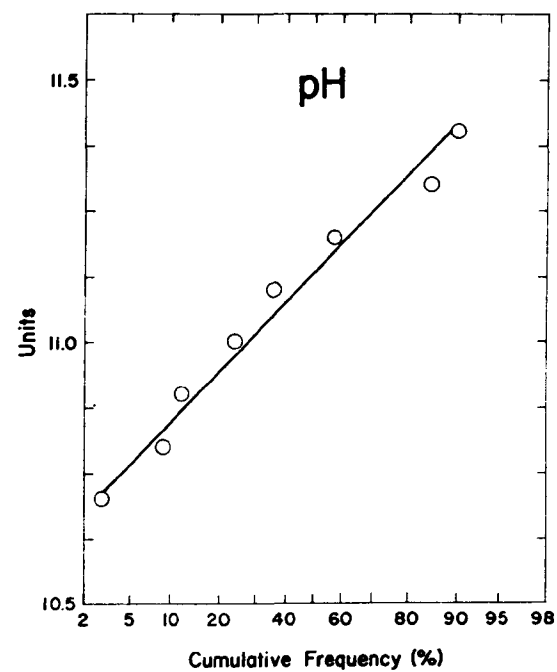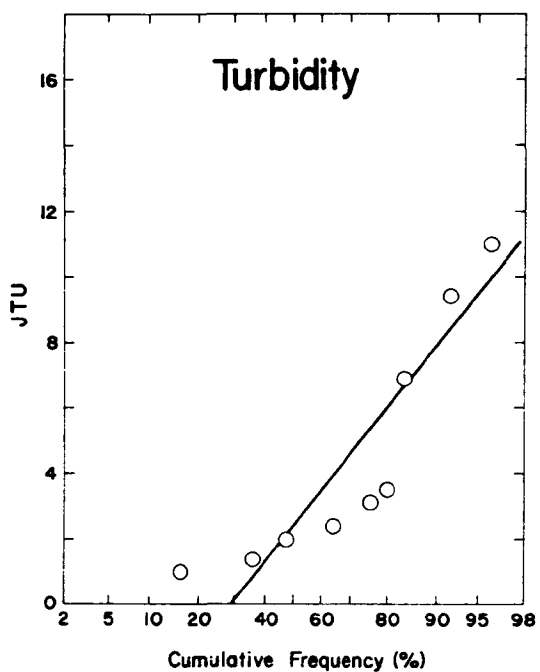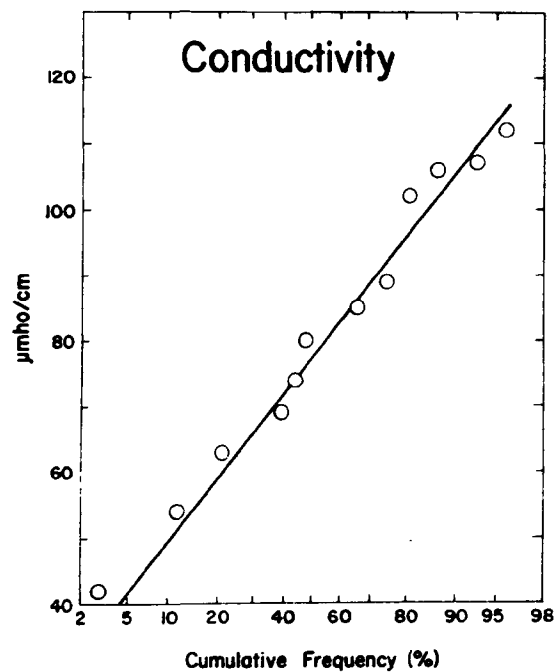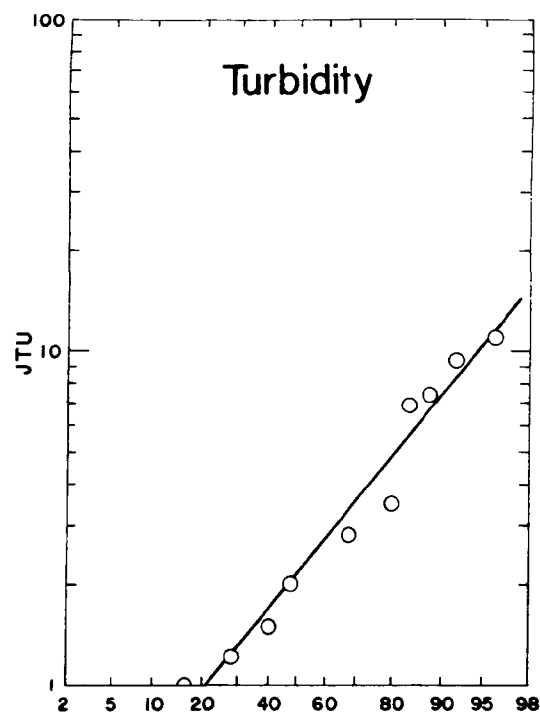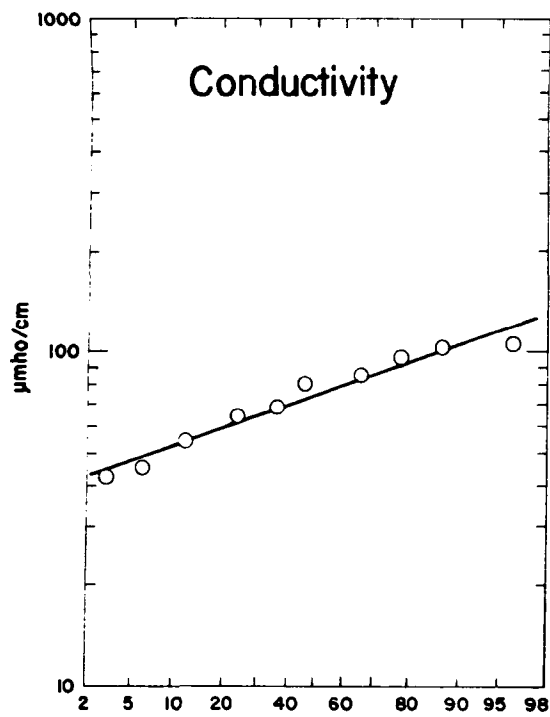
Figure 14. Cumulative Frequency Plots for the Ash Pond Effluent at Plant E
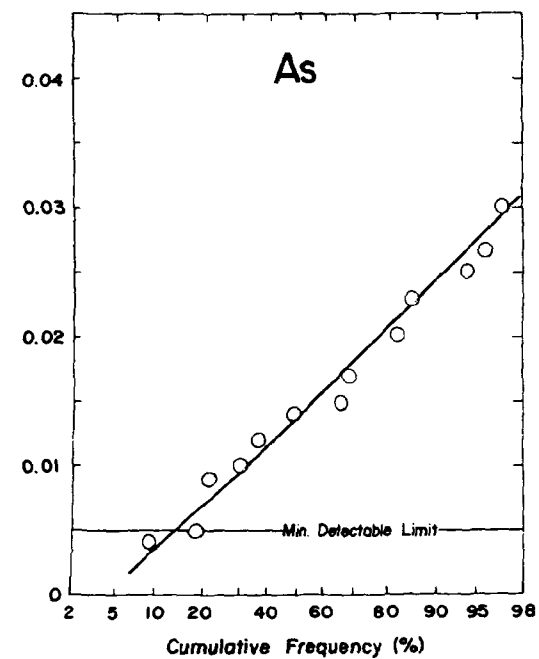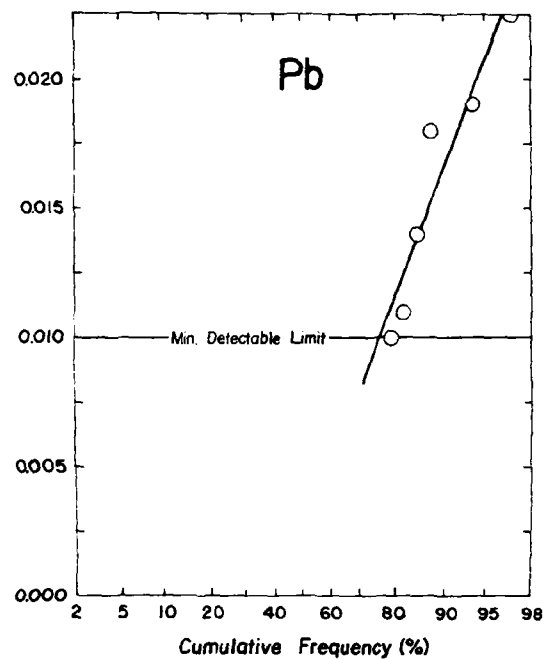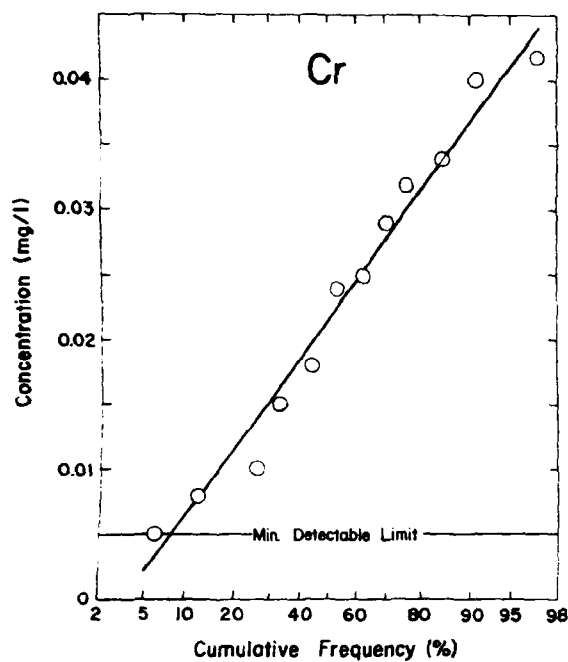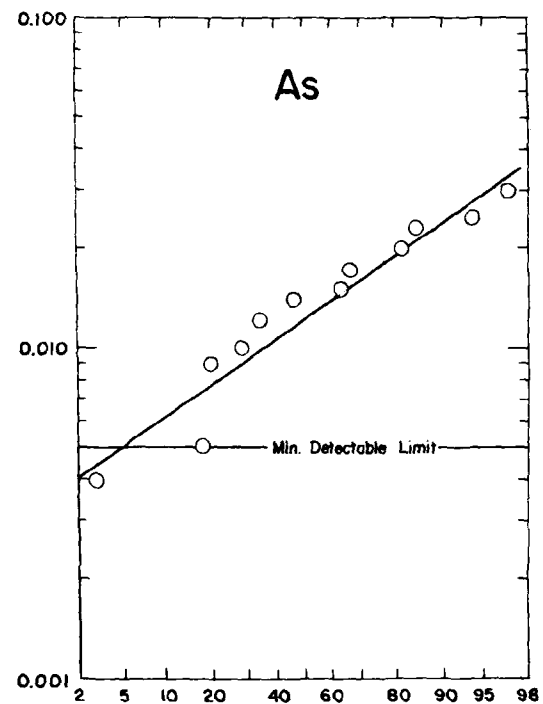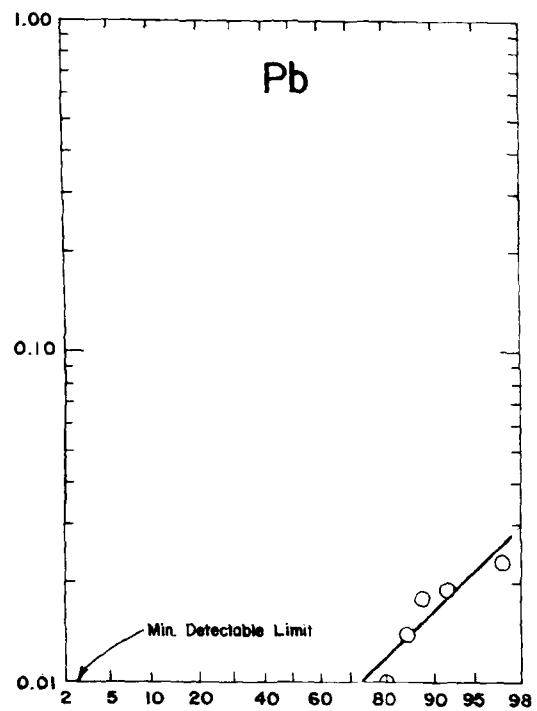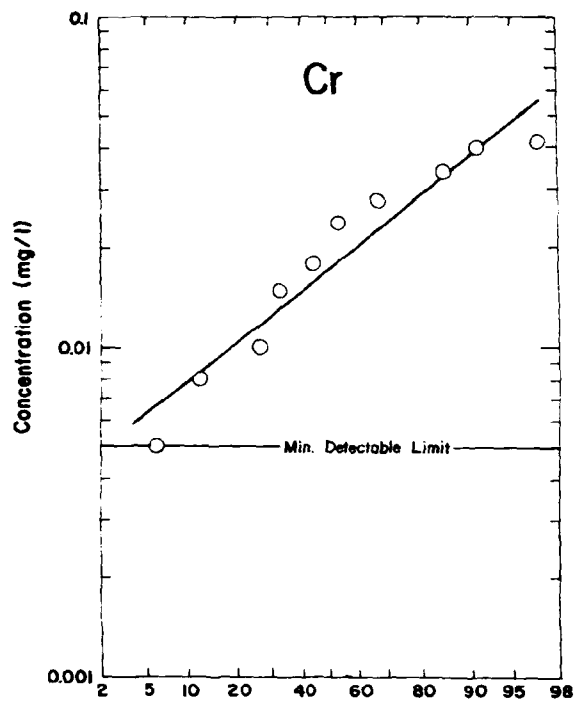
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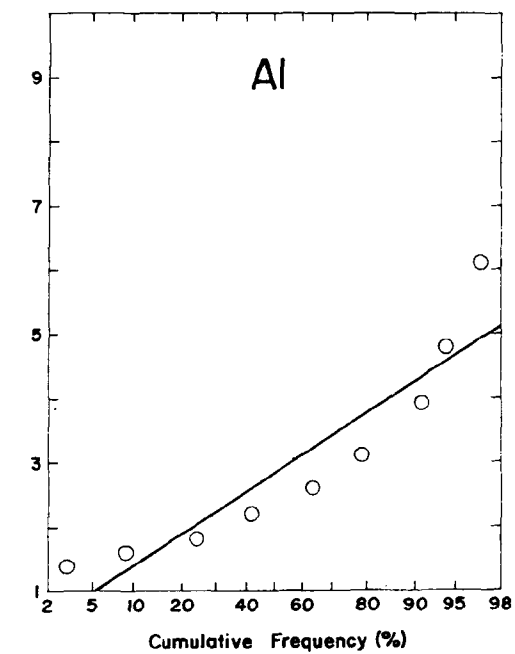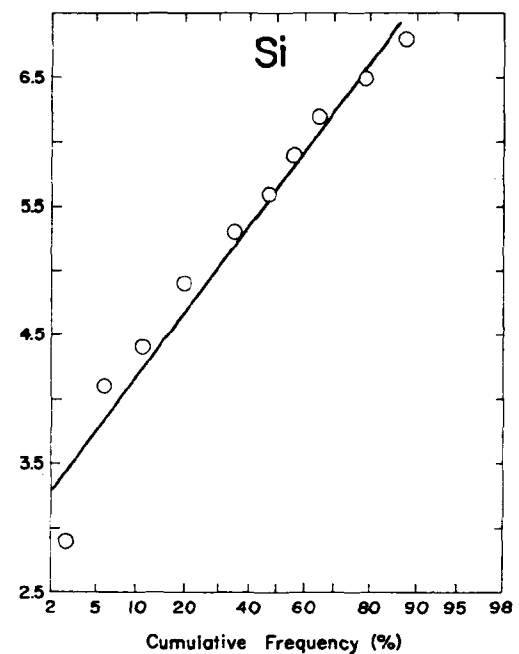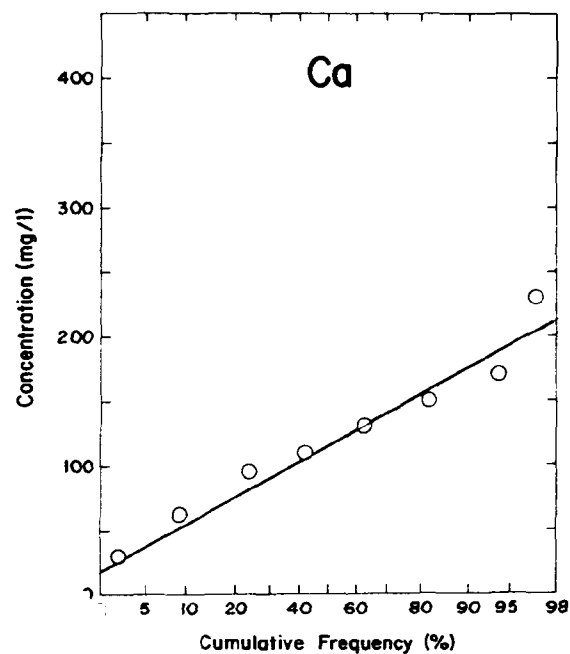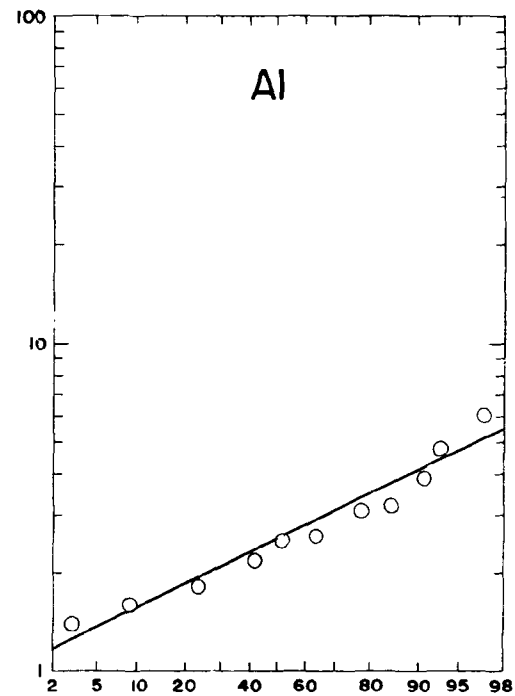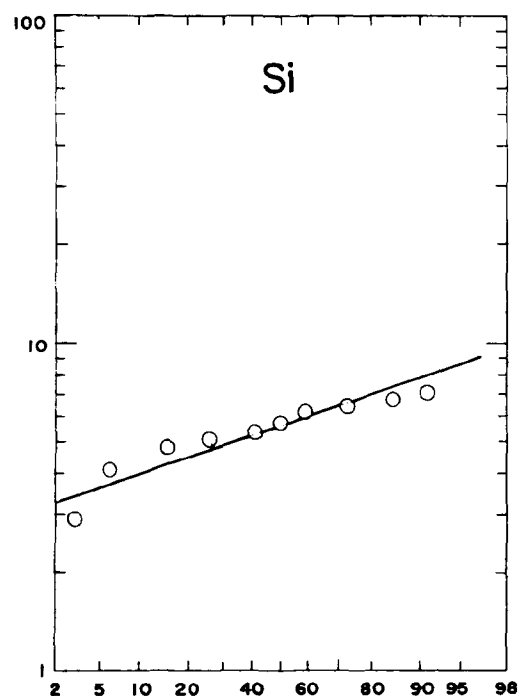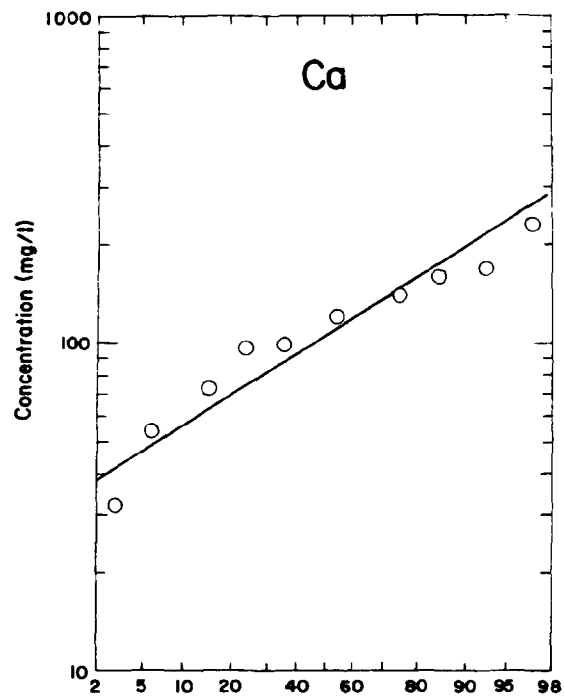
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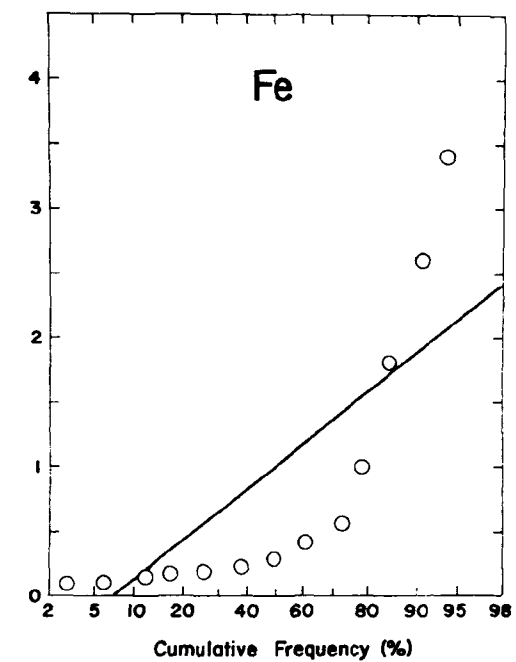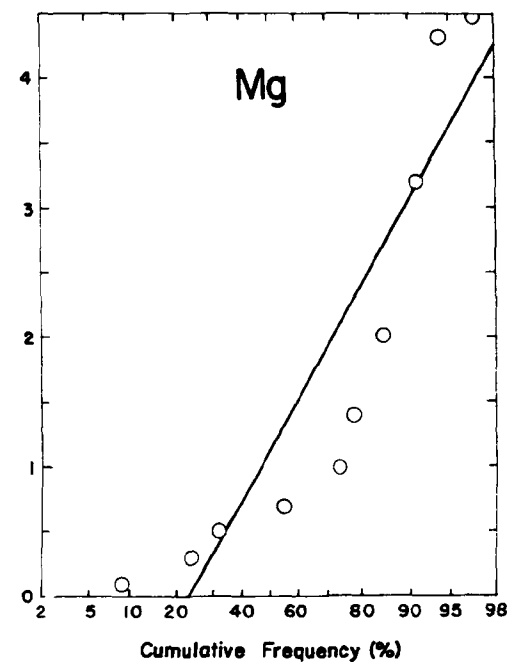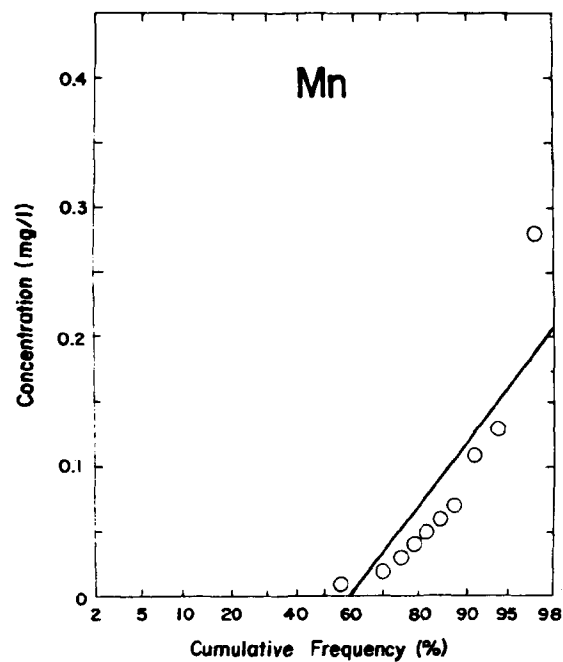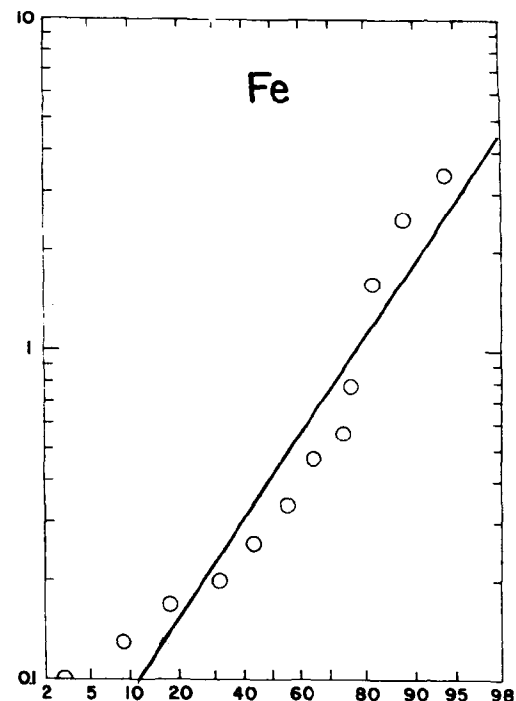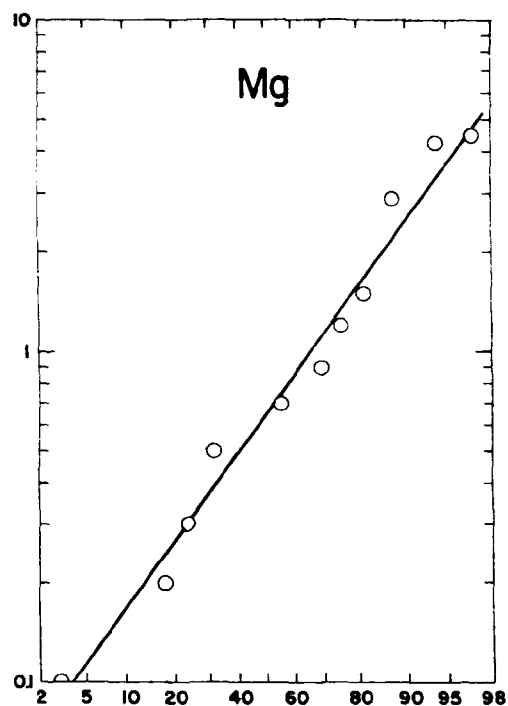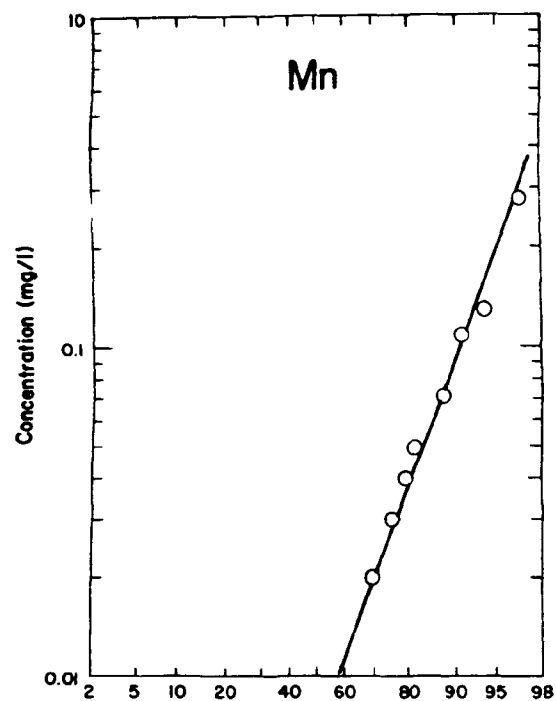
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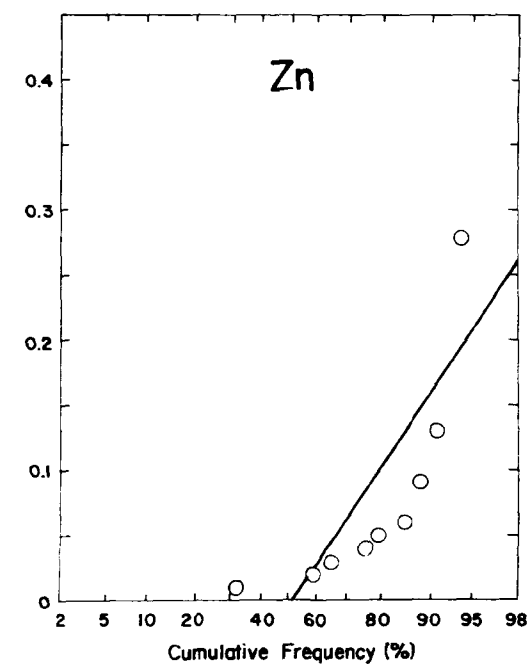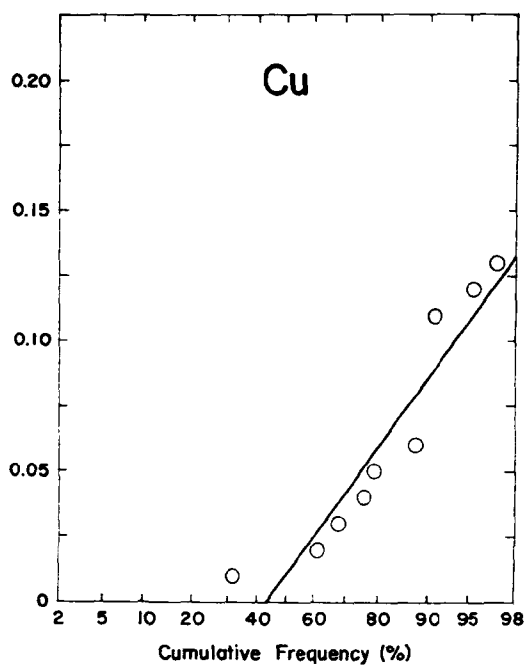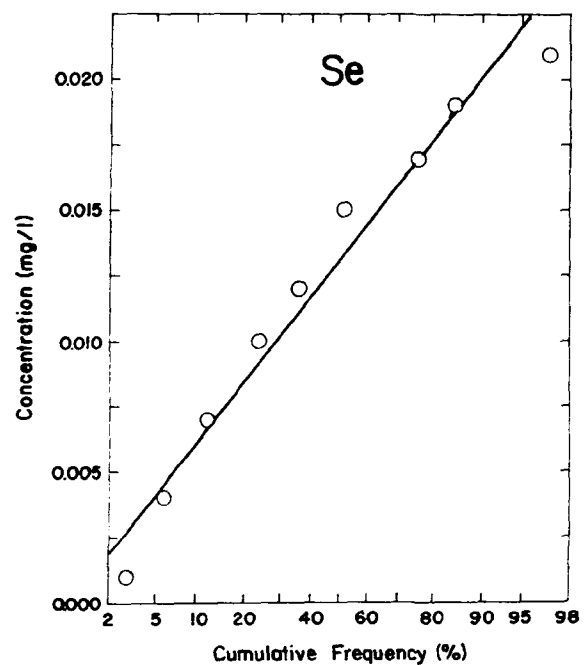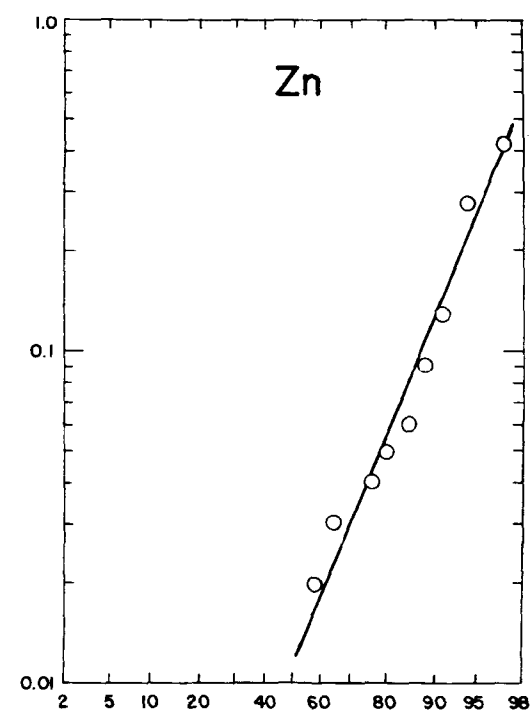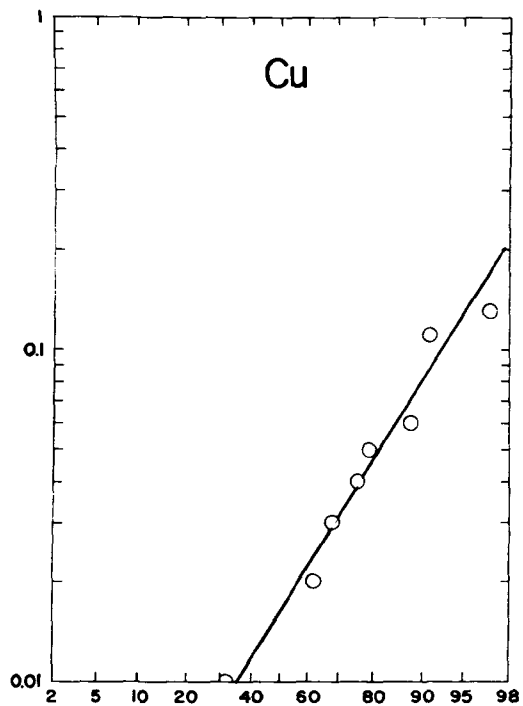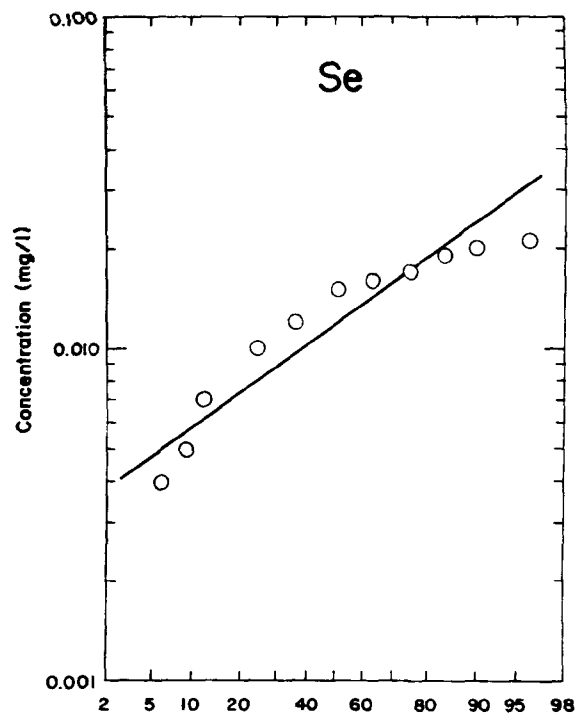
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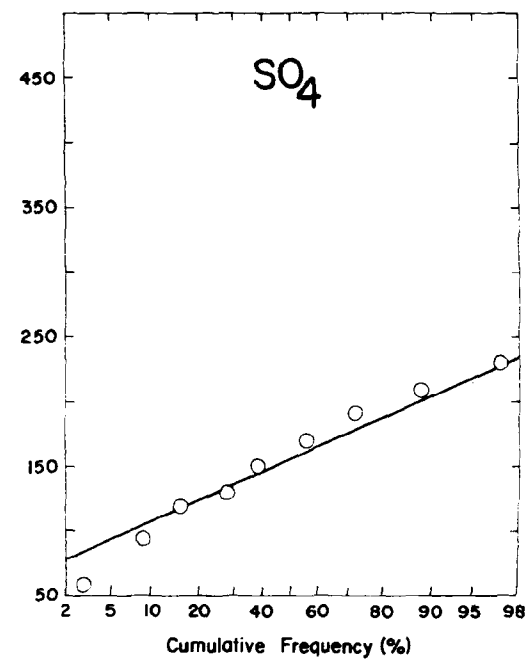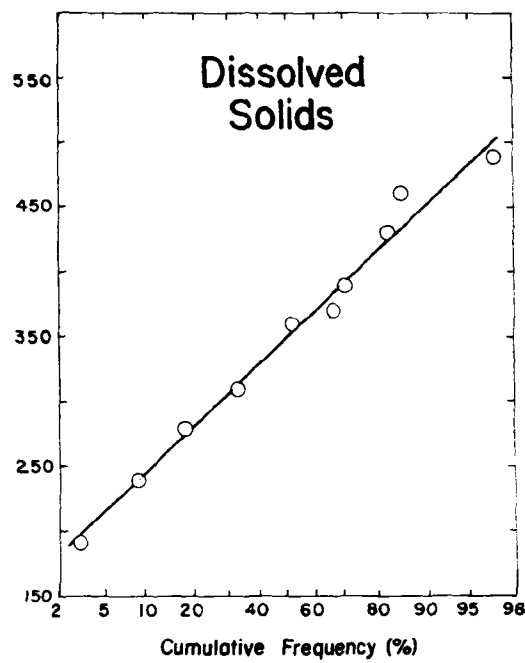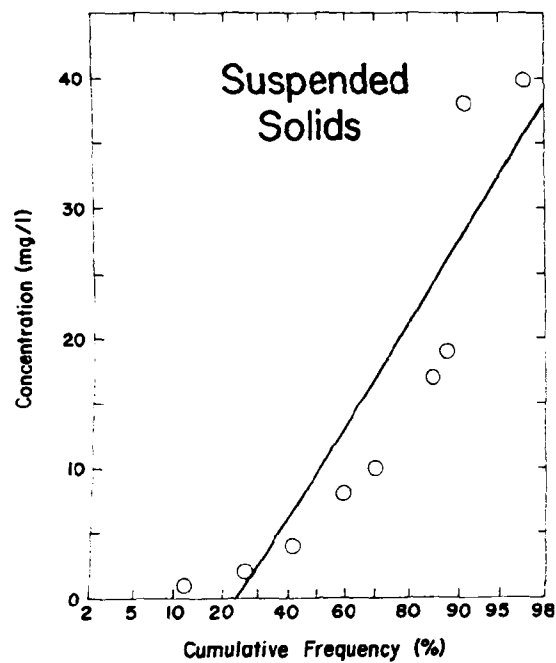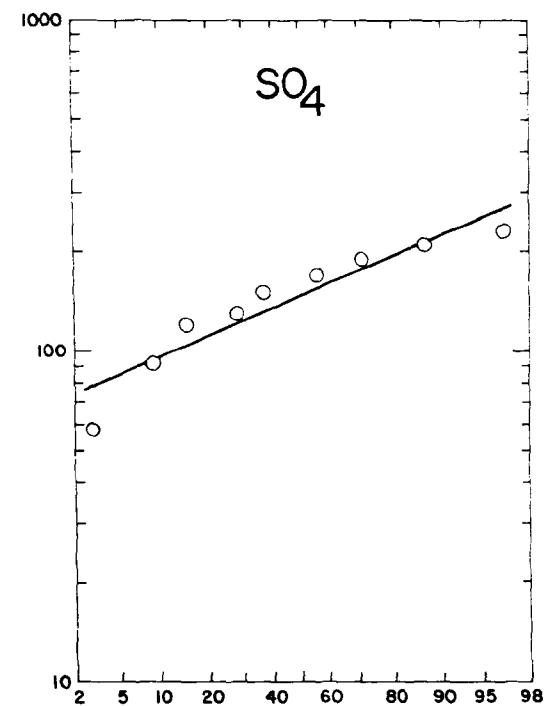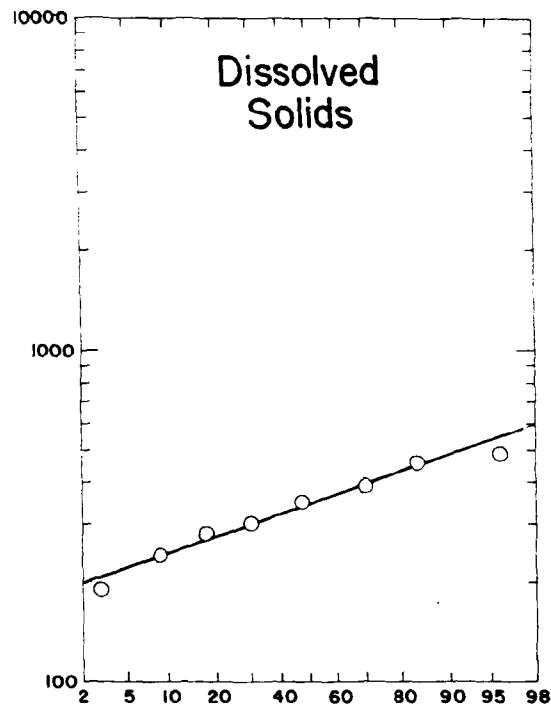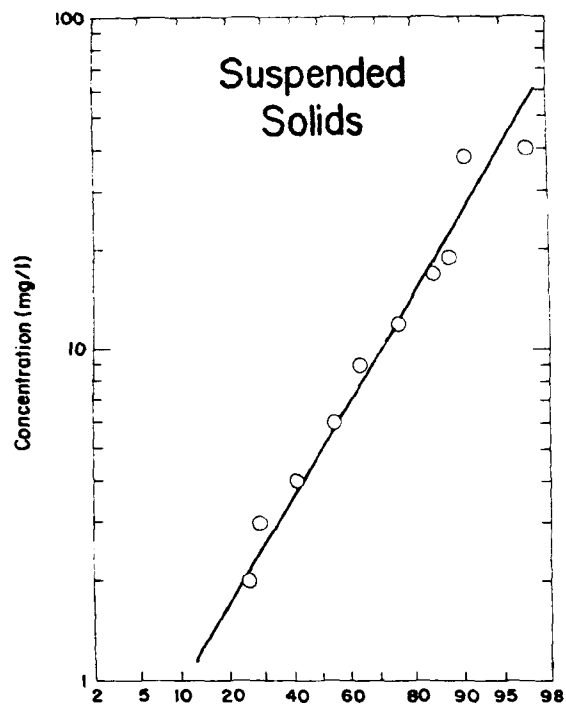
Figure 14 (Continued)

TABLE 21. TYPE OF DISTRIBUTION AND STATISTICAL CHARACTERISTICS OF THE ASH POND EFFLUENT AT PLANT E

Parameters	Type of Distribution	Mean[a]	Variance[a]	Number of Samples	$(S^2)(t^2)$ for various confidence levels[b]		
					99%	95%	80%
Aluminum	Lognormal	0.414	0.0397	33	0.298	0.165	0.068
Arsenic	Normal	0.017	0.0017	34	0.013	0.007	0.003
Calcium	Lognormal	2.061	0.0321	33	0.241	0.133	0.055
Conductivity	Lognormal	1.883	0.0133	33	0.100	0.055	0.023
Chromium	Normal	0.023	0.0015	34	0.011	0.006	0.003
Copper	Lognormal	-1.605	0.1463	34	1.095	0.606	0.250
Dissolved Solids	Lognormal	2.548	0.0137	33	0.103	0.057	0.023
Iron	Lognormal	-0.334	0.2960	34	2.216	1.227	0.506
Magnesium	Lognormal	-0.134	0.2093	34	1.567	0.868	0.358
Manganese	Log Normal	-1.689	0.2042	34	1.529	0.846	0.349
Lead	Normal	0.02	0.0014	34	0.010	0.006	0.002
pH	Normal	11.2	0.0403	33	0.303	0.167	0.069
Selenium	Normal	0.014	0.00003	33	0.0002	0.0001	0.00005
Dissolved Silica	Normal	5.7	0.9573	34	7.167	3.968	1.638
Sulfate	Normal	167	3030	32	22831	12610	5192
Suspended Solids	Lognormal	0.778	0.2298	34	1.720	0.953	0.393
Turbidity	Lognormal	0.374	0.1207	25	0.944	0.514	0.210
Zinc	Lognormal	-1.552	0.2306	34	1.726	0.956	0.395

[a]The values given for lognormal distributions are for the logarithms of the concentrations while those for normal distributions are for the untransformed concentrations.

[b]See equation 3 for definition of $(S^2)(t^2)$.

Tables 22 gives the mean, appropriate ash pond effluent limitation or proposed water quality criteria and the probability that these limitations or criteria are exceeded for the effluent parameters assuming a normal distribution. Table 23 gives the mean of the logarithms of the concentrations, the logarithm of the geometric mean, appropriate ash pond effluent limitation or proposed water quality criteria and the probability that these limitations or criteria are exceeded for the effluent parameters assuming a lognormal distribution. The mean of the logarithms of the concentrations and the logarithm of the geometric mean different slightly because the geometric mean was determined from the appropriate cumulative frequency plot in Figure 14. All calculations for lognormal distributions will be based on the values given in Table 23 for the logarithm of the geometric mean.

For most of the elements, less than 5 percent of the samples were below their minimum detectable limit. Lead was an exception, however, with 80 percent of the samples being below the minimum detectable limit of 0.01 mg/1.

The effluent limitations given in Tables 22 and 23 for pH and suspended solids are those outlined for the steam-electric power generating industry by EPA in 1974 (1) for the achievement, by 1977, of best practical control technology currently available (BPCTCA). The pH is to be maintained between 6 and 9 and the average daily suspended solids for a 30-day period is to be below 30 mg/1 with a daily maximum less than 100 mg/1. Since limitations for the ash pond effluents at Plant E for the remaining elements have not yet been promulgated, the criteria specified in EPA's "Water Quality Criteria" (10) for dometic water supply intakes are used. A list of the criteria are given in Appendix C. This does not suggest that the ash pond effluent should meet these criteria because the effluent is diluted between 20 and 80 times with the condenser cooling water before final discharge. They are only given for comparison purposes and as an aid in establishing the desired precision for the future monitoring program. The data in Tables 22 and 23 shows that greater than 98 percent of the time the pH is greater than 9, whereas only 9 percent of the time the suspended solids are above 30 mg/1. Less than 2 percent of the samples had concentrations of arsenic, chromium, lead, sulfate, copper, and zinc above the domestic water supply criteria proposed by EPA. However, for selenium, iron, and manganese, 70, 60, and 19 percent of the samples, respectively, were above the domestic water supply criteria.

ESTIMATION OF THE MEAN AS A FUNCTION OF THE PRECISION

The number of samples, n, required to estimate the mean as a function of L was plotted for each parameter based on the data given in Table 21 and equation 3. The results are shown in Figure 15. They were constructed by dividing the values shown under the column labeled "$(S^2)(t^2)$" in Table 21 by various values of $(L)^2$ to yield various sample sizes, n. The values for $(S)^2(t)^2$ given in Table 21 were obtained by multiplying the various, S^2, times the appropriate t value squared. The values used for t are a function of the confidence level and number of data points used to generate the variance. The t values necessary for calculating the $(S)^2(t)^2$ values in Table 21 are given in Appendix D.

TABLE 22.   COMPARISON OF THE ASH POND EFFLUENT CHARACTERISTICS
FOLLOWING A NORMAL DISTRIBUTION AT PLANT E WITH ASH POND EFFLUENT
LIMITATIONS OR WATER QUALITY CRITERIA (BASED ON DATA COLLECTED
PRIOR TO JANUARY 1978)

Parameter	Mean of the Concentrations (mg/l)	Standard or Water Quality Criteria (mg/l)	Frequency that Standard is Exceeded %
Arsenic	0.017	0.05[a]	<2
Chromium	0.023	0.05[a]	<2
Lead	0.02	0.05[a]	<2
pH	11.2	6 to 9[b]	>98
Selenium	0.014	0.01[a]	70
Dissolved Silica	5.7	c	-
Sulfate	167	250[a]	<2

[a]Proposed EPA intake standards for domestic drinking water supplies (EPA 1976).

[b]Effluent limitation specified in the NPDES permit. Units are standard units.

[c]No criteria proposed for drinking water supplies.

TABLE 23. COMPARISON OF THE ASH POND EFFLUENT CHARACTERISTIC FOLLOWING
A LOG NORMAL DISTRIBUTION AT PLANT E WITH ASH POND EFFLUENT LIMITATIONS
OR WATER QUALITY CRITERIA (BASED ON DATA COLLECTED PRIOR TO JANUARY 1978)

Parameter	Mean of the Logarithms of the Concentrations[a]	Logarithms of the Geometric Mean[b]	Standard or Water Quality Criteria (mg/l)	Probability that Standard is Exceeded
Aluminum	0.414	0.407	b	-
Calcium	2.061	2.050	c	-
Conductivity	1.883	1.870	c	-
Copper	-1.605	-1.778	1.0	<2
Dissolved Solids	2.548	2.531	c	-
Iron	-0.334	-0.370	0.3[d]	60
Magnesium	-0.134	-0.148	c	-
Manganese	-1.689	-2.111	0.05[d]	19
Suspended Solids	0.778	0.704	30[e]	9
Turbidity	0.374	0.370	c	-
Zinc	-1.552	-1.926	5[d]	<2

[a]Values given are logarithms to the base 10 of the concentrations in mg/l.

[b]Values given are the logarithms to the base 10 of the estimated geometric mean in mg/l.

[c]No criteria proposed for drinking water supplies.

[d]Proposed EPA intake standards for domestic drinking water supplies (EPA 1976).

[e]Effluent limitations specified in the NPDES permit.
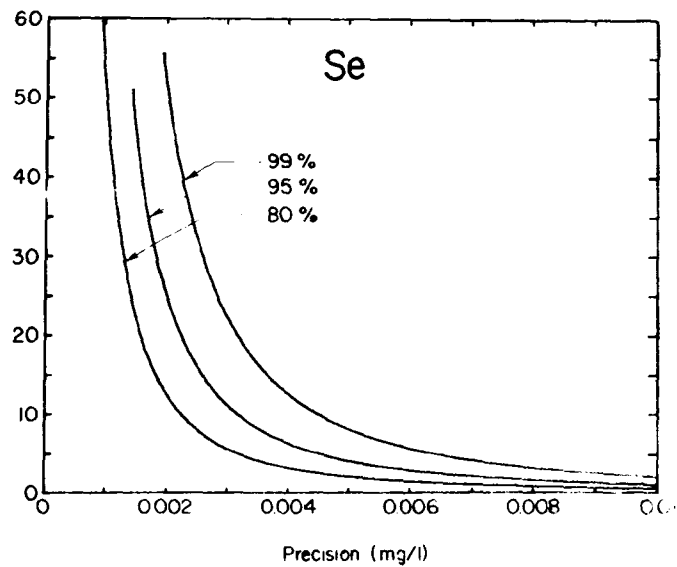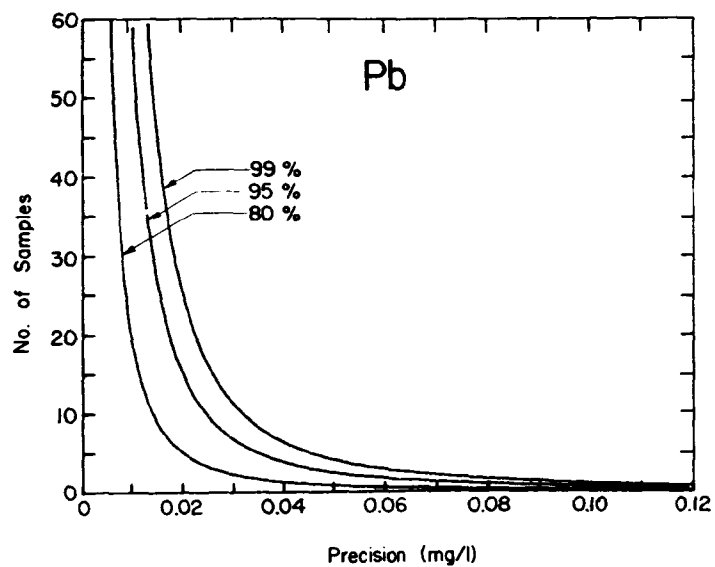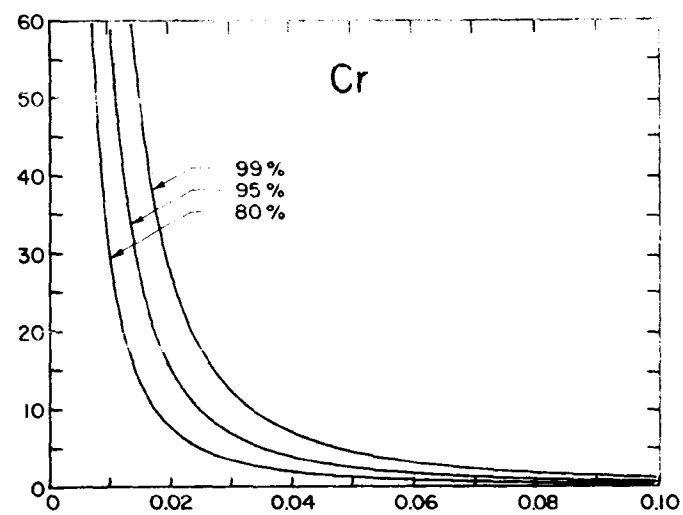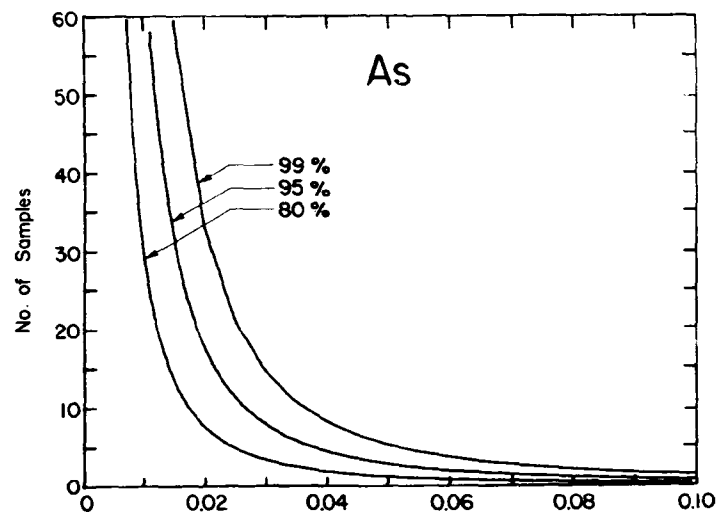
Figure 15. Number of Samples Required for a Given Precision for the Plant E Ash Pond Effluent
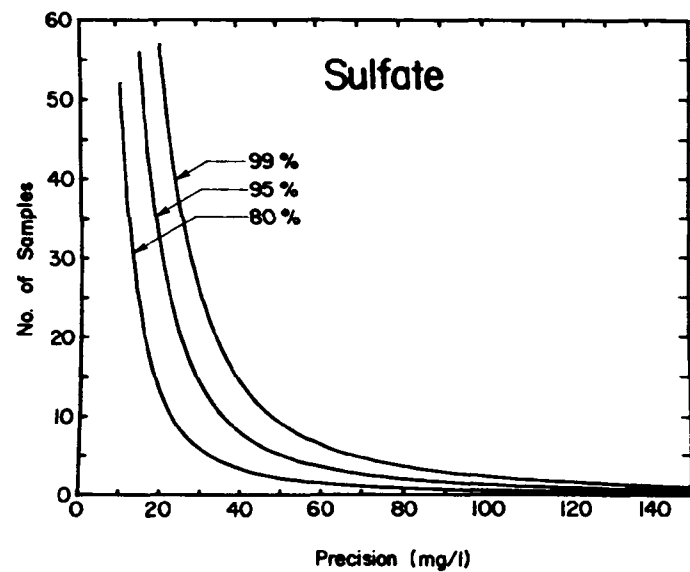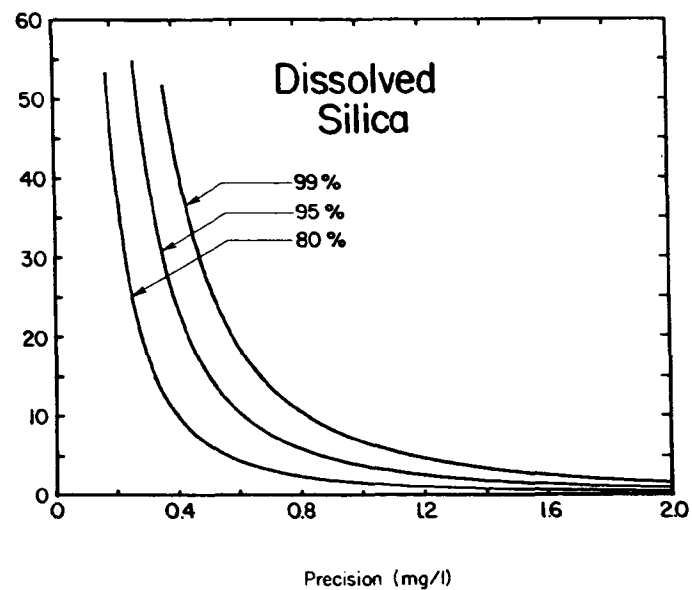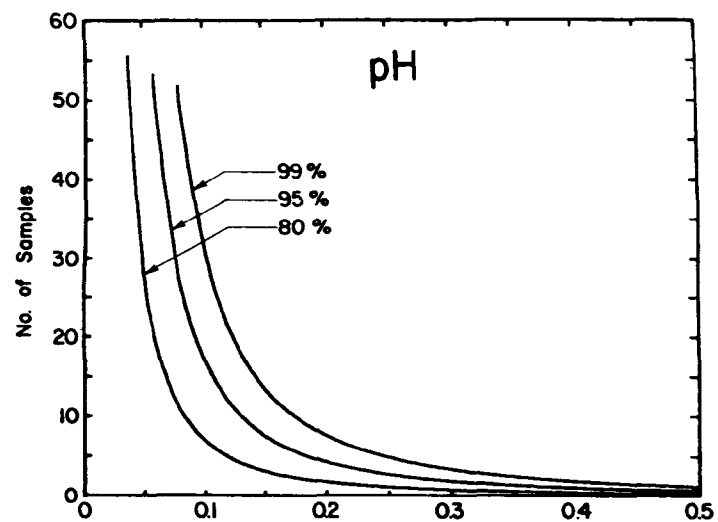
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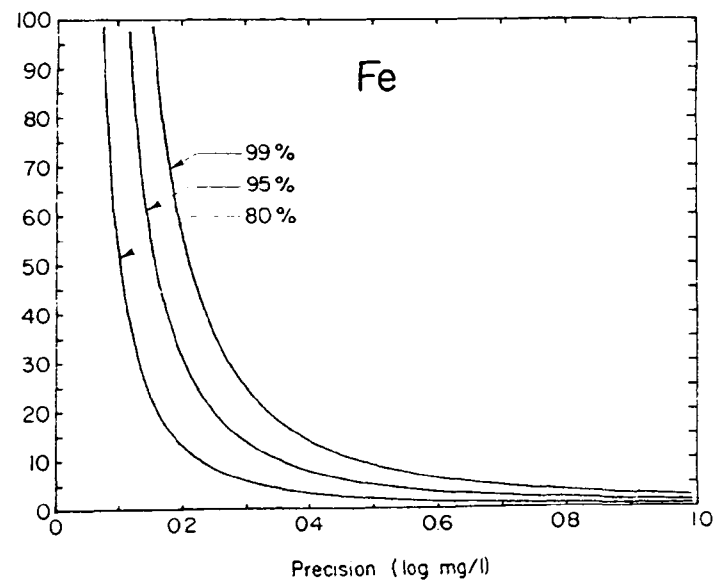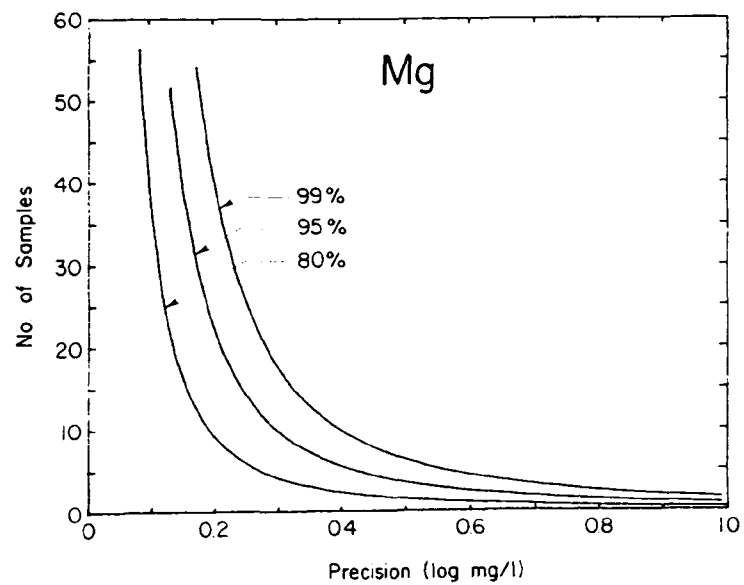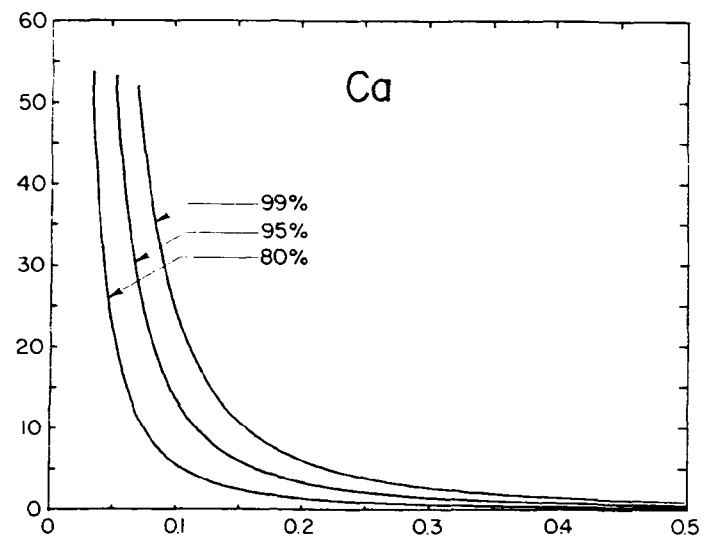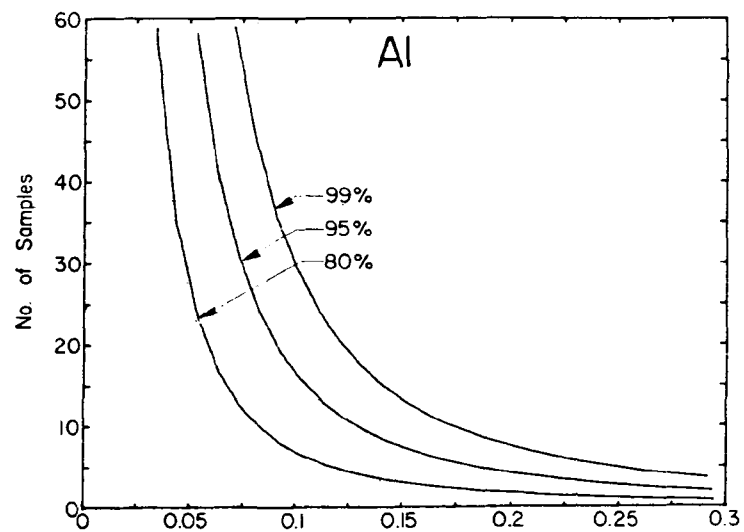
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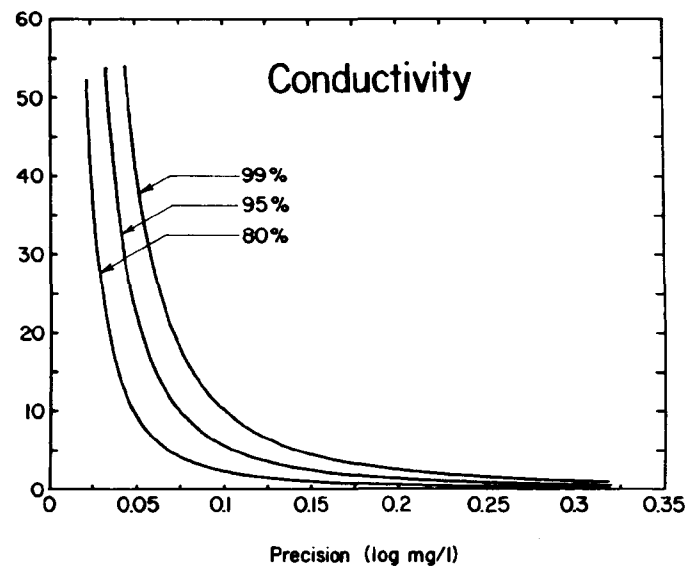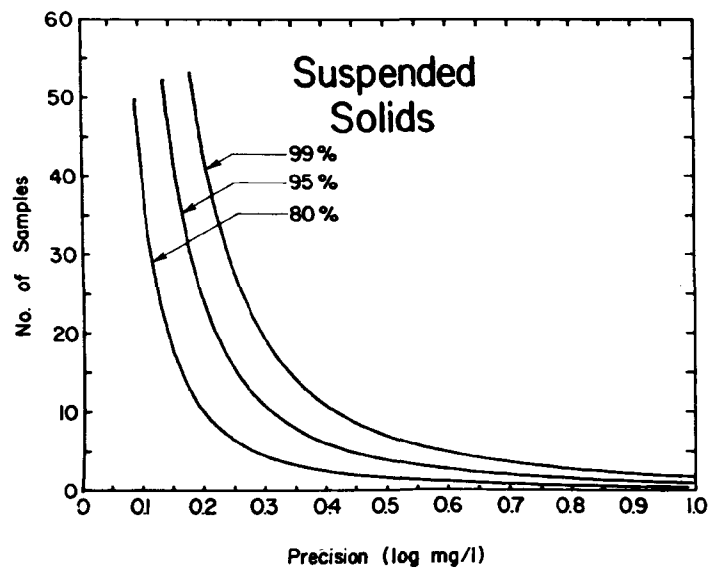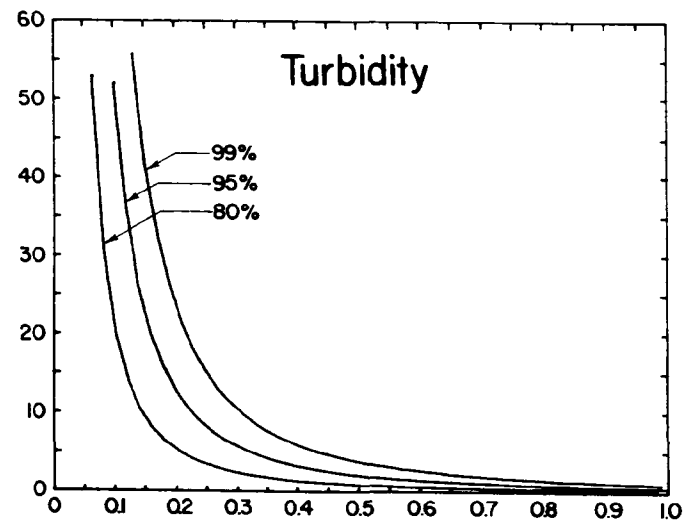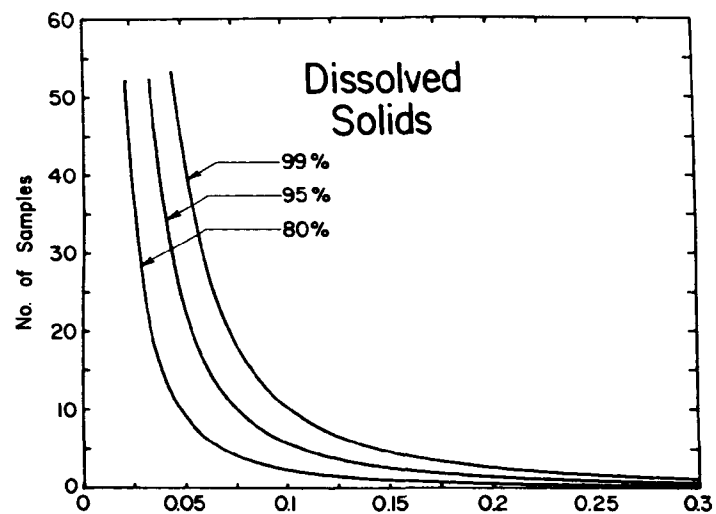
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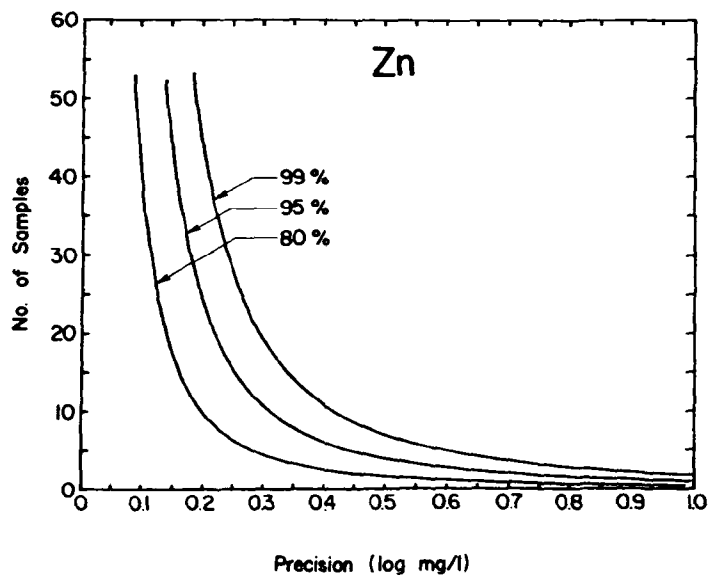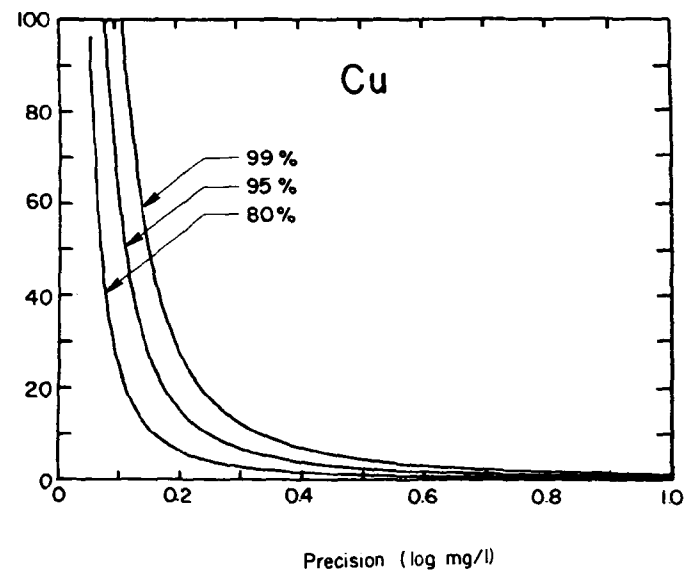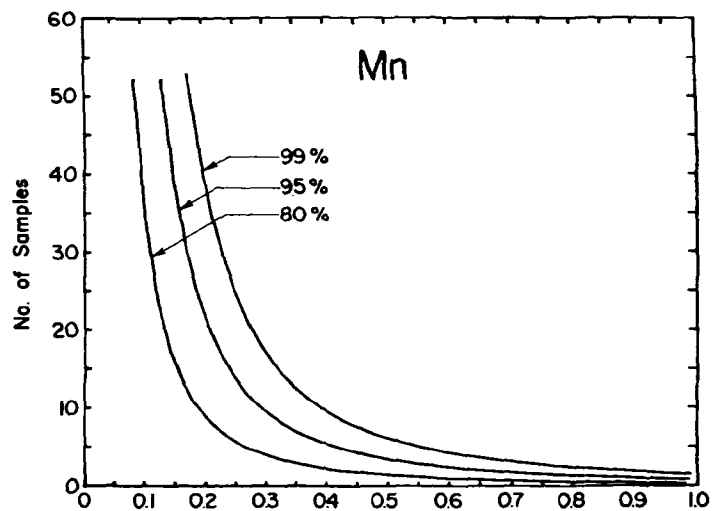
Figure 15 (Continued)

SELECTION OF THE PRECISION

The upper and lower limits (ℓ_1 and ℓ_2) for the critical range of the precision at the 99 percent confidence level for the ash pond effluent characteristics at Plant E are given in Table 24. The upper limit given is for the precision produced by one sample. However, for all elements except for selenium and aluminum, the curve had become asymptotic to the x-axis at a precision less than the upper limit given in Table 24. Therefore, for some elements, the upper limit given in Table 24 is not shown in Figure 15. They were calculated using equation 3. In some cases, the difference in the precision between one and two samples may be significant. For example, the precision for As at one sample is 0.114 mg/l, whereas at two samples it is 0.081 mg/l. However, the upper limit of the critical range was given based on one sample because that precision may be adequate for the monitoring program. The lower limit given is for the precision produced by 52 samples or where the curve becomes asymptotic to the y-axis, whichever gives the larger value of L. Determining the lower limit in this manner, assumes resources are not available for the collection or analysis of more than 52 samples in any one sample period. The curve in Figure 15 had not become asymptotic to the y-axis at 52 samples for any of the ash pond effluent charac-teristics, and therefore the lower limits given in Table 24 were determined based on the assumed availability of resources. If the value of the precision required for the monitoring program is greater than the upper limit, then only one sample per period needs to be collected. However, if the precision value is less than the lower limit, then 52 samples per period would be collected. If for some reason the precision for 52 samples is not adequate for an element of a monitoring program, then a decision would have to be made as to whether or not to increase the level of resources allocated to the monitoring program. If the required precision is between the limits, then the data in Figure 15 would be consulted to determine the number of samples. Therefore, the information in Table 24 gives valuable insight into the importance of the required precision on the design of an ash pond effluent monitoring program for Plant E.

Suspended solids and pH are the only parameters included in this study for which ash pond effluent limitations have been set for Plant E. Use of the design procedure discussed in Section 3 to show compliance can, therefore, only be applied to suspended solids. The procedure requires that the effluent be in compliance, and Figure 14 shows that greater than 98 percent of the time the pH is greater than the effluent limitation of 9. However, suspended solids is only above the effluent limitation 9 percent of the time. Therefore, the precision required for suspended solids can be determined by subtracting the logarithm of the geometric mean of the concentrations given in Table 19 for suspended solids (0.704, see Table 23) from the logarithm of the effluent limita-tion (log 30 = 1.477). This yields a value of 0.773 for the required precision or deviation from the true mean.

Defining the precision which should be used to design the moni-toring program at Plant E is difficult where effluent limitations have not yet been promulgated. One method is to assume some precision based on a given percentage of the sample mean. For comparison purposes,

TABLE 24. UPPER AND LOWER LIMITS FOR THE CRITICAL RANGE OF
THE PRECISION FOR THE EFFLUENT CHARACTERISTICS OF PLANT E

Element	Lower Limit of L (mg/l)	Upper Limit of L (mg/L)
Elements Following A Normal Distribution		
Arsenic	0.016	0.114
Chromium	0.015	0.105
Lead	0.014	0.100
pH	0.076	0.550
Selenium	0.002	0.014
Dissolved Silica	0.37	2.68
Sulfate	21	151
Elements Following A Lognormal Distribution		
Aluminum	0.076	0.546
Calcium	0.068	0.490
Conductivity	0.043	0.316
Copper	0.145	1.046
Dissolved Solids	0.045	0.321
Iron	0.206	1.489
Magnesium	0.174	1.25
Manganese	0.171	1.24
Suspended Solids	0.182	1.31
Turbidity	0.135	0.97
Zinc	0.182	1.31

sampling frequencies based on estimating the yearly mean within 10 and 20 percent of the true mean at the 99 and 80 percent significance levels will be discussed in the next subsection. Another method for establishing the precision is to allow for a certain level of pollutant loading to the receiving stream. This cannot be done without some estimate of the receiving stream water quality before addition of pollutants. Therefore, the water quality characteristics shown in Table 25 will be assumed for the stream receiving the ash pond effluent from Plant E. These values are based on the 1976 data for the intake water to Plant E. They differ somewhat from the data given in Table 5 for the intake water during 1974 and 1975. The major reason for this may be in the difference in the number of samples used in generating the two data sets. Note that the significance level and precision for the data in Table 25 are not specified. For design purposes, these values will be assumed to be absolute. In addition, some dilution factor and maximum allowable average concentration in the receiving stream must be specified. The dilution factor assumed for Plant E's ash pond effluent is approximately 8.6×10^3. It is based on a seven day miminum flow of 7880 cubic feet per second (cfs) for the receiving stream and a maximum ash pond flow of 67 cfs (~30,000 gpm). The value of 67 cfs was obtained by rounding off the highest reported value for the flow in Table 19. Table 26 gives the allowable ash pond input to the receiving stream and precision required by the monitoring program assuming the maximum allowable average concentration in the receiving stream is based on maintaining the concentration in the receiving stream equal to or below the EPA proposed water quality criteria for domestic water supply intakes (see Appendix C for a summary of these criteria). Table 27 gives the same information for a monitoring program assuming the maximum allowable average concentration in the receiving stream is below or equal to the maximum value given in Table 25. Remember the value given in Table 25 represents the maximum value reported in 1976 for the intake water to the plant. A precision was not given for Se in Table 27 because the reported Se concentration in the effluent was above the maximum average allowable concentration calculated by this method, therefore, the procedure developed in Section 4 for determining the number of samples to show compliance with a selected water quality criteria could not be used. An example calculation for the element As and an input based on the EPA water quality criteria of the assumed allowable input to the stream and the associated precision is shown in Appendix E. The sampling frequencies associated with these precisions will be discussed in the following subsection.

ESTIMATED SAMPLING FREQUENCIES

The precision required to determine the minimum number of samples needed to show that the ash pond effluent for Plant E is in compliance with the effluent limitation for suspended solids, was calculated to be 0.773 in the previous section. This value falls within the critical range of the deviation for suspended solids indicating the number of samples can be determined from Figure 15. For the 99 percent confidence level, this means 3 samples per sample period are required. Since the effluent limitation specifies that the concentration must not exceed an average of 30 mg/l for 30 consecutive days, the number of samples derived

TABLE 25. ASSUMED WATER QUALITY CHARACTERISTICS FOR
THE RECEIVING STREAM AT PLANT E

Element	Average Concentration	Maximum Concentration
Aluminum (mg/1)	1.7	2.1
Arsenic (mg/1)	0.004	0.005
Calcium (mg/1)	19	26
Conductivity (μmhos)	158	180
Chromium (mg/1)	0.008	0.016
Copper (mg/1)	0.018	0.020
Dissolved Solids	100	120
Iron (mg/1)	0.4	0.54
Magnesium (mg/1)	3.4	4.7
Manganese (mg/1)	.046	0.1
Lead (mg/1)	0.012	0.016
pH (Standard units)	6.9	7.3
Selenium (mg/1)	0.002	0.002
Dissolved Silica (mg/1)	4.1	5.0
Sulfate (mg/1)	22	41
Suspended Solids (mg/1)	12	18
Turbidity (JTU)	7	14
Zinc (mg/1)	0.015	0.030

TABLE 26. REQUIRED PRECISION FOR THE MONITORING PROGRAM OF PLANT E
ASSUMING AN AVERAGE ALLOWABLE CONCENTRATION IN THE RECEIVING STREAM
EQUAL TO THE EPA PROPOSED WATER QUALITY CRITERIA

Element	Maximum Average Allowable Concentration in the Effluent	Required Precision
Arsenic (mg/l)	5.4	5.383
Chromium (mg/l)	4.9	4.877
Copper (mg/l)	115.5	3.841
Iron	a	-
Manganese (mg/l)	0.516	1.824
Lead (mg/l)	4.48	4.460
Selenium (mg/l)	0.943	0.929
Dissolved Silica (mg/l)		
Sulfate (mg/l)	26838	26671
Zinc (mg/l)	586	4.694

[a]Intake water already exceeds the criteria.

TABLE 27. REQUIRED PRECISION FOR THE MONITORING PROGRAM OF PLANT E
ASSUMING AN AVERAGE ALLOWABLE CONCENTRATION IN THE RECEIVING STREAM
EQUAL TO THE MAXIMUM VALUE REPORTED FOR THE INTAKE WATER

Element	Maximum Average Allowable Concentration in the Effluent	Required Precision
Aluminum (mg/l)	48	1.274
Arsenic (mg/l)	0.122	0.105
Calcium (mg/l)	842	0.875
Conductivity (μmhos)	2745	1.569
Chromium (mg/l)	0.95	0.927
Copper (mg/l)	0.253	1.179
Dissolved Solids (mg/l)	2452	0.859
Iron (mg/l)	16.9	1.598
Magnesium (mg/l)	156	2.341
Manganese (mg/l)	6.40	2.917
Lead (mg/l)	0.48	0.46
Selenium (mg/l)	a	-
Dissolved Silica (mg/l)	110	104.3
Sulfate (mg/l)	2257	2090
Suspended Solids (mg/l)	718	2.152
Turbidity (JTU)	830	2.549
Zinc (mg/l)	1.78	2.176

[a]The reported ash pond effluent concentration exceeds the maximum average
allowable concentration calculated by this method; therefore, the procedure
developed in Section 4 for determining the number of samples to show com-
pliance with a selected water quality criteria cannot be used.

from Figure 15 represents a sampling frequency of 3 samples per 30 days or 36 samples per year, assuming 30 days per month. This represents a *sampling frequency of one sample every 10 days.* This assumes, of course, *that the variance obtained for the data over the period of the extensive sampling program and used to construct Figure 15, would be the same had the period of the survey been any one month and the same number of samples been collected.* As discussed earlier, this assumption is valid *when the data are randomly distributed.* Corresponding sampling frequencies for the 95 and 80 percent confidence levels would be 2 and 1 times per month, respectively.

The sampling frequency of one sample per 10 days (3 per month) for the 99 percent significance level is slightly more often than the sampling frequency of two per month currently being required by the NPDES permit. The current requirement results in 29 samples per year whereas 36 are required according to the study. These additional 12 samples result in a decrease at the 99 percent confidence level of 22 percent (from 0.219 for 36 samples to 0.268 for 24 samples) in the deviation of the logarithm of the estimated yearly geometric mean from the logarithm of the true yearly geometric mean and also a decrease of 22 percent in the deviation of the daily mean for a 30-day period. The effect of establishing an averaging period within an effluent limitation specification (i.e., 30 mg/l in any 30-day period) is readily apparent from the above discussion. Had the average period been shortened to 15 days or extended to 60 days, the number of samples required per year would have been 72 and 18, respectively. Therefore, care should be exercised in establishing these averaging periods for effluent limitations.

The NPDES sampling frequency of 2 samples per month provides for a 95 percent confidence level and even 1 sample per month would provide for an 80 percent confidence level. Considering the relative significance of suspended solids to the environment, the high dilution factor by the relatively high minimum flow in the receiving stream, and the insignificance of the potential incremental increase in suspended solids above the effluent limitation, the 80 percent confidence level appears to be sufficient to ensure adverse environmental impacts will not occur. By collecting one sample per month, the 30-day average suspended solids concentration can be shown to be below 22 mg/l with 80-percent confidence.

The above estimates are appropriate if the average of 30 mg/l is interpreted to mean the geometric mean of 30 mg/l when dealing with lognormal data. The geometric mean is always smaller than the arthimetic mean, thus, in effect, creating a slightly higher standard when transforming the standard to a logarithmic value and comparing it with the geometric mean. However, in this case the error introduced due to this assumption is insignificant because the mean for suspended solids is well below the effluent limitation.

Table 28 shows the number of samples required per year to estimate the yearly mean (geometric mean for lognormal data) within 20 percent of the true mean for the 99, 95, and 80 percent confidence levels. A substantial sampling effort (greater than 52 samples per year) would be required to estimate the yearly mean within 20 percent for As, Cr, Fe, Mg, Pb, and turbidity at all three confidence levels, whereas a minimal

TABLE 28. NUMBER OF SAMPLES REQUIRED TO ESTIMATE THE YEARLY
MEAN WITHIN 20% OF THE TRUE YEARLY MEAN OF PLANT E

Element	Number of Samples Required Per Year		
	99% SL	95% SL	80% SL
Aluminum	29	16	7
Arsenic	719	387	166
Calcium	1	1	1
Conductivity	1	1	1
Chromium	332	182	91
Copper	6	4	2
Dissolved Solids	1	1	1
Iron	259	144	60
Magnesium	1144	634	262
Manganese	6	4	2
Lead	400	240	80
pH	1	1	1
Selenium	16	9	5
Dissolved Silica	4	2	1
Sulfate	13	8	3
Suspended Solids	56	31	13
Turbidity	111	61	25
Zinc	8	5	2

SL = Significance level.

effort (only 1 sample per year) would be required for Ca, conductivity, dissolved solids, and pH. The remaining parameters would require between 2 and 56 samples per year.

Selecting the sampling frequency based on a precision which estimates the yearly mean within a given percentage of the population mean has two major weaknesses. First, the method does not take into account the significance of the concentration in the waste stream, and second, it tends to reduce the precision value (increase the number of samples) as the concentration in the waste stream decreases. As a result of these weaknesses, a monitoring program based on this method above would result in 1,973 turbidity samples and only 26 selenium samples per year. Selenium in the effluent probably deserves more attention than turbidity because of its toxicity relative to the concentrations found in the effluent.

To overcome these weaknesses and add additional meaning to the monitoring program, Table 29 gives the estimated sampling frequencies for the precisions given in Tables 26 and 27. Table 29 indicates that a sampling frequency of once per year for all parameters except for selenium and arsenic, ensures within 99 percent confidence that the yearly average concentration in the receiving stream will not be increased (by the ash pond effluent) above the maximum value reported in the intake water for 1976. Arsenic would require two samples per year for the same assurance. Likewise, only one sample per year for all parameters ensures within 99 percent confidence that the receiving stream's yearly average concentration will not be increased (by the ash pond effluent) above the EPA proposed water quality criteria. Therefore, establishing monitoring frequencies based on maintaining the average concentration in the receiving stream equal to or below the maximum value reported in the intake water in 1976 automatically ensures monitoring frequencies as great or greater than those based on maintaining the average concentration in the receiving stream equal to or below the EPA proposed water quality criteria for domestic water supply intakes.

The sampling frequencies listed in Tables 28 and 29 differ considerably. The frequencies based on the assumed allowable level of increase in the receiving steam are substantially lower than those required to estimate the mean within 20 percent. The sampling frequency used in the final monitoring program should, therefore, be a compromise between the frequencies given in Tables 28 and 29. As an aid in estimating the point of compromise, the deviation of the yearly sample mean from the true mean for the 99 percent confidence level is given for the following frequencies: yearly, quarterly, bimonthly (once every two months), monthly, biweekly (once every two weeks), and weekly. These frequencies were selected because they are the most widely used frequencies. The data given in Table 30 indicates that the deviation of the sample mean from the true mean varies from parameter to parameter at each sampling frequency. This indicates the fallacy in establishing the same monitoring frequency for every parameter. By doing so, some parameters are estimated more accurately than others, possibly making comparisons between parameters misleading.

TABLE 29. ESTIMATE SAMPLING FREQUENCIES FOR THE MONITORING PROGRAM
AT PLANT E ASSUMING ALLOWABLE AVERAGE CONCENTRATIONS IN THE RECEIVING
STREAM EQUAL TO THE EPA WATER QUALITY CRITERIA AND MAXIMUM VALUE
REPORTED FOR THE INTAKE WATER

Element	Number of Samples per Year[a]	
	Precision based on Water Quality Criteria[b]	Precision based on Maximum value reported for the intake water[c]
Aluminum	d	1
Arsenic	1	2
Calcium	d	1
Conductivity	d	1
Chromium	1	1
Copper	1	1
Dissolved Solids	d	1
Iron	e	1
Magnesium	d	f
Manganese	1	1
Lead	1	1
Selenium	1	g
Dissolved Silica	d	1
Sulfate	1	1
Suspended Solids	d	1
Turbidity	d	1
Zinc	d	1

a. Values are for the 99% significance level.
b. See Table 25 for the precision values.
c. See Table 26 for the precision values.
d. Criteria not proposed for drinking water intake supplies.
e. Intake water exceeds criteria.
f. Intake concentration exceeds effluent concentration.
g. The average ash pond effluent concentration exceeds the maximum concentration reported for the intake water.

TABLE 30. DEVIATION OF THE YEARLY SAMPLE MEAN FROM THE TRUE MEAN FOR THE 99% CONFIDENCE LEVEL AT VARIOUS SAMPLING FREQUENCIES

Parameter	Deviation from the True Mean[a]					
	Yearly	Quarterly	Bimonthly	Monthly	Biweekly	Weekly
Aluminum	57(0.546)	40(0.273)	35(0.223)	28(0.156)	21(0.107)	16(0.076)
Arsenic	87(0.114)	77(0.057)	73(0.047)	66(0.033)	56(0.022)	48(0.016)
Calcium	19(0.490)	11(0.245)	9(0.200)	6(0.142)	4(0.096)	3(0.068)
Conductivity	14(0.316)	8(0.158)	6(0.129)	5(0.091)	3(0.062)	2(0.044)
Chromium	82(0.105)	69(0.052)	65(0.043)	57(0.030)	48(0.021)	39(0.015)
Copper	37(1.046)	23(0.523)	19(0.427)	15(0.302)	10(0.205)	8(0.145)
Dissolved Solids	11(0.320)	5.9(0.160)	4.9(0.31)	3.5(0.093)	2.4(0.063)	1.7(0.045)
Iron	80(1.489)	67(0.744)	62(0.608)	54(0.430)	44(0.292)	36(0.206)
Magnesium	89(1.252)	81(0.626)	78(0.511)	71(0.361)	62(0.245)	54(0.174)
Manganese	37(1.237)	23(0.618)	19(0.505)	14(0.357)	10(0.243)	8(0.171)
Lead	83(0.100)	71(0.050)	67(0.041)	59(0.029)	50(0.020)	41(0.014)
pH	4.7(0.550)	2.4(0.275)	2.0(0.225)	1.4(0.159)	1.0(0.108)	0.6(0.076)
Selenium	50(0.014)	33(0.007)	30(0.006)	22(0.004)	18(0.003)	13(0.002)
Dissolved Silica	32(2.677)	19(1.339)	16(1.093)	12(0.773)	8(0.525)	6(0.371)
Sulfate	48(151)	31(76)	27(62)	21(44)	15(30)	11(21)
Suspended Solids	65(1.311)	48(0.656)	43(0.535)	35(0.379)	27(0.257)	21(0.182)
Turbidity	72(0.972)	57(0.486)	52(0.397)	43(0.280)	34(0.191)	27(0.135)
Zinc	41(1.314)	25(0.657)	22(0.536)	16(0.379)	12(0.258)	9(0.182)

a. Values are given as percent of deviation from the true mean. Numbers in parenthesis indicate the deviation in mg/l or log mg/l.

EXAMPLE SAMPLING PROGRAM FOR PLANT E

An example sampling program for Plant E to meet NPDES require-
ments is shown in Table 31. It is based on the previous discussion and
the following criteria:

1. The element must be required by the NPDES permit.

2. The 99 percent confidence level was assumed.

3. The precision used to estimate the sampling frequency was based
    on maintaining the average concentration in the receiving stream
    below or equal to the maximum concentration reported for the
    receiving in 1976 under the 7-day 10-year minimum flow. This
    justification for trace metals was assumed because biological
    studies performed for P.L. 92-500, Section 316 demonstrations,
    indicated no adverse biological effects of the discharges from
    Plant E.

4. If the average concentration in the effluent exceeded the maxi-
    mum value reported for the intake water and the EPA proposed
    water quality criteria, then the frequency was established based
    on estimating the average within at least 33 percent of the true
    mean.

5. For those elements for which an effluent limitation has been
    set, the recommended frequency ensures an average which shows
    compliance if the effluent is in compliance.

6. Unless specified, the sample(s) can be collected any time
    during the averaging period.

7. If the data shows that the effluent concentration is below the
    detection limit, the element will not be included in the moni-
    toring program even if required by the current NPDES permit.

The remaining discussion gives the justification for this program by
element.

Aluminum

Aluminum is not recommended as part of the monitoring program
because it is not required by the NPDES permit.

Arsenic

Two samples per year are recommended. Monitoring of arsenic is
required by the NPDES permit. Two samples show with 99 percent con-
fidence that the ash pond effluent does not increase the yearly average
receiving stream concentration above 0.005 mg/l. It also allows
estimation of the yearly average concentration in the effluent within
83 percent.

TABLE 31. EXAMPLE SAMPLING PROGRAM FOR PLANT E

Element	Sampling Frequency (No. per year)	Precision[a] (% of true mean)
Aluminum	0	-
Arsenic	2	83
Cadmium	0	-
Calcium	0	-
Chromium	1	82
Conductivity	0	-
Copper	1	37
Dissolved Silica	0	-
Dissolved Solids	0	-
Iron	1	80
Lead	1	83
Magnesium	0	-
Manganese	1	37
Mercury	0	-
Nickel	0	-
pH	1	4.7
Selenium	4	33
Sulfate	0	-
Suspended Solids	36[b]	24
Turbidity	0	-
Zinc	1	41

a. At the 99% confidence level.

b. The frequency should be 1 sample every 10 days.

Cadmium

Cadmium is not recommended as part of the monitoring program because the data during 1974 and 1975 indicated that the concentration was below the detection limit.

Calcium

Calcium is not recommended as part of the monitoring program because it is not required by the NPDES permit.

Chromium

One sample per year is recommended. Monitoring of chromium is required by the NPDES permit. This one sample shows within 99 percent confidence that the ash pond effluent does not increase the yearly average receiving stream concentration above 0.009 mg/l. It also allows estimation of the yearly average concentration in the effluent within 82 percent of the true mean.

Conductivity

Conductivity is not recommended as part of the monitoring program because it does not provide any useful information.

Copper

One sample per year is recommended. Copper is required by the NPDES permit and one sample shows that the ash pond effluent does not increase the yearly average receiving stream concentration above 0.02 mg/l. It also allows the yearly mean in the effluent to be estimated within 37 percent.

Dissolved Silica

Dissolved silica is not recommended as part of the monitoring program because it is not required by the NPDES permit.

Dissolved Solids

Dissolved solids is not recommended as part of the monitoring program because it is not required by the NPDES permit.

Iron

One sample per year is recommended. Iron is required by the NPDES permit. The concentration of iron in the intake water exceeds the EPA proposed water quality criteria for drinking water intake supplies, however, one sample shows that the effluent does not increase the yearly average intake concentration above 0.54 mg/l. It also allows estimation of the yearly average concentration in the effluent within 80 percent.

Lead

One sample per year is recommended. Lead is required by the NPDES permit. This one sample shows with 99 percent confidence that the ash pond effluent does not increase the yearly average receiving stream concentration above 0.013 mg/l. It also allows estimation of the yearly average concentration in the effluent within 83 percent of the true mean.

Magnesium

Magnesium is not recommended as part of the monitoring program because it is not required by the NPDES permit and the concentration in the effluent was consistently less than that in the intake water.

Manganese

One sample per year is recommended. Manganese is required by the NPDES permit and one sample shows that the ash pond effluent does not increase the yearly average receiving stream concentration above 0.05 mg/l. It also allows the yearly mean in the effluent to be estimated within 37 percent.

Mercury

Mercury is not recommended as part of the monitoring program because the data during 1974 and 1975 indicated that the concentration was below the detection limit.

Nickel

Nickel is not recommended as part of the monitoring program because the data during 1974 and 1975 indicated that the concentration was below the detection limit.

pH

One sample per year is recommended. The pH of the effluent exceeds the limitation established in the NPDES permit greater than 98 percent of the time and one sample estimates the yearly average within 4.7 percent of the true mean at the 99 percent confidence level.

Selenium

Four samples per year are recommended. Selenium is required by the NPDES permit. The concentration in the intake water is consistently at or below the minimum detectable limit of 0.002 mg/l, while the ash pond effluent concentration is consistently above this concentration (the average during the extensive survey was 0.014 mg/l). Therefore, four samples were recommended because they estimate the yearly average within 33 percent.

Sulfate

Sulfate is not recommended as part of the monitoring program because it is not required by the NPDES permit.

Suspended Solids

Thirty-six samples per year at 10-day intervals are recommended. This frequency shows with 99 percent confidence that the effluent is in compliance with the effluent limitation of 30 mg/l specified in the NPDES permit.

Turbidity

Turbidity is not recommended as part of the monitoring program at this time. However, under certain influent water quality conditions a relationship could possibly be developed between turbidity and suspended solids. This could allow installation of an automatic turbidity meter with an alarm system set to activate an automatic sampler when the effluent suspended solids exceed 30 mg/l. Such an arrangement may reduce the number of samples required for suspended solids and reduce sampling and analysis costs.

Zinc

One sample per year is recommended. Zinc is required by the NPDES permit. This sample shows that the ash pond effluent does not increase the yearly average receiving stream concentration above 0.017 mg/l. It also allows the yearly mean in the effluent to be estimated within 41 percent.

SUMMARY

The example sampling program given in Table 31 requires a total of 48 analyses per year for 9 different elements whereas the NPDES permit requires a total of 56 analyses per year for 12 different elements. Under the recommended program, estimates of the yearly average were obtained for the following elements: As, Cr, Cu, Fe, Pb, Mn, Se, suspended solids, and Zn. The example program excludes sampling for Cd, Ni, and Hg, which are required by the NPDES permit, because past data showed them to be below the minimum detectable amount. The above totals exclude pH, flow, and oil and grease.

At the time of this writing the ash pond effluent at Plant E was considered to be in compliance with existing effluent limitations as defined in the NPDES permit for that plant. Special provisions or plant modifications specific for Plant E may be required in the future to ensure continued compliance. One example of a recent provision in the NPDES permit pertains to the pH limitation. Although the effluent limitation for pH cited in this report was not met, the pH of the ash pond effluent is not considered out of compliance. Provisions have been made such that the effluent is allowed to mix with another waste stream (condenser cooling water) before meeting the effluent limitations. This provision was started after the extensive sampling program was begun and therefore not included in this report.

SECTION 6

ASH POND MONITORING PROGRAM FOR PLANT J

The following section demonstrates how the procedure outlined in Section 4 was used to design a monitoring program for the ash pond effluent at TVA's Plant J.

DESCRIPTION OF PLANT J

Plant J consists of nine pulverized coal-fired units with a combined full load capacity of 1.7 million kilowatts. Each of units 1-4 has a maximum generator nameplate rating of 175 megawatts and each of units 5-9 has a rating of 200 megawatts. At full capacity, the plant consumes about 16,200 tons of coal per day. The majority of the coal comes from eastern Kentucky and eastern Tennessee and has an average sulfur content of 2.1 percent and an average ash content of 19.1 percent.

Fly ash control is accomplished by the use of mechanical collectors and electrostatic precipitators installed in series on each unit. The overall collection efficiency of the collection system is estimated at 98 percent, 70 percent efficiency for mechanical and 95 percent efficiency for the electrostatic precipitators.

Assuming operation at full load capacity, approximately 3050 tons of ash per day would be produced by Plant E. This ash is sluiced to a 275-acre ash pond with a storage capacity of about 3.25 million cubic yards. The effluent is discharged to the condenser cooling water intake.

In addition to the ash, the ash pond also receives chemical cleaning wastes, coal pile drainage, and treated sanitary sewage. The coal pile drainage and sanitary sewage flows represent approximately 0.6 and 0.04 percent of the total flow from the ash pond. The chemical cleaning wastes are discharged intermittently (3 times per year) and during their discharge they represent approximately 1.0 percent of the total flow from the ash pond. These flows are assumed insignificant in determining the overall ash pond effluent characteristics.

MECHANICS OF THE ASH POND SYSTEM AT PLANT J

A summary of the ash pond effluent characteristics for Plant J from 1970 to 1975 were given in Section 3. There were insufficient data on the operating conditions of Plant J during this period to determine the relationship between the ash pond effluent and plant operation. However, there were some significant correlations at Plant J indicated in Section 3. Of these, the most interesting was the one between the alkalinity of the intake water and the ash pond effluent. This relationship is believed to exist because of the large changes that occur in the alkalinity of the intake water. The intake water used for sluicing can consist of either Emory River water or Clinch River water or a combination of both since the Clinch River has been known to progress as much as 14 miles up

the Emory under different hydrologic conditions. According to a 1961-1962 survey, the alkalinity ranged from 64 to 108 mg/l in the Clinch River and from 3 to 85 mg/l in the Emory River. This change in intake water quality, therefore, probably accounts for the seasonal cycle indicated in Table 4 for pH, alkalinity, conductivity, dissolved solids, and hardness in the ash pond effluent at Plant J.

The mixing characteristics of the ash pond contents for Plant J were not investigated as fully as those for Plant E. Cenospheres on the surface of the ash pond at Plant J were observed to readily move about the pond depending on wind conditions, and for this reason the mixing characteristics were assumed to be similar to those at Plant E. The detention time within the ash pond at Plant J was not determined by a dye study. However, samples of the effluent during the sluicing of chemical cleaning wastes showed the detention time of the ash pond to be about 2 to 4 hours. However, during more windy conditions, which provide pond mixing and destratification, the detention time is probably closer to 60 hours. At first this seems to be contradictory to the detention times given for the ash pond at Plant E since the pond at Plant J is larger. These shorter times are probably due to more short-circuiting and the higher flow at Plant J than Plant E. Because of this shorter detention time, the variation of the effluent characteristics are probably more dependent on the variation in plant operating conditions.

SUMMARY OF THE ASH POND EFFLUENT CHARACTERISTICS AT PLANT J

The weekly effluent data from 1970 to 1975 for Plant J showed that there was a yearly cycle for pH, total alkalinity, conductivity, dissolved solids, total solids, and hardness. The data did not indicate a yearly cycle for flow, phenolphthalin alkalinity, turbidity or suspended solids. The data given in Figure 7 for Plant J showed that the variation of daily composite samples for several elements, including dissolved and suspended solids, trace metals, and pH, over a four day period was no greater than that exhibited by the weekly data. Therefore, a weekly cycle is assumed nonexistent.

As concluded at the end of Section 3, except for pH and suspended solids, there is insufficient data on those parameters required by the NPDES permit for Plant J to adequately estimate the true yearly mean. Therefore, a more intensive sampling program of the ash pond effluent at Plant J was conducted from January 1977 through September 1977 to better estimate the effluent characteristics. Grab samples were collected by power plant personnel on a varying work day of each week the same as at Plant E. These samples were then shipped to the Laboratory Branch in Chattanooga, Tennessee, for analysis. They were analyzed for the following parameters which are required by the NPDES permit for Plant J: pH, suspended solids, flow, total arsenic, chromium, copper, iron, lead, manganese, nickel, selenium, and zinc. The NPDES permit also calls for cadmium and mercury to be monitored, however, these elements were not included in this study because previous data (see Table 5) indicated the concentrations were near the minimum detectable amount. In addition, the samples were analyzed for aluminum, calcium, magnesium, sulfate, and

dissolved solids. These elements were included because previous data indicated their presence. The samples were collected in the ash pond discharge prior to mixing with any other waste stream as required by the NPDES permit. The sampling period was such that samples were collected during all phases of the yearly cycle.

The results of this extensive sampling program are given in Table 32. A summary at the bottom of the table gives the minimum, mean, and maximum values for each element. Linear correlation coefficients were developed between each element. A significant correlation at the 95 percent significance level is represented by an R value greater than 0.325 in Table 33 (2). Chromium is not shown because most samples were below the mimimum detection limit. Every element except chromium, nickel, suspsended solids, and sulfate were significantly correlated with pH. This is not surprising, for the elements Al, Cu, Fe, Pb, Mn, and Zn are normally more soluble at lower pH and this trend is indicated by the negative R values. The positive R values for Ca and Mg are also not surprising since alkalinity increases with increasing pH. The positive R values for As and Se indicate that their concentration decreases with decreasing pH in the pH range 8.5 to 4.5. The pH was significantly correlated with flow and therefore, some of the elements correlated with pH were significantly correlated with flow. They are Al, Ca, Fe, Mg, Se, As, and dissolved solids. Aluminum and iron were the only elements significantly correlated with suspended solids. Several of the trace metals were correlated with each other. These correlations indicate that the heavy metals in the ash pond effluent are interrelated with one another. However, development of these relationships are beyond the scope of this study.

The only R values which indicated a relationship between parameters which may be beneficial to a monitoring program were those with pH. Since the pH varies considerably (4.5 to 8.5) on a seasonal basis and some of the trace elements are dependent on the pH, pH may be useful as an indicator of certain trace elements when the concentration of these trace elements are at that concentration which has the most potential for causing environmental harm.

The summary of the ash effluent characteristics for Plant J given in Table 32 will now be used to complete steps 3 through 8 of the design procedure summarized in Section 4.

VARIATION OF THE ASH POND EFFLUENT CHARACTERISTICS AT PLANT J WITH TIME

The variation with time of the ash pond effluent characteristics given in Table 33 for Plant J is shown in Figure 16. The majority of the concentrations of chromium, lead, and nickel were below the minimum detectable amounts, and therefore the occurrence of a cycle could not be determined. A yearly cycle was indicated for pH as expected. In addition, a yearly cycle was indicated for Al, As, Ca, dissolved solids, Fe, Mg, Se, and sulfate. These cycles probably exist as a result of the cycle in pH. The data in Figure 16 also indicates a yearly cycle for flow, however, this is not the case. At about the time the flow is shown to increase in Figure 16, additional electrostatic precipitators

TABLE 32. ASH POND EFFLUENT CHARACTERISTICS AT PLANT J

Date	pH	Flow (MGD)	Aluminum (mg/l)	Calcium (mg/l)	Chromium (mg/l)	Copper (mg/l)	Iron (mg/l)	Lead (mg/l)	Magnesium (mg/l)	Manganese (mg/l)	Zinc (mg/l)	Selenium (mg/l)	Arsenic (mg/l)	Nickel (mg/l)	Dissolved Solids (mg/l)	Suspended Solids (mg/l)	Sulfate (mg/l)
1-19	4.9		1.8	26	<0.005	0.11	3.9	<0.01	4.3	0.28	0.06	0.006	0.026	<0.05	150	14	85
1-27	6.7	20.2	0.5	32	<0.005	0.02	4.1	<0.01	6.4	0.18	0.03	0.006	0.001	<0.05	190	18	72
2-11	7.6	21	0.5	39	<0.005	<0.01	0.48	<0.01	8.0	0.08	<0.01	0.005	0.04	<0.05	180	2	82
2-17	7.7	20	0.2	31	<0.005	0.02	0.46	<0.01	6.7	0.10	0.01	0.006	0.011	<0.05	140	1	50
2-23	7.3	21	0.8	35	<0.005	0.04	0.66	<0.01	7.1	0.14	<0.01	0.008	0.042	<0.05	NA	NA	NA
3-3	5.9	21	0.9	19	<0.005	0.01	1.9	<0.01	3.5	0.21	0.01	0.005	0.014	<0.05	90	3	83
3-9	4.5	19	1.3	23	<0.005	0.35	2.5	<0.01	3.0	0.24	0.13	0.005	0.04	<0.05	160	6	64
3-16	4.5	21	1.7	26	<0.005	0.11	2.2	0.016	3.9	0.33	0.07	0.002	0.012	<0.05	120	12	47
3-23	4.7	19	1.1	22	<0.005	0.04	0.57	0.014	3.3	0.24	0.05	0.003	0.018	<0.05	100	2	68
3-31	7.5	35	.5	19	<0.005	0.03	0.48	<0.01	3.8	0.1	0.01	0.008	0.041	<0.05	90	12	26
4-15	5.6	37	1.1	19	<0.005	0.06	0.37	<0.01	4.0	0.22	0.20	0.005	0.011	<0.05	120	5	100
4-19	NA	NA	0.2	26	<0.005	0.01	0.12	<0.01	7.1	0.13	0.07	0.006	0.031	<0.05	170	<1	72
4-28	6.1	38	0.9	30	<0.005	0.04	0.67	0.15	4.9	0.26	<0.01	0.004	0.031	<0.05	140	1	93
5-4	6.1	39.6	0.9	26	<0.005	0.25	0.86	<0.01	5.7	0.33	0.10	0.018	0.027	0.06	160	2	97
5-9	7.8	41	0.5	29	<0.005	0.06	0.13	<0.01	7.2	0.23	0.03	0.005	0.062	<0.05	170	2	9.
5-17	7.5	38.8	0.61	36	<0.005	<0.01	0.25	<0.01	8.3	0.10	0.04	0.10	0.17	<0.05	180	2	73
5-25	NA	NA	0.51	44	<0.005	<0.01	0.3	<0.01	9.4	0.23	<0.01	0.016	0.048	<0.05	190	3	120
6-2	7.8	NA	0.34	28	<0.005	0.06	1.0	<0.01	7.8	0.07	<0.01	<0.001	<0.004	<0.05	120	7	20
6-8	8.1	39	0.74	43	<0.005	<0.01	0.30	<0.01	8.1	0.09	0.05	0.006	0.09	<0.05	190	11	92
6-16	7.8	35	0.29	42	<0.005	0.20	0.42	<0.01	8.2	0.11	0.01	0.006	0.069	<0.05	200	4	88
6-21	8.1	49	0.29	40	<0.005	0.01	0.37	<0.01	8.4	0.09	0.09	0.007	0.041	<0.05	200	1	89
6-30	7.6	40	0.88	48	<0.005	0.03	0.34	<0.01	7.8	0.08	0.03	0.020	0.056	<0.05	180	5	100
7-6	8.5	39	0.70	46	<0.005	0.04	0.38	<0.01	8.4	0.09	0.01	0.018	0.078	<0.05	190	5	100
7-20	7.9	39	0.50	48	<0.005	16.0	0.49	<0.01	8.0	0.07	<0.01	0.016	0.084	<0.05	200	1	100
7-12	8.2	40	<0.2	50	<0.005	0.01	0.36	<0.01	7.4	0.04	0.07	0.018	0.095	<0.05	210	3	120
7-29	7.4	39	0.4	48	<0.005	0.07	0.47	<0.01	8.3	0.29	0.05	0.007	0.039	<0.05	220	<1	130
8-1	7.4	39	0.4	44	<0.005	0.02	0.50	<0.01	8.7	0.30	0.05	0.006	0.046	0.06	230	1	120
8-16	7.3	37	0.41	50	<0.005	<0.01	0.33	<0.01	7.7	0.22	0.01	0.010	0.042	<0.05	220	2	66
8-10	7.4	36	0.3	50	<0.005	0.04	0.44	<0.01	8.0	0.18	0.09	0.011	0.036	<0.05	210	2	120
8-31	8.2	40	0.8	51	<0.005	0.02	0.24	<0.01	10	0.08	0.04	0.016	0.068	<0.05	210	6	95
9-8	7.6	32	0.5	53	<0.005	0.02	0.55	<0.01	9.6	0.33	0.06	0.006	0.008	<0.05	260	2	130
9-15	7.4	40	0.6	54	<0.005	0.02	0.38	<0.01	9.6	0.21	0.20	0.016	0.020	<0.05	230	7	120
9-19	7.4	39	0.2	50	<0.005	0.02	0.23	<0.01	8.4	0.20	0.05	0.012	0.04	<0.05	230	11	120
9-28	7.0	40	0.9	70	<0.005	0.05	0.56	<0.01	8.0	0.33	0.03	0.005	0.01	<0.05	190	24	130
Min.	4.5	19.0	0.2	19	<0.005	<0.01	0.12	<0.010	3.0	0.04	<0.01	0.001	0.001	0.05	90	<1	20
Avg.	7.0	33.8	0.66	38	<0.005	0.06	0.80	0.010	7.0	0.18	0.05	0.009	0.043	0.051	177	5	90
Max.	8.5	49	1.8	70	<0.005	0.35	4.10	0.016	10.0	0.33	0.20	0.020	0.170	0.060	260	24	130

TABLE 33. LINEAR CORRELATION COEFFICIENTS FOR THE VARIOUS ASH POND EFFLUENT PARAMETERS AT PLANT J

	Flow	pH	Aluminum	Calcium	Copper	Iron	Lead	Magnesium	Manganese	Zinc	Selenium	Arsenic	Nickel	Dissolved Solids	Suspended Solids	Sulfate
Flow	1.000															
pH	0.571	1.000														
Aluminum	-0.376	-0.807	1.000													
Calcium	0.509	0.596	-0.374	1.000												
Copper	-0.194	-0.507	0.420	-0.306	1.000											
Iron	-0.614	-0.609	0.562	-0.390	0.349	1.000										
Lead	-0.294	-0.553	0.479	-0.294	0.055	0.144	1.000									
Magnesium	0.556	0.833	-0.623	0.805	-0.417	-0.514	-0.457	1.000								
Manganese	-0.118	-0.619	0.454	-0.039	0.321	0.294	0.343	-0.269	1.000							
Zinc	0.163	-0.335	0.239	-0.076	0.281	0.043	-0.036	-0.139	0.269	1.000						
Selenium	0.490	0.428	-0.194	0.457	-0.080	-0.305	-0.344	0.438	-0.294	0.073	1.000					
Arsenic	0.409	0.439	-0.193	0.220	-0.097	-0.363	-0.209	0.336	-0.499	-0.186	0.423	1.000				
Nickel	0.170	-0.068	-0.007	-0.064	0.274	-0.032	-0.077	0.022	0.369	0.128	0.154	-0.045	1.000			
Dissolved Solids	0.491	0.554	-0.465	0.826	-0.164	-0.278	-0.408	0.825	0.016	0.089	0.423	0.267	0.108	1.000		
Suspended Solids	-0.099	-0.198	0.365	0.135	0.048	0.493	0.014	-0.150	0.018	0.001	0.167	-0.257	-0.183	0.105	1.000	
Sulfate	0.537	0.250	-0.159	0.683	-0.149	-0.285	-0.243	0.516	0.299	0.247	0.433	0.116	0.169	0.700	-0.079	1.000
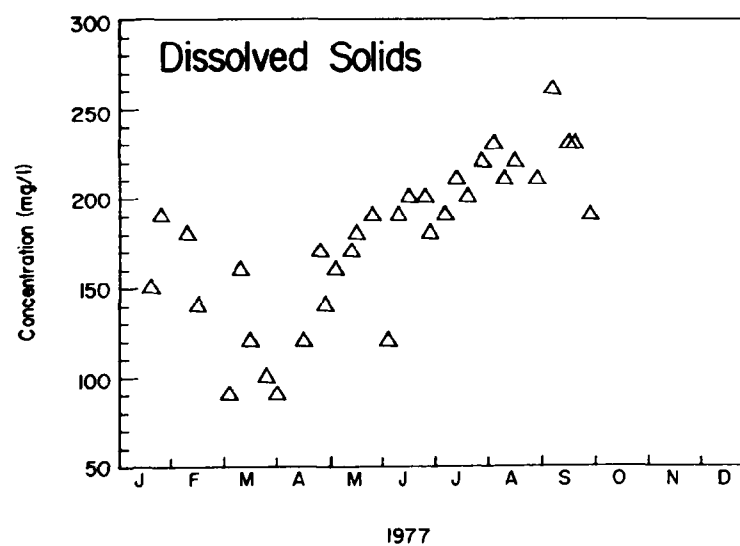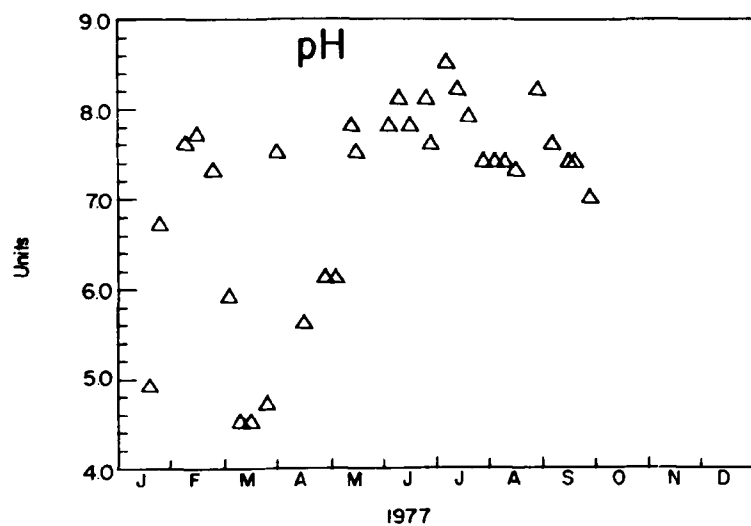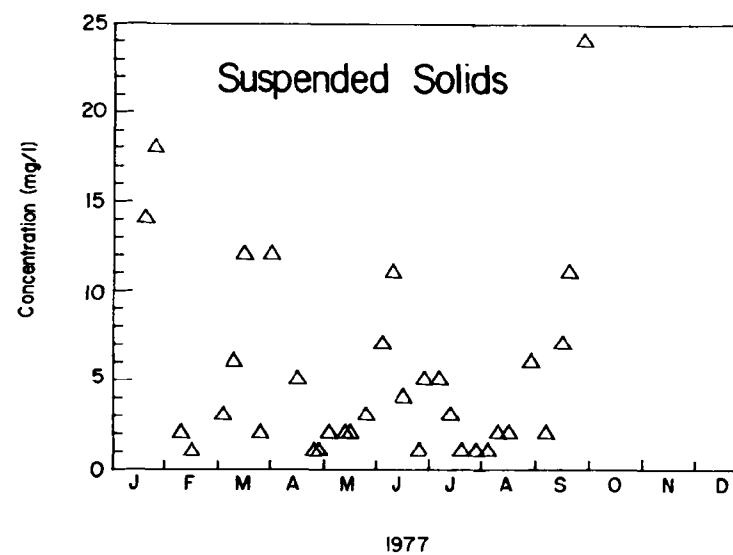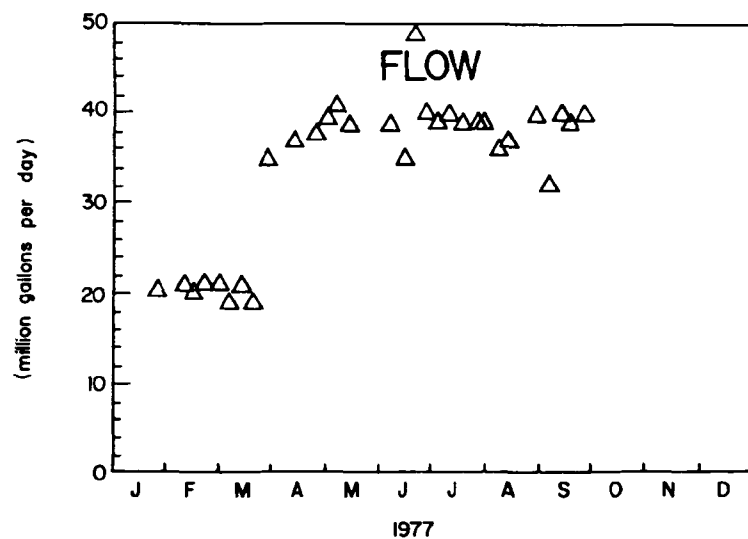
Figure 16. Variation of Ash Pond Effluent Characteristics with Time at Plant J
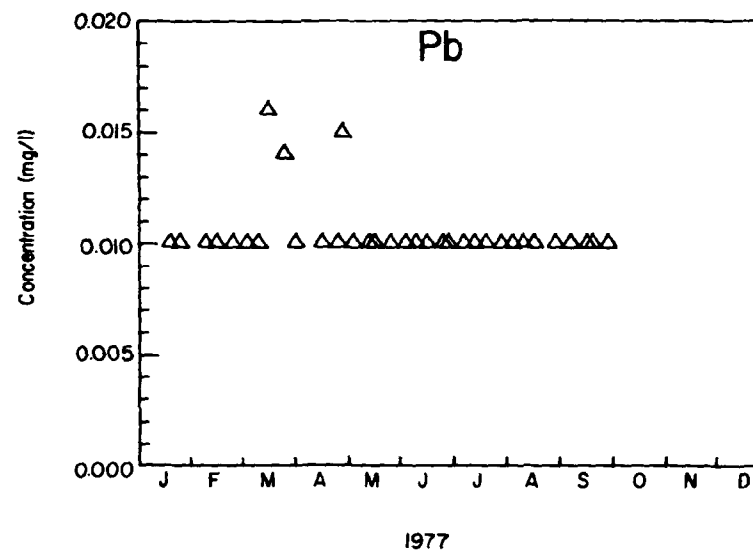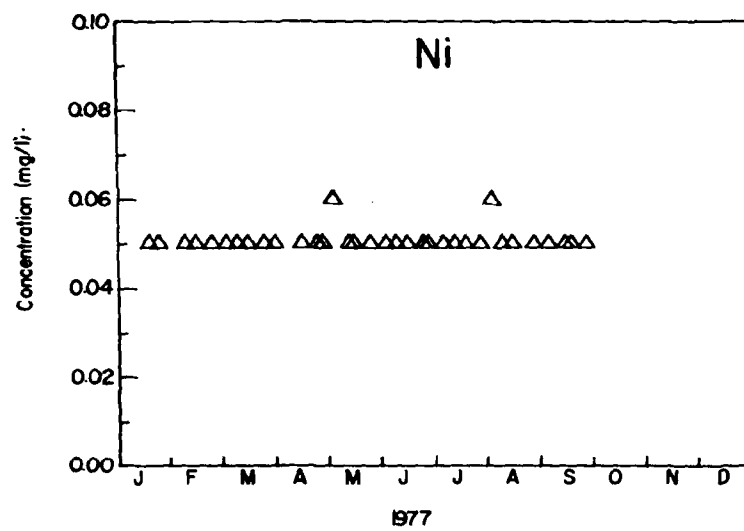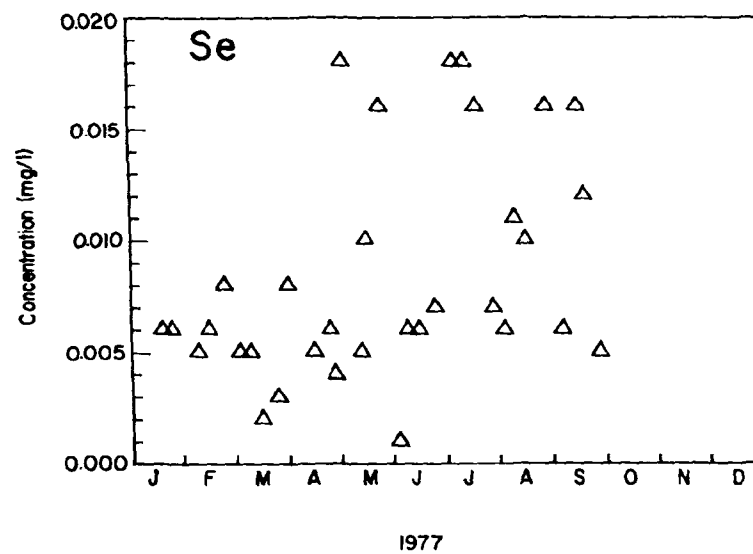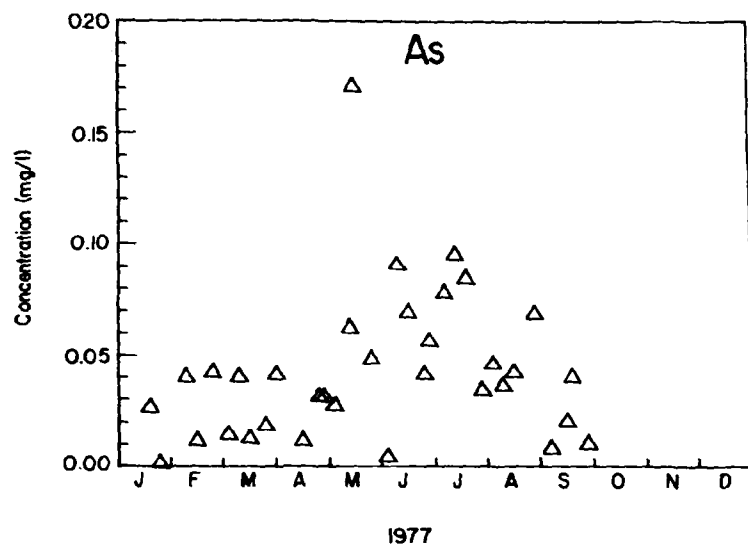
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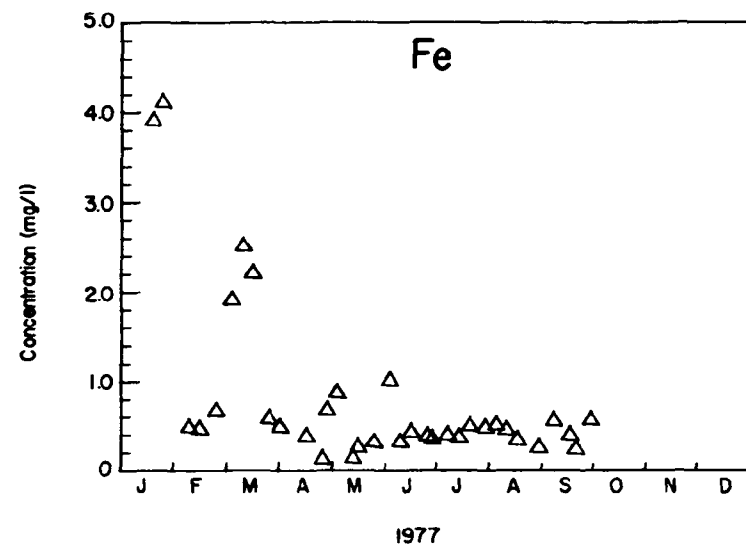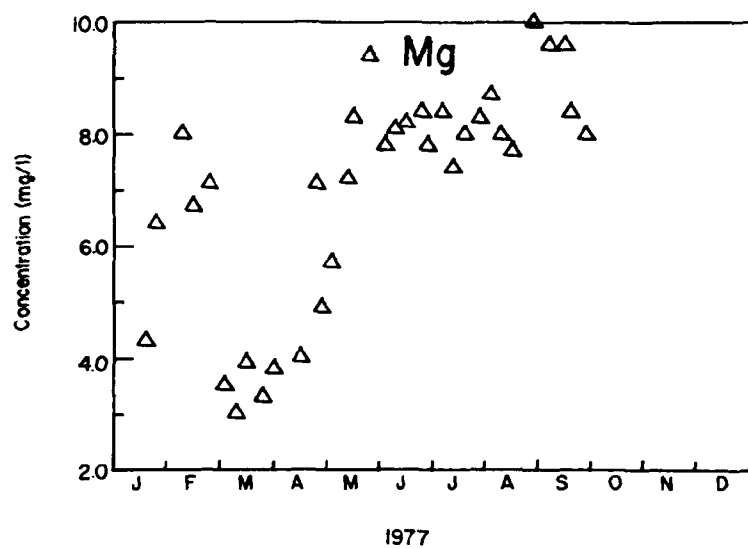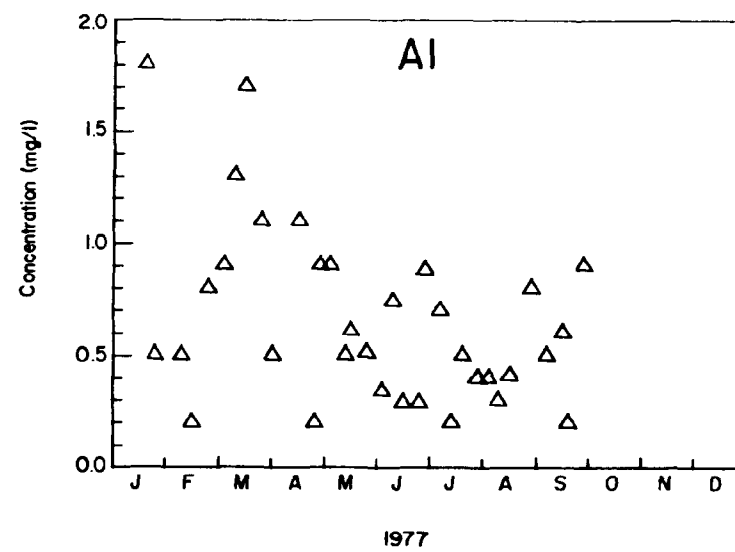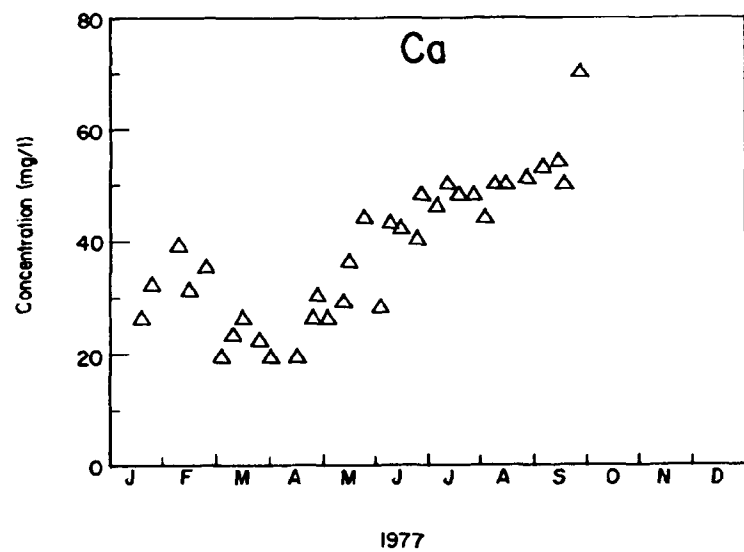
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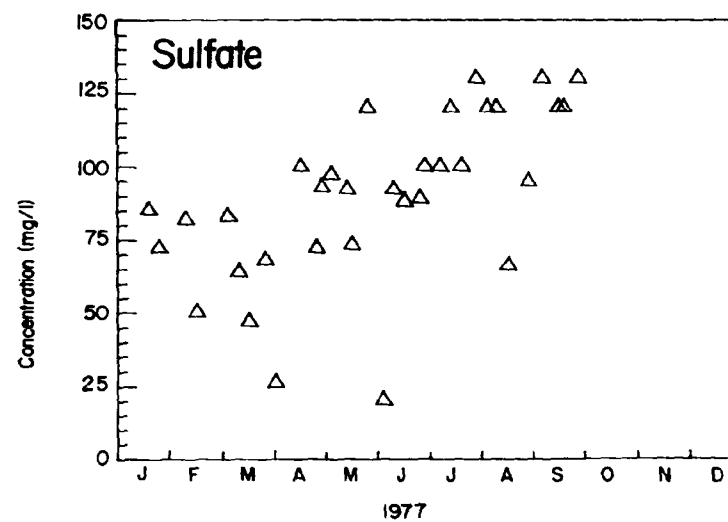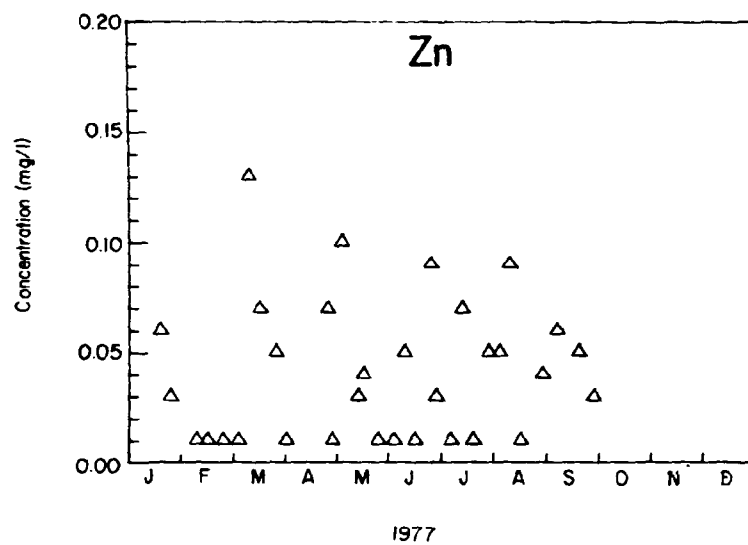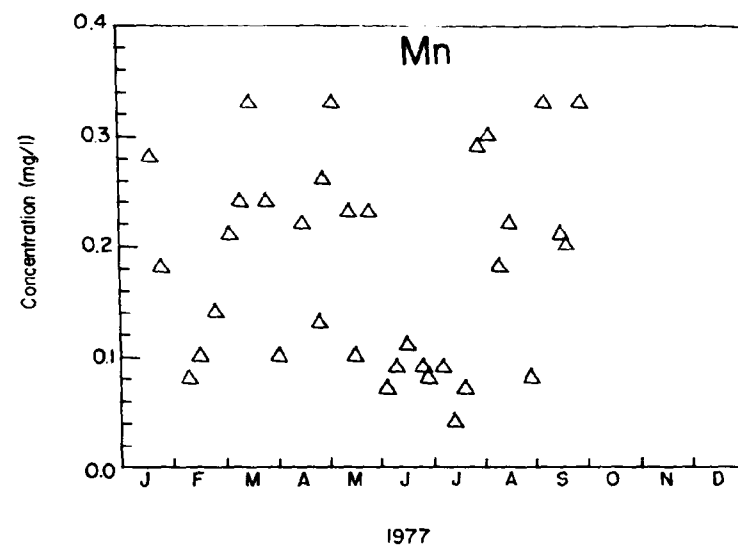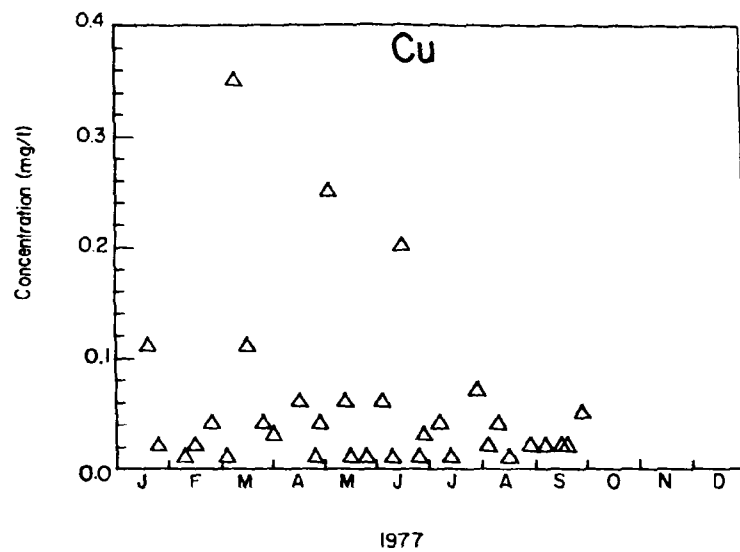
(Figure 16 (Continued))

(ESP) were put into operation causing an additional estimated flow of 12 million gallons per day (MGD). Therefore, the changes in the trace metals could be associated with the possible change in ash characteristics as a result of the new ESP units. However, since the change in flow occurs approximately one month before the pH change and the change in trace metals occurred at approximately the same time as the pH, the new ash probably does not account for the changes shown for trace metals in Figure 16. A cycle was not indicated for suspended solids, lead, zinc, manganese or copper.

By assuming there to be a yearly cycle for some parameters, the data set must be divided into smaller data sets of random events in order to estimate the effluent characteristics for the various time periods. Since most of the elements exhibiting a cycle were significantly correlated with pH and the pH appears to change in April, the data for the following elements was divided into two data sets: pH, Al, As, Ca, dissolved solids, Fe, Mg, Se, and sulfate. The two data sets consist of the data from November 1 to April 30 and from May 1 to October 31. The change in pH does not always occur at the same time each year as indicated by the data in Figure 3, therefore, the year was divided into a 6-month period although the low pH period may only last 3 months out of every year. For the elements defined as having a yearly cycle the variation at any point in time is the same and only the relative concentration has changed, whereas for others the variation has changed considerably. Calcium is a good example of the first case, while As is a good example of the second case. For those parameters defined as not having a yearly cycle, the data was not divided into two distinct sample periods. Therefore, the remainder of this section deals with the three data sets previously discussed.

STATISTICAL DISTRIBUTION OF THE EFFLUENT CHARACTERISTICS AT PLANT J

Cumulative frequency plots were prepared for the data given in Table 32 for the time periods discussed in the previous subsection. These plots are shown in Figures 17, 18, and 19. The best fit straight line was determined by visual placement. Figure 17 is for the parameters for which no yearly cycle was indicated. Figures 18 and 19 are for the periods November 1 to April 30 and May 1 to October 31, respectively, for those parameters for which a yearly cycle was defined. Plots are given for the linear and logarithmic scales the same as for Plant E. These plots were compared visually to determine the best estimate of the type distribution of the data. For those elements exhibiting a cycle, the distribution of the data was assumed the same for both periods in order to simplify the calculations.

Table 34 lists the various parameters and the assumed distribution based on this comparison. The following elements were assumed to exhibit no cycle and be lognormal: Cu, Mn, and suspended solids. Zinc was assumed to exhibit no cycle and be normal. For those elements which were assumed to exhibit a yearly cycle, the following were assumed lognormal: Ca, dissolved solids, Fe, Mg, pH, Cu, Mn, and suspended solids, and the following were assumed normal: Al, As, Se, and sulfate.
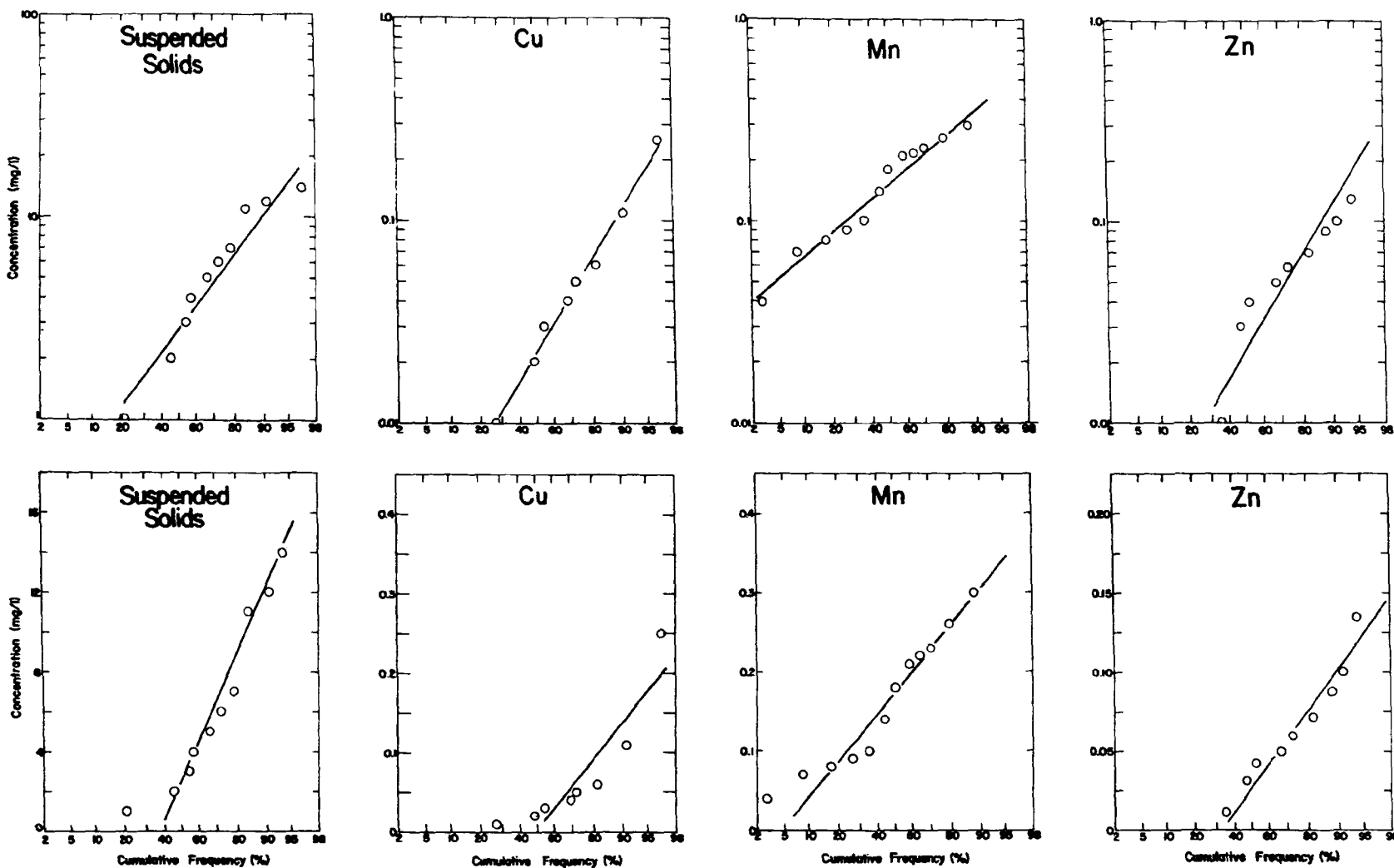
Figure 17.   Cumulative Frequency Plots for the Ash Pond Effluent at Plant J for the Period January 1 to December 31
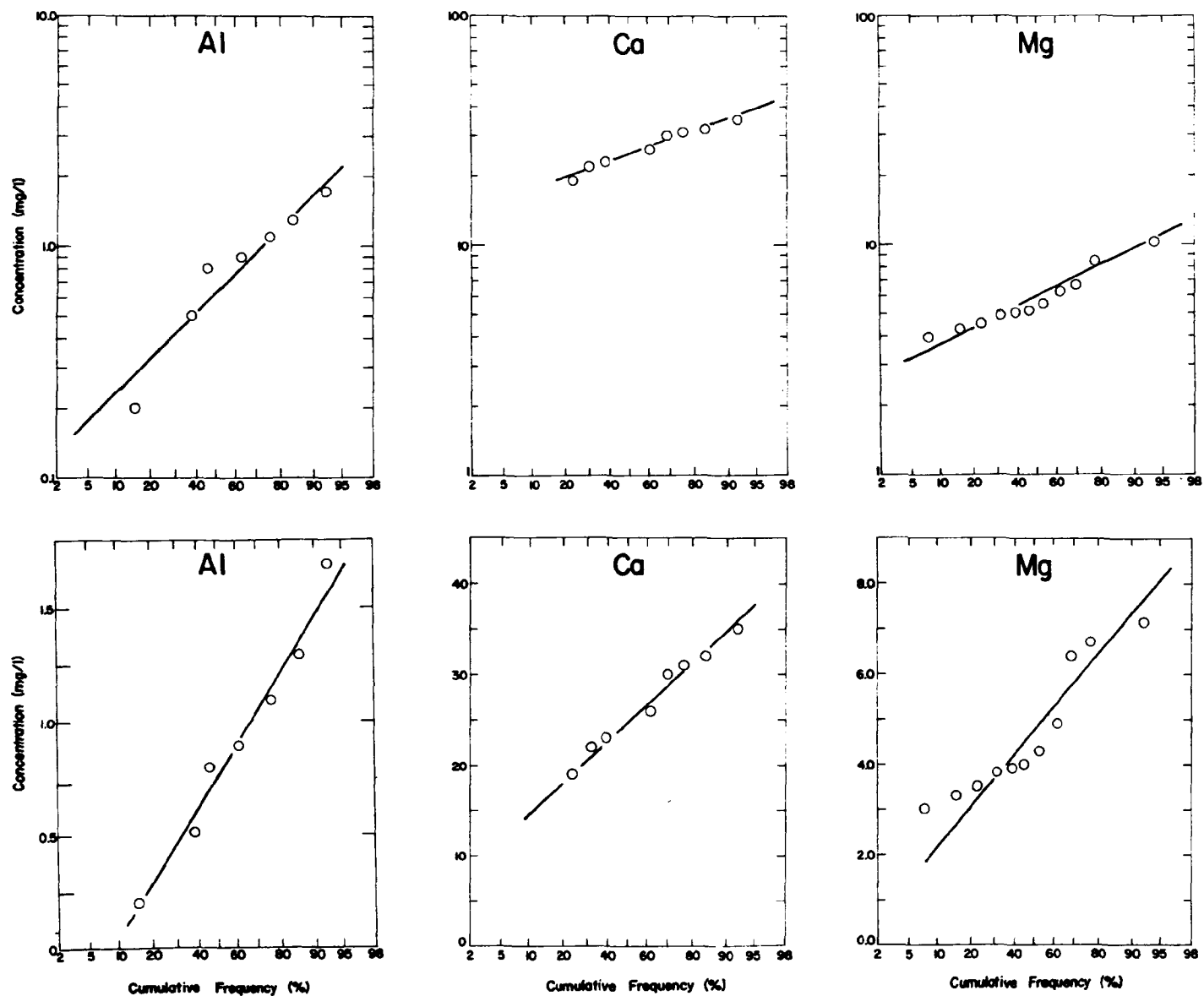
Figure 18. Cumulative Frequency Plots for the Ash Pond Effluent at Plant J
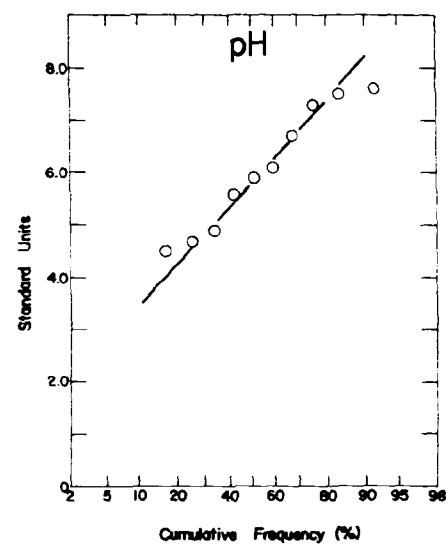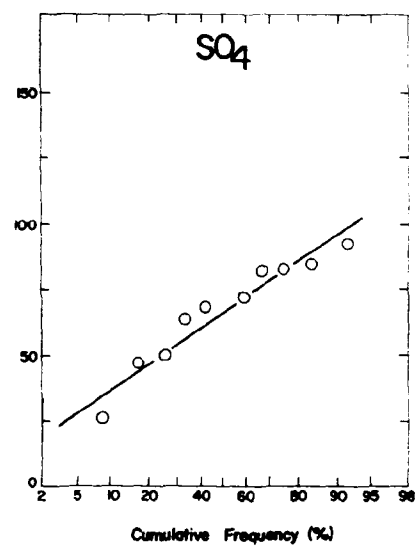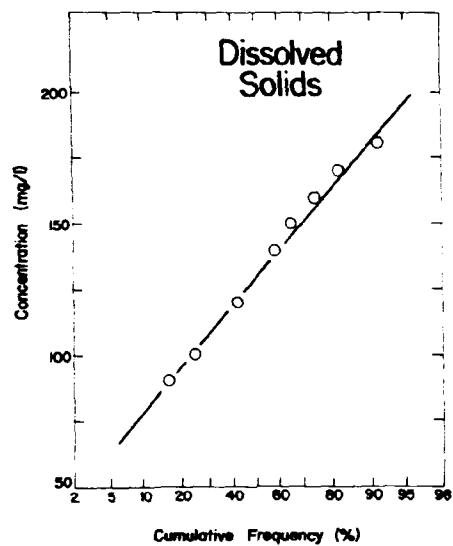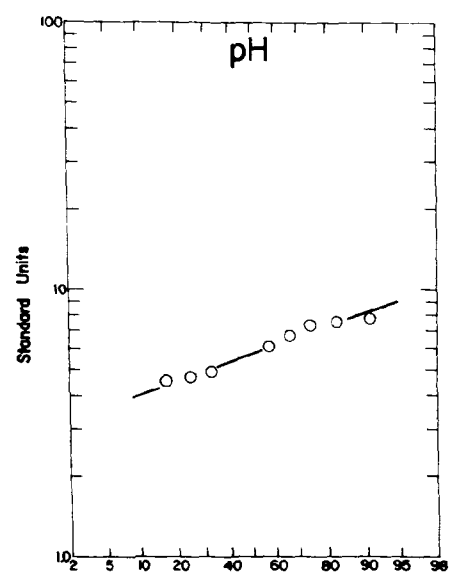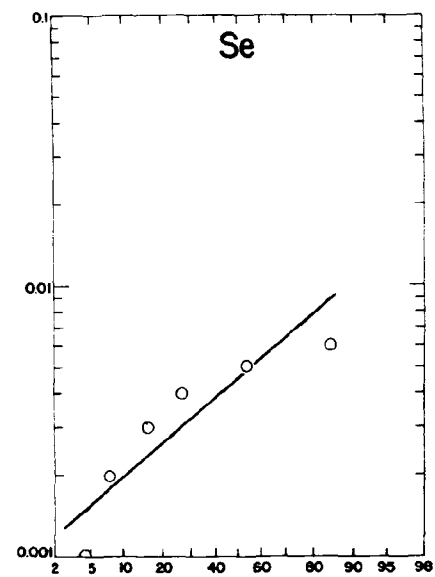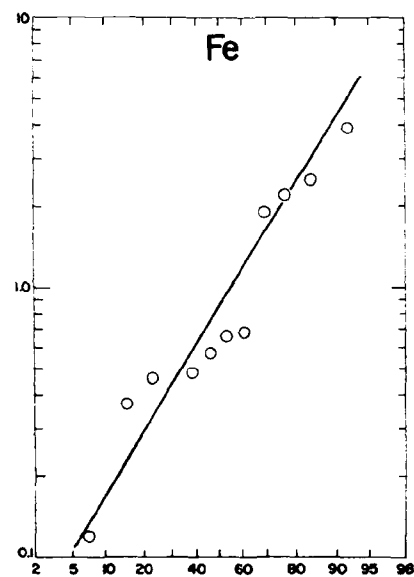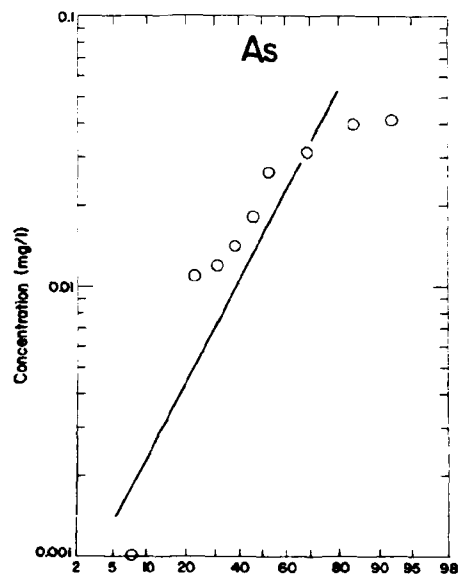for the Period November 1 to April 30.
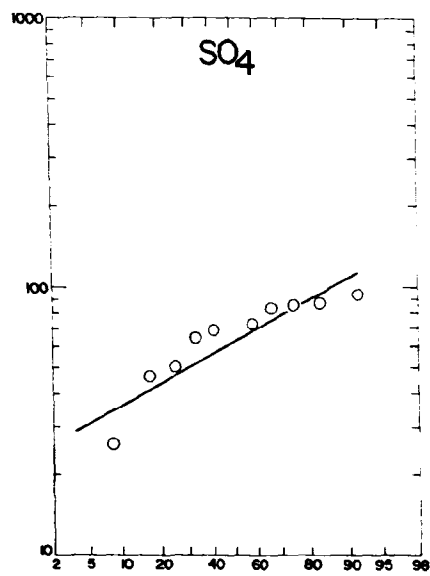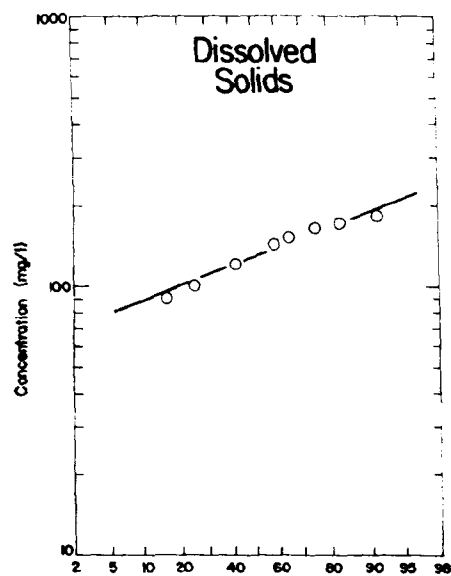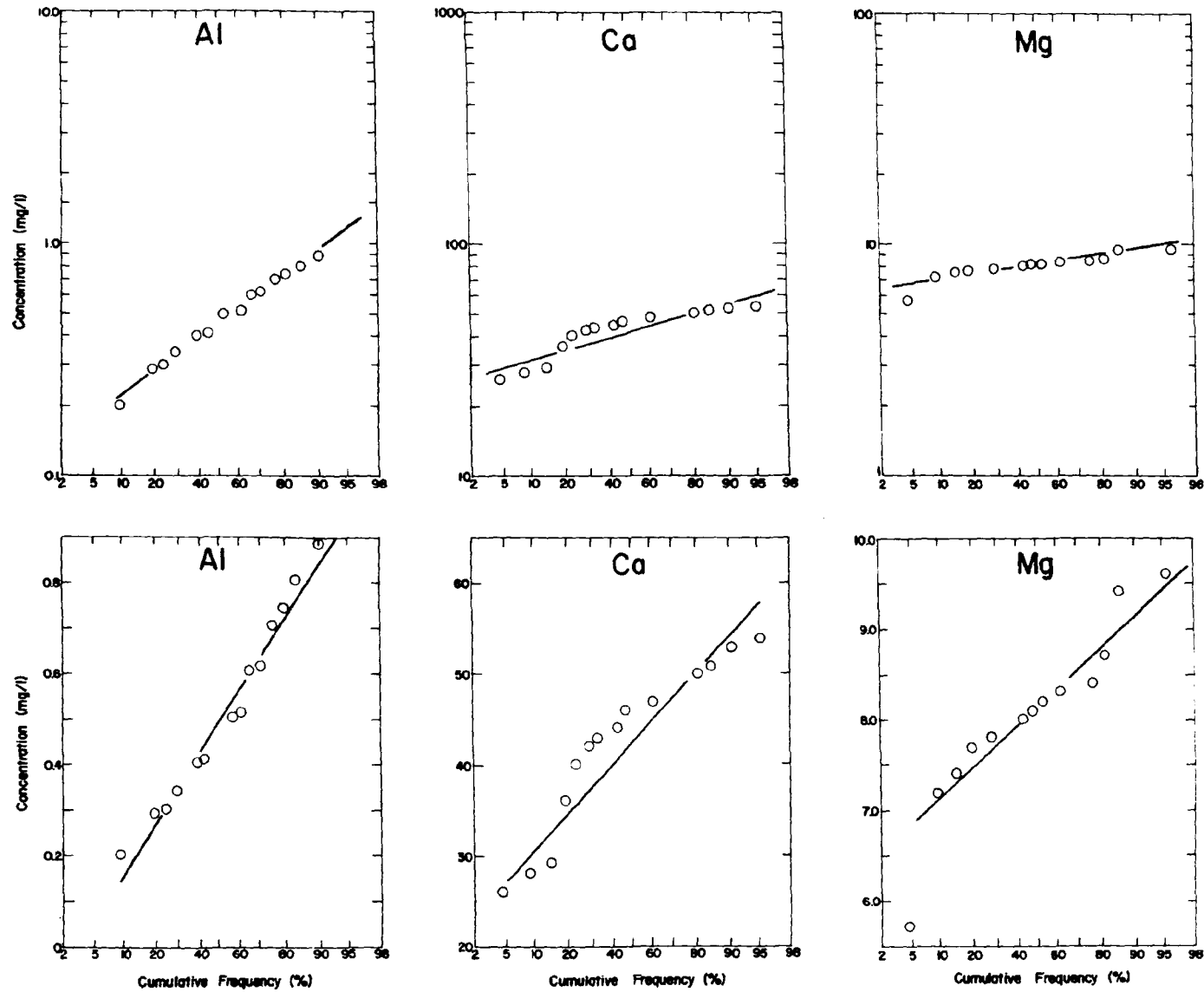
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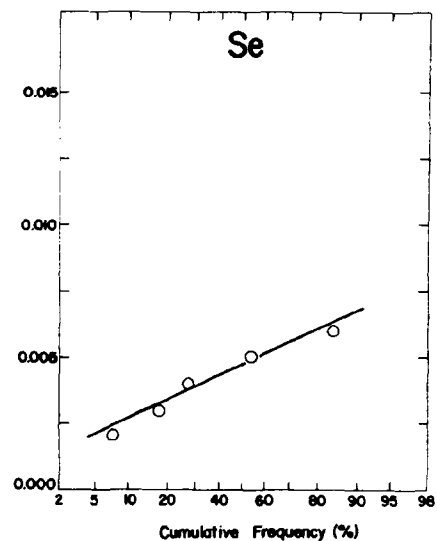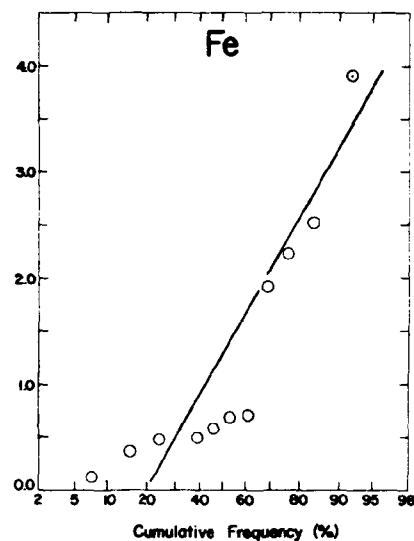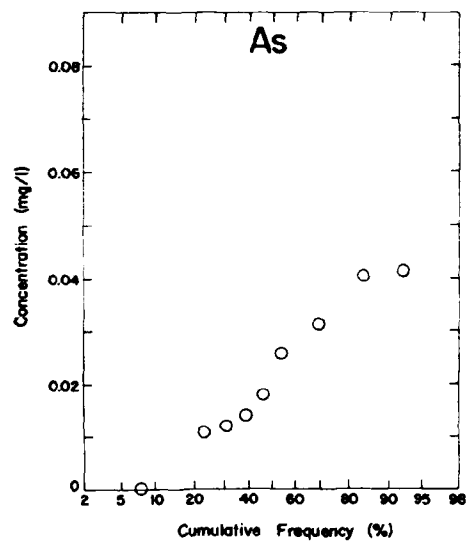
Figure 18 (Continued)

Figure 19. Cumulative Frequency Plots for the Ash Pond Effluent at Plant J
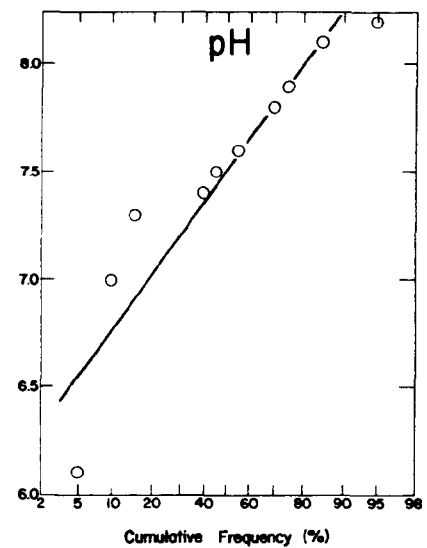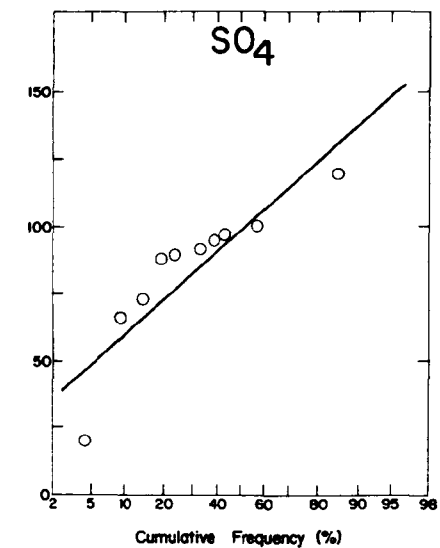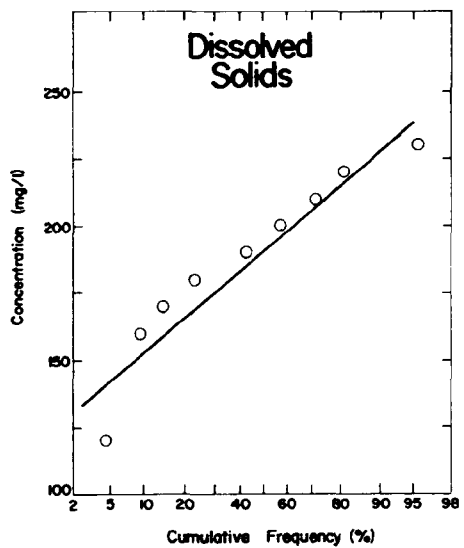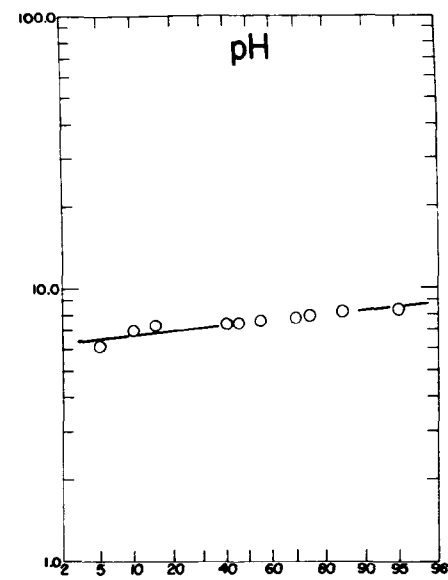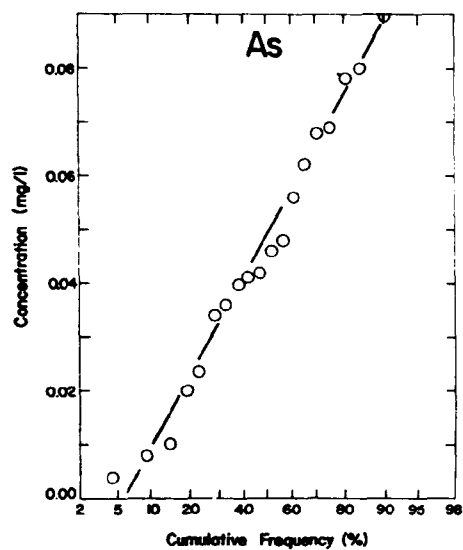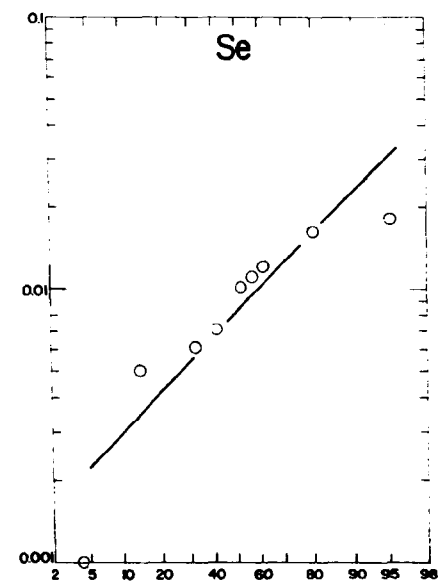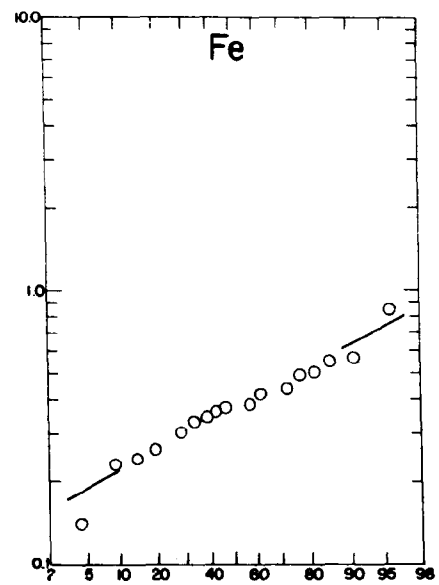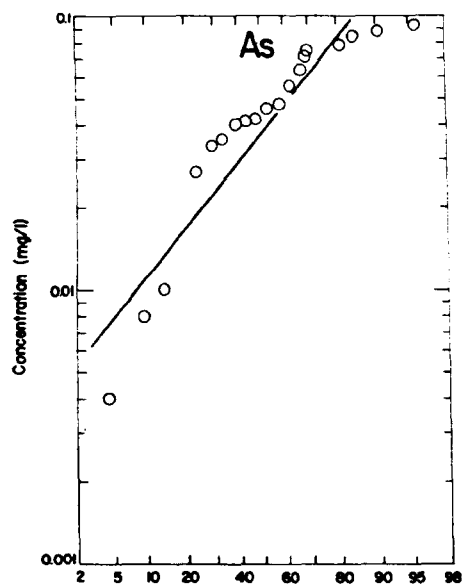for the Period May 1 to October 31
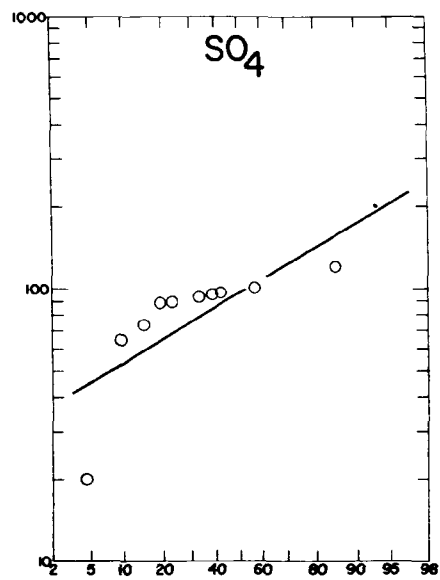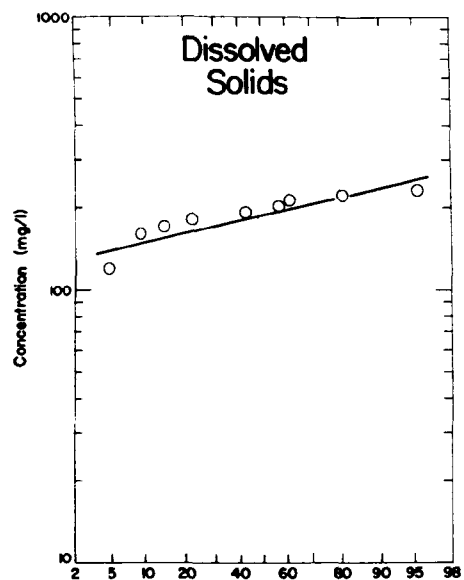
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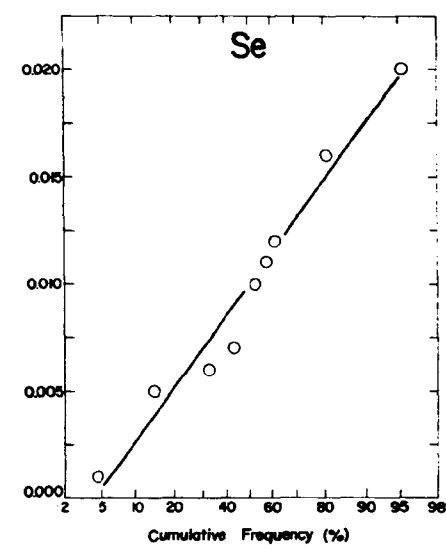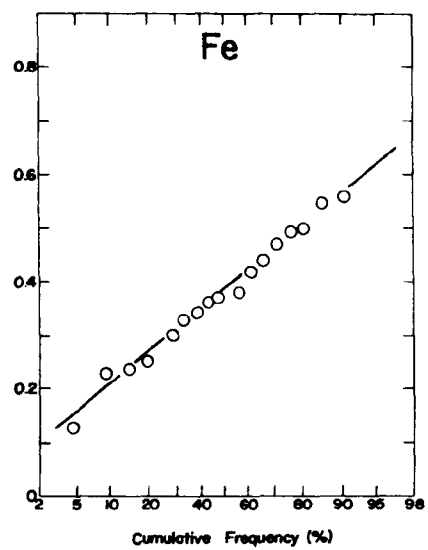
Figure 19 (Continued)

TABLE 34. SELECTED SAMPLING PERIOD, TYPE OF DISTRIBUTION AND STATISTICAL CHARACTERISTICS OF THE ASH POND EFFLUENT AT PLANT J

Parameter	Sample Period[a]	Type of Distribution	Mean[b]	Variance[b]	Number of Samples	$(S^2)(t^2)$ for various confidence levels[c]		
						99%	95%	80%
Aluminum	1	Normal	0.88	0.2631	13	2.456	1.274	0.489
	2	Normal	0.52	0.0513	21	0.415	0.223	0.090
Arsenic	1	Normal	0.024	0.0002	13	0.0019	0.0010	0.0004
	2	Normal	0.054	0.0014	21	0.011	0.006	0.002
Calcium	1	Lognormal	1.415	0.0108	13	0.101	0.052	0.020
	2	Lognormal	1.645	0.0105	21	0.085	0.046	0.018
Dissolved Solids	1	Lognormal	2.125	0.0127	12	0.123	0.062	0.024
	2	Lognormal	2.295	0.0049	21	0.040	0.021	0.009
Iron	1	Lognormal	-0.054	0.2095	13	1.956	1.015	0.389
	2	Lognormal	-0.415	0.0381	21	0.308	0.166	0.067
Magnesium	1	Lognormal	0.683	0.0215	13	0.201	0.104	0.040
	2	Lognormal	0.913	0.0027	21	0.022	0.012	0.005
pH	1	Lognormal	0.775	0.0084	12	0.081	0.041	0.016
	2	Lognormal	0.881	0.0010	20	0.008	0.004	0.002
Selenium	1	Normal	0.005	0.000003	13	0.00003	0.00001	0.000006
	2	Normal	0.011	0.00003	21	0.0002	0.0001	0.00005
Sulfate	1	Normal	70	444	12	4283	2151	825
	2	Normal	101	689	21	5577	2998	1210
Copper	3	Lognormal	-1.507	0.1904	32	1.435	0.792	0.326
Manganese	3	Lognormal	-0.804	0.628	33	0.472	0.261	0.108
Suspended Solids	3	Lognormal	0.540	0.1737	32	1.309	0.723	0.298
Zinc	3	Normal	0.050	0.0024	33	0.018	0.010	0.004

[a]Sample period number 1 is from November 1 to April 30. Sample period number 2 is from May 1 to October 31. Sample period number 3 is for the entire year.

[b]The values given for lognormal distribution are for the logarithms of the concentrations while those for normal distributions are for the untransformed concentrations.

[c]See equation 3 for definition of $(S^2)(t^2)$.

These assumption are in agreement with those for the effluent at Plant E. Exceptions, however, are Al, pH, and Zn. Table 34 contains additional information which will be discussed in the following subsection.

Table 35 gives the mean, appropriate ash pond effluent limitation or proposed water quality criteria and the probability that these limitations or criteria are exceeded for the effluent parameters assuming a normal distribution. Table 36 gives the mean of the logarithms of the concentrations, the logarithm of the geometric mean, appropriate ash pond effluent limitation or proposed water quality criteria and the probability that these limitations or criteria are exceeded for the effluent parameters assuming a lognormal distribution. All calculations for lognormal distributions will be based on the values given in Table 36 for the logarithm of the geometric mean.

The effluent limitations given in Tables 35 and 36 for pH and suspended solids are those outlined for the steam-electric power generating industry by EPA in 1974 (1) for the achievement, by 1977, of best practicable control technology currently available (BPCTCA). The pH is to be maintained between 6 and 9 and the average daily suspended solids for a 30-day period is to be at or below 30 mg/l with a daily maximum equal to or less than 100 mg/l. Since limitations for the ash pond effluent at Plant J for the remaining elements have not yet been promulgated, the criteria specified in EPA's "Water Quality Criteria" (9) for domestic water supply intakes are used. A list of the criteria are given in Appendix C. This does not suggest that the ash pond effluent should meet these criteria. They are only given for comparison purposes and as an aid in establishing the desired precision for the future monitoring program. The data in Table 36 show that the pH during the sample period November 1 to April 30 is not in the pH range of 6 to 9 approximately 62 percent of the time. However, during the period May 1 to October 31 the pH is not in the 6 to 9 range less than 2 percent of the time. The suspended solids concentration is above 30 mg/l less than 2 percent of the time. Arsenic and selenium are shown to be above the EPA proposed water quality criteria approximately 50 percent of the time during the period May 1 to October 31, but during the remainder of the year, only exceed the criteria 4 percent and less than 2 percent of the time, respectively. Iron and manganese were above the criteria greater than 70 percent and 95 percent of the time, respectively. Copper, sulfate, and zinc exceeded the criteria less than 2 percent of the time.

ESTIMATION OF THE MEAN AS A FUNCTION OF THE PRECISION

The number of samples, n, required to estimate the mean as a function of L was plotted for each parameter based on the data given in Table 34 and equation 3. The results are shown in Figures 20, 21, and 22. Figure 20 is for those parameters to be sampled during the period January 1 to December 31. Figures 21 and 22 are for those parameters for which the data set was divided into two periods. They were constructed by dividing the values shown under the column labeled "$(S^2)(t^2)$" in Table 34 by various values of $(L)^2$ to yield various sample sizes, n. The values for $(S)^2(t)^2$ given in Table 34 were obtained by multiplying the variance, S^2, times the appropriate t value squared. The values

TABLE 35. COMPARISON OF THE ASH POND EFFLUENT CHARACTERISTICS FOLLOWING
A NORMAL DISTRIBUTION AT PLANT J WITH THE ASH POND EFFLUENT LIMITATIONS
OR WATER QUALITY CRITERIA

Parameter	Sample Period	Mean of the Concentrations (mg/l)	Standard or Water Quality Criteria (mg/l)	Probability that Standard is Exceeded
Aluminum	1	0.88	b	-
	2	0.52	b	-
Arsenic	1	0.024	0.05^c	4
	2	0.054	0.05^c	50
Selenium	1	0.005	0.01^c	<2
	2	0.011	0.01^c	50
Sulfate	1	70	250^c	<2
	2	101	250^c	<2
Zinc	3	0.05	5.0^c	<2

[a] 1 = November 1 to April 30; 2 = May 1 to October 31;
3 = January 1 to December 31.

[b] No criteria proposed for drinking water supplies.

[c] Proposed EPA intake standards for domestic drinking water supplies
(EPA 1976).

TABLE 36. COMPARISON OF THE ASH POND EFFLUENT CHARACTERISTICS FOLLOWING A
LOGNORMAL DISTRIBUTION OF PLANT J WITH THE ASH POND EFFLUENT LIMITATIONS
OR WATER QUALITY CRITERIA

Parameter	Sample Period[a]	Mean of the Logarithms of the Concentrations[b]	Logarithms of the Geometric Mean[c]	Standard or Water Quality Criteria (log mg/l)	Probability that Standard is Exceeded
Calcium	1	1.415	1.362	d	-
	2	1.645	1.602	d	-
Dissolved Solids	1	2.125	2.114	d	-
	2	2.295	2.280	d	-
Iron	1	-0.054	-0.060	0.3^e	80
	2	-0.415	-0.420	0.3^e	70
Magnesium	1	0.683	0.771	b	-
	2	0.913	0.903	b	-
pH	1	0.775	0.756	6 to 9^f	62
	2	0.881	0.863	6 to 9^f	<2
Copper	3	-1.507	-1.658	1.0^e	<2
Manganese	3	-0.804	-0.854	0.05^e	95
Suspended Solids	3	0.540	0.415	30^f	<2

[a] 1 = November 1 to April 30; 2 = May 1 to October 31; 3 = January 1 to December 31.

[b] Values given are logarithms to the base 10 of the concentrations in mg/l.

[c] Values given are the logarithms to the base 10 of the estimated mean in mg/l.

[d] No criteria proposed for drinking water supplies.

[e] Proposed EPA intake standards for domestic drinking water supplies (EPA 1976).

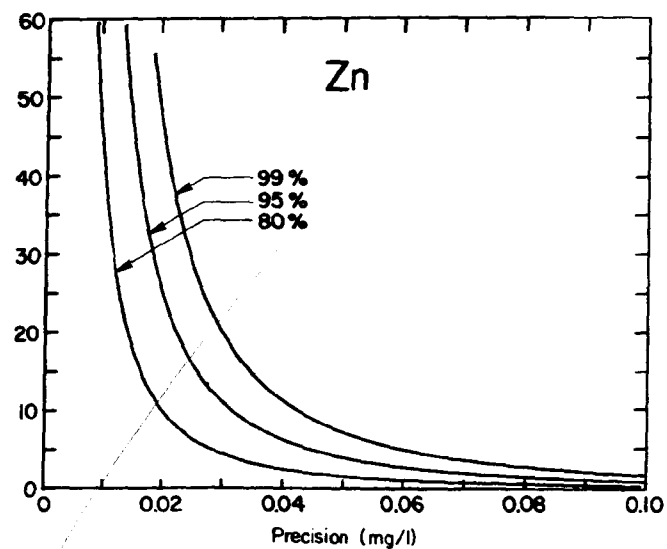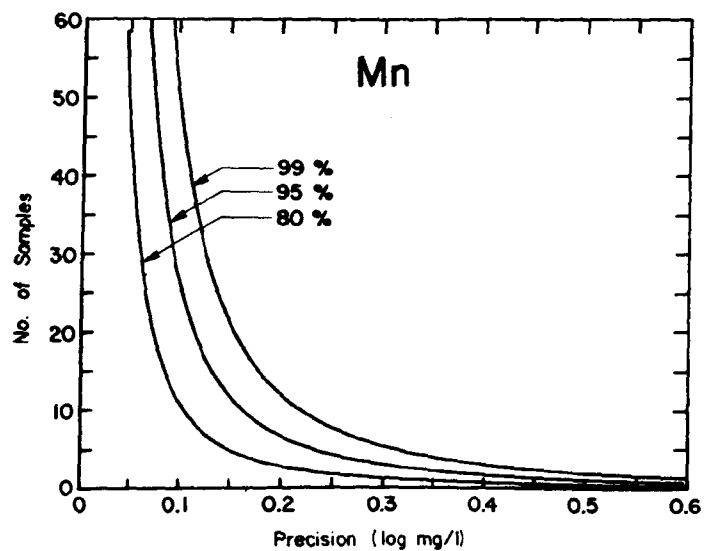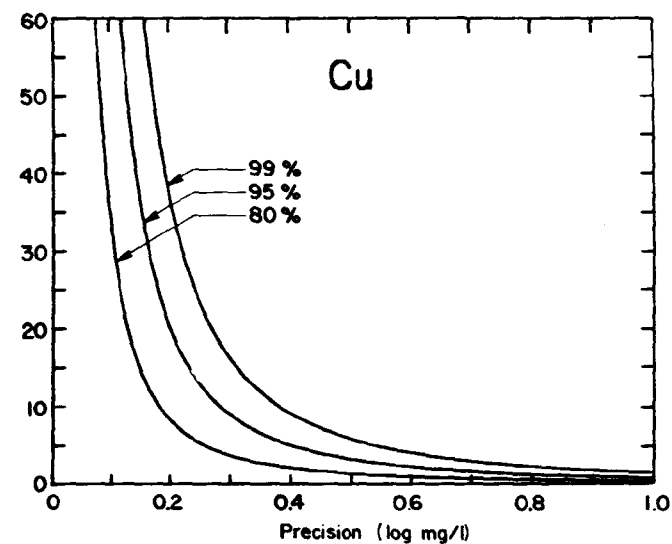[f] *Effluent limitation specified in the NPDES permit.*

Figure 20. Number of Samples Required for a Given Precision for the Ash Pond Effluent
at Plant J for the Period January 1 to December 31

Figure 21. Number of Samples Required for a Given Precision for the Ash Pond Effluent
at Plant J for the Period November 1 to April 30
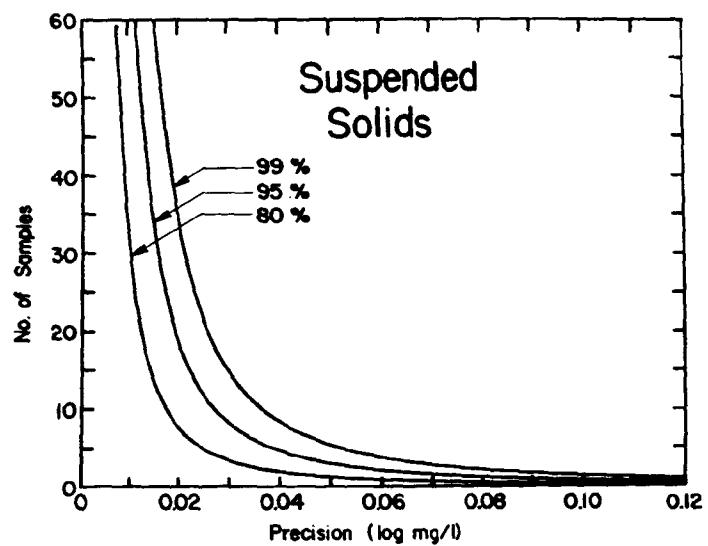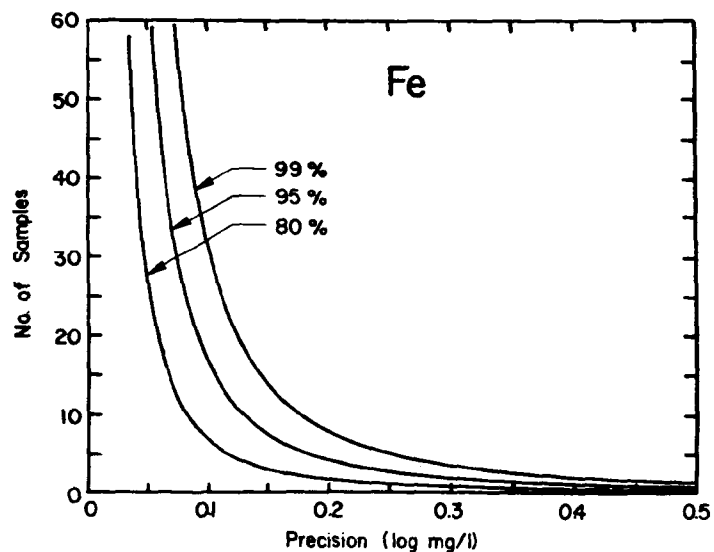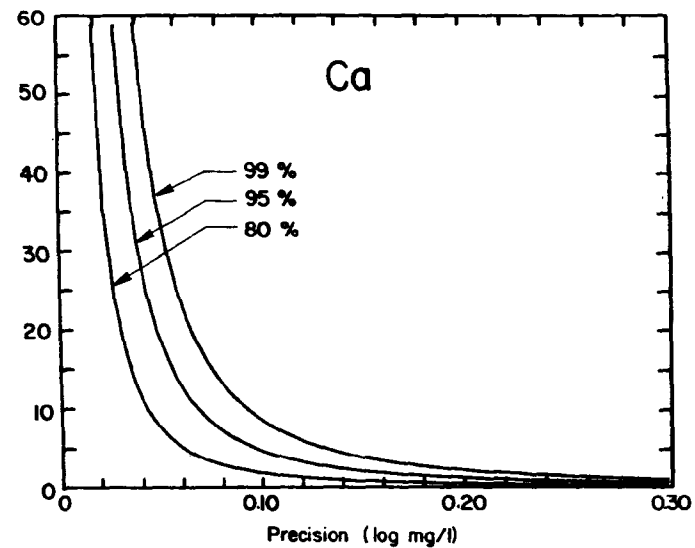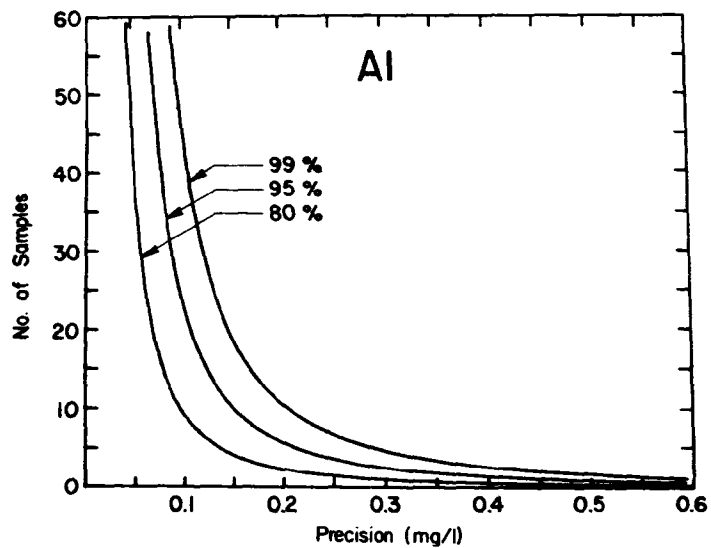
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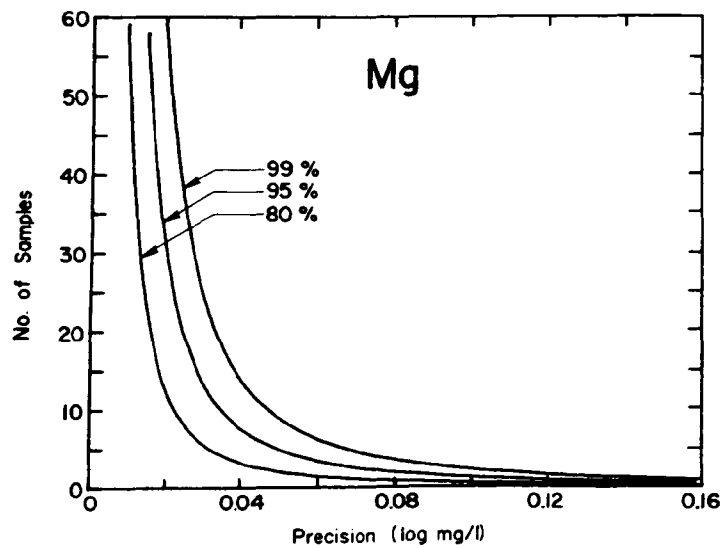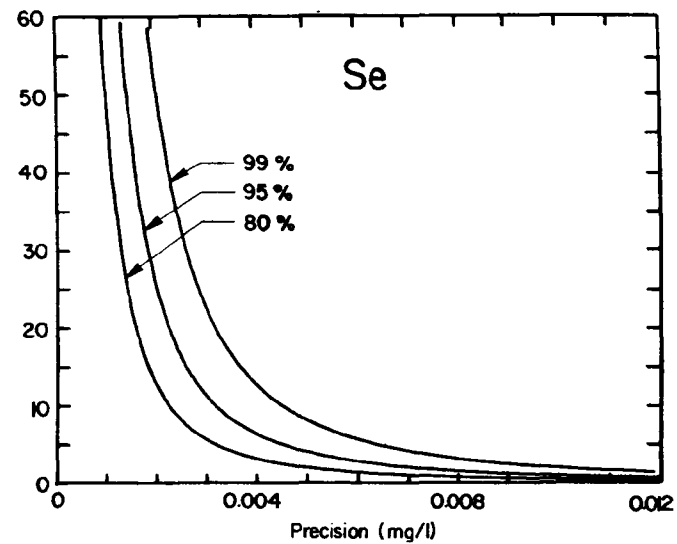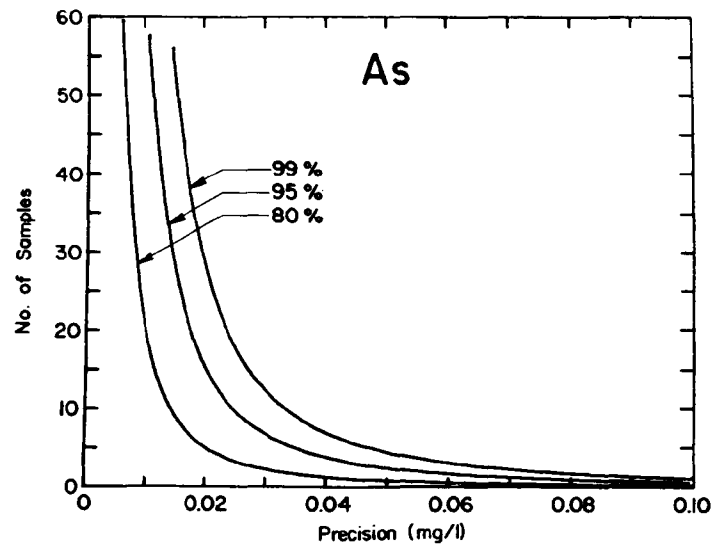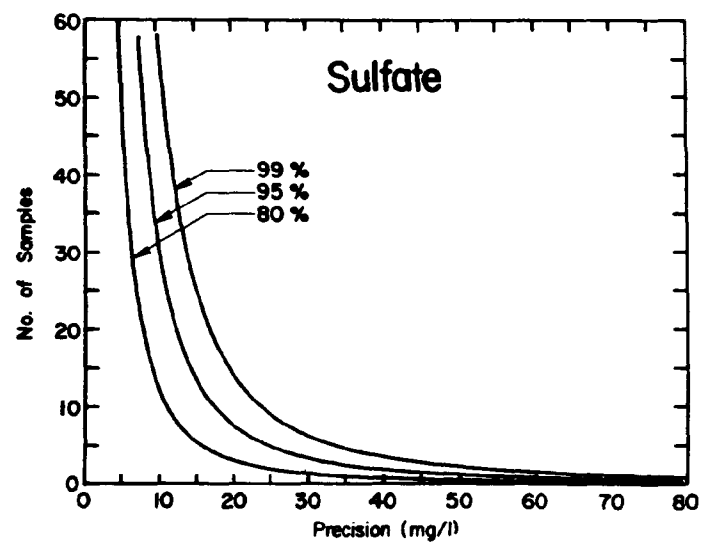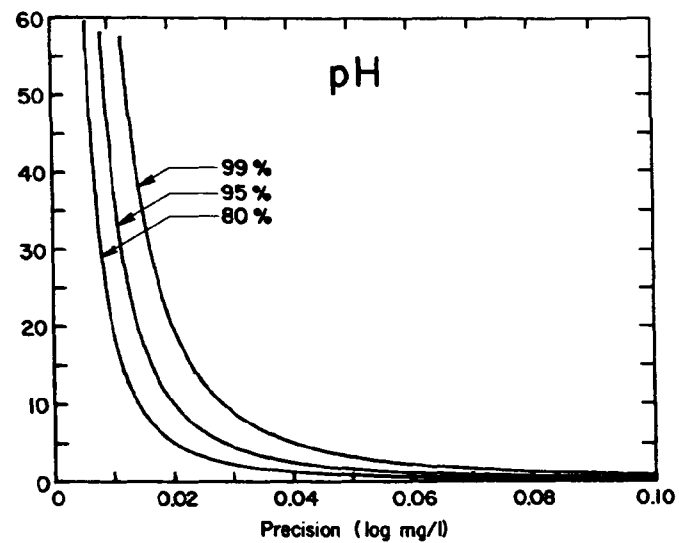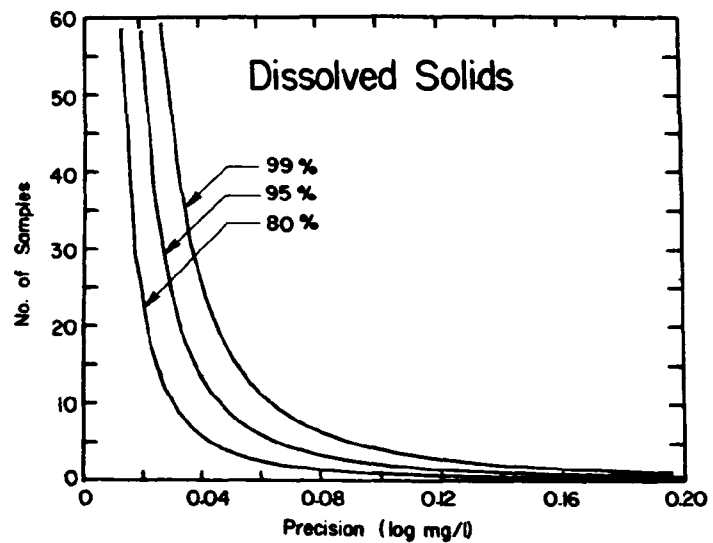
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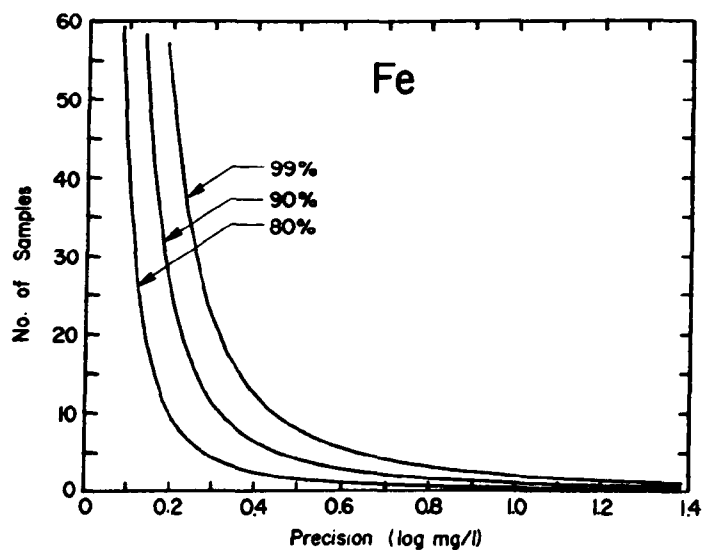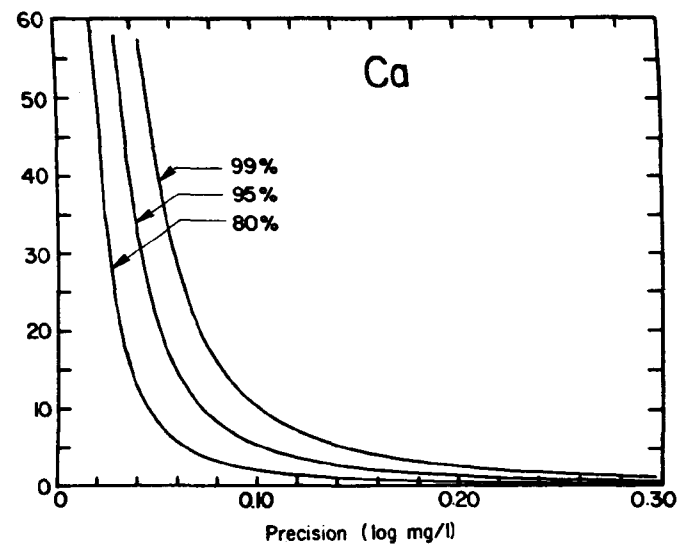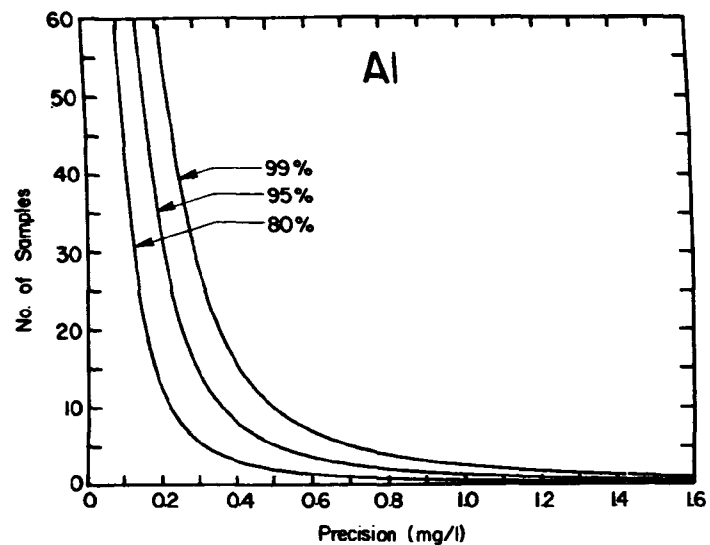
Figure 22. Number of Samples Required for a Given Precision for the Ash Pond Effluent at Plant J for the Period May 1 to October 31
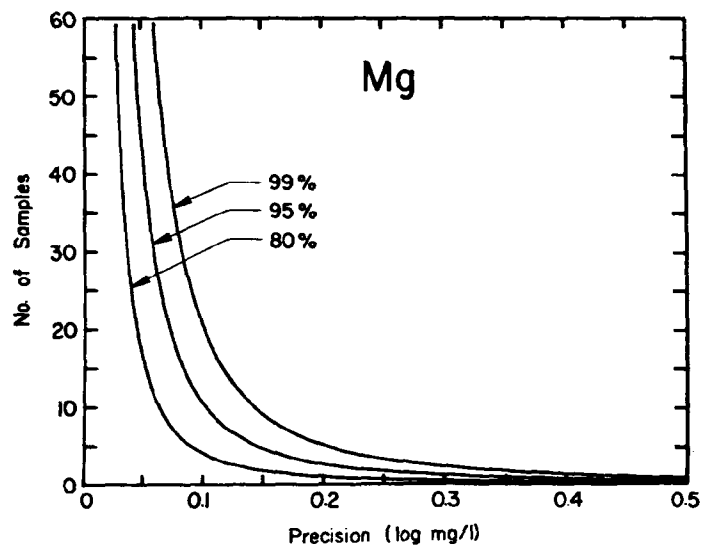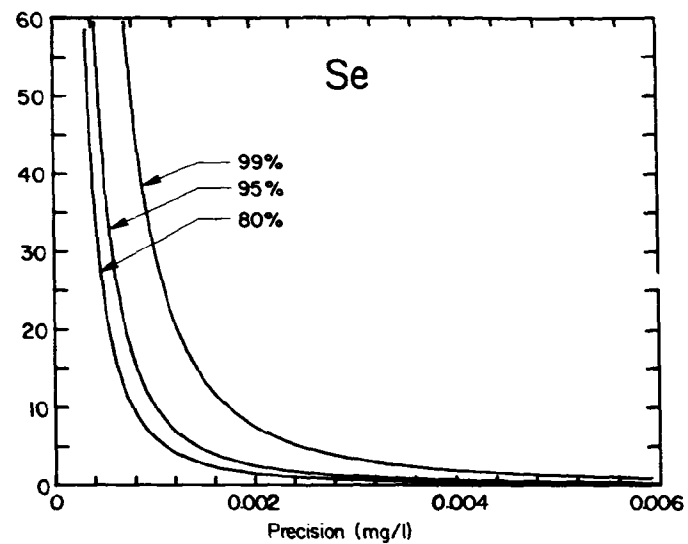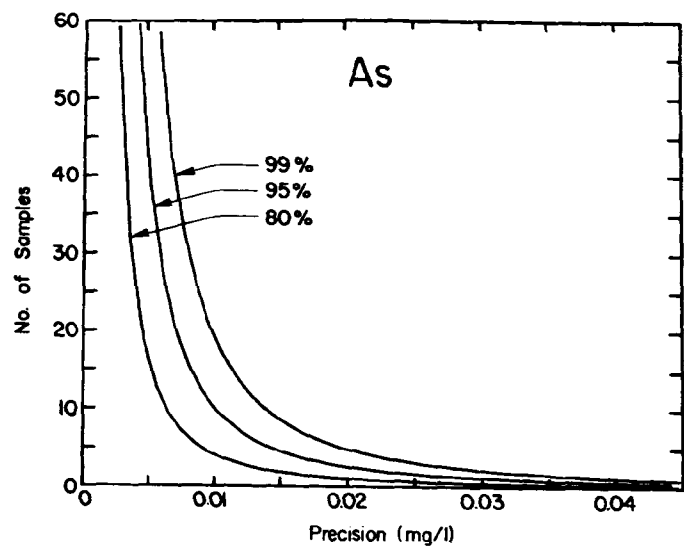
Figure 22 (Continued)
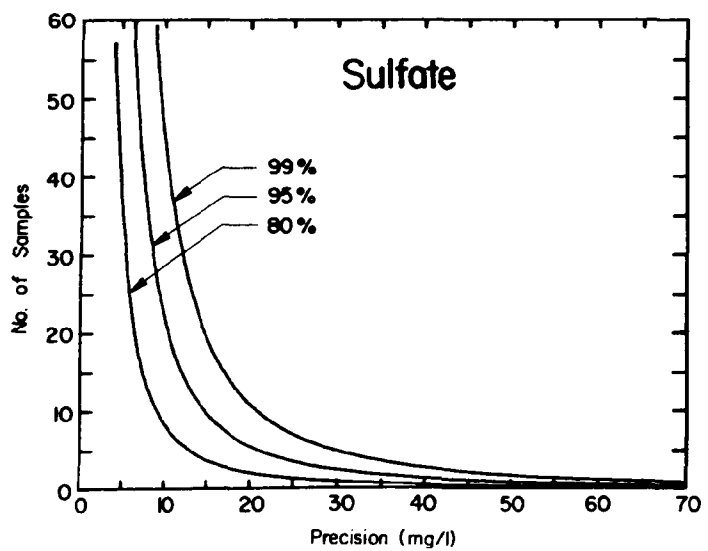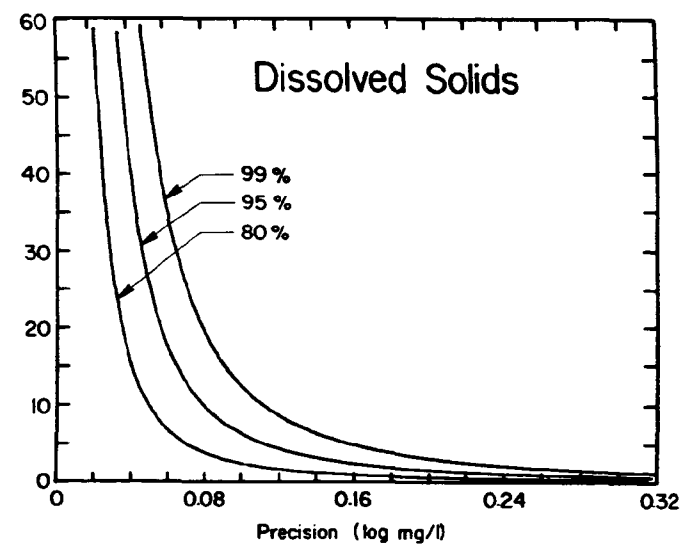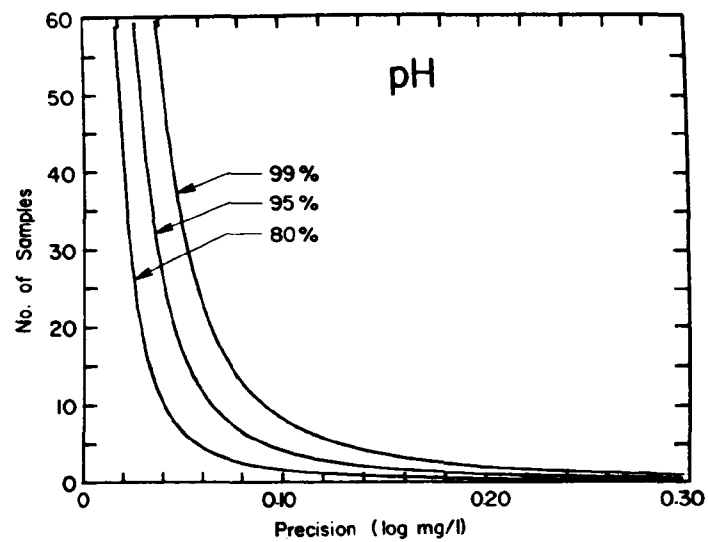
Figure 22 (Continued)

used for t are a function of the confidence level and number of data points used to generate the variance. The t values necessary for calculating the $(S)^2(t)^2$ values in Table 34 are given in Appendix D.

SELECTION OF THE PRECISION

The upper and lower limits (ℓ_1 and ℓ_2) for the critical range of the precision at the 99 percent confidence level for the ash pond efflu-ent characteristics at Plant J are given in Table 37. The upper limit given is for the precision produced by one sample. However, for all elements, the curve had become asymptotic to the x-axis at a precision less than the upper limit given in Table 37 indicating the precision could be increased significantly by the addition of one more sample. The upper limit of the critical range was given based on one sample because that precision may be adequate for the monitoring program. The lower limit given is for the precision produced by 52 samples because the curve had not become asymptotic to the y-axis for any of the elements. This assumes resources are not available for the collection or analysis of more than 52 samples in any one sample period. If the value for the precision required for the monitoring program is greater than the upper limit, only one sample per period needs to be collected. However, if the value is less than the lower limit, then 52 samples per period would be required. If for some reason the precision for 52 samples is not adequate for an element of a monitoring program, then a decision would have to be made whether or not to increase the level of resources allocated to the monitoring program. If the required precision is between the limits, then the data in Figures 20, 21, or 22 would be consulted to determine the sampling frequency. Table 37, therefore, gives valuable insight into the importance of the required precision on the design of an ash pond effluent monitoring program for Plant J.

Suspended solids and pH are the only parameters included in this study for which ash pond effluent limitations have been set for Plant J. The design procedure discussed in Section 4, using the relationship, $L = \mu - X$, can only be applied to suspended solids and pH during the period from May 1 to October 31. The precision required for suspended solids is calculated by subtracting the estimate of the geometric mean of the logarithms of the data given in Table 32 for suspended solids (0.415, see Table 36) from 1.477 (log of the effluent limitation of 30 mg/l). This yields a precision of 1.062. The precision required for the pH during the period May 1 to October 31 is calculated by substi-tuting 0.778 (log 6) for μ and 0.903 for X. This yields a value of 0.125 for the precision.

Defining the precision which should be used to design the monitoring program at Plant J is difficult where effluent limitation have not yet been promulgated. One method is to assume some precision based on a given percentage of the sample mean. For comparison purposes, sampling frequencies based on estimating the yearly mean within 10 and 20 percent of the true mean at the 99 and 80 percent significance levels will be discussed in the next subsection. Another method for establishing the precision L is to allow for a certain level of environmental harm (or pollutant loading to the receiving stream). This cannot be done

TABLE 37. UPPER AND LOWER LIMITS FOR THE CRITICAL RANGE OF
THE PRECISION FOR THE EFFLUENT CHARACTERISTICS OF PLANT J

Element	Sample Period	Lower Limit of L (mg/l)	Upper Limit of L (mg/l)
Elements following a normal distribution			
Aluminum	1	0.217	1.57
	2	0.089	0.644
Arsenic	1	0.006	0.044
	2	0.015	0.105
Selenium	1	0.0008	0.0055
	2	0.002	0.014
Sulfate	1	9	65
	2	10	75
Zinc	3	0.018	0.134
Elements following a lognormal distribution			
Calcium	1	0.044	0.318
	2	0.040	0.292
Dissolved Solids	1	0.049	0.351
	2	0.028	0.200
Iron	1	0.194	1.399
	2	0.077	0.555
Magnesium	1	0.062	0.448
	2	0.021	0.148
pH	1	0.039	0.028
	2	0.012	0.089
Copper	3	0.166	1.198
Manganese	3	0.095	0.687
Suspended Solids	3	0.159	1.144

without some estimate of the receiving stream water quality. The effluent was discharged directly to the river (although upstream of the water intake) during the period when the data in Table 32 was collected. The effluent discharge location was changed after the data in Table 32 was collected. The ash pond effluent at Plant J now discharges to the main water intake canal serving the entire power plant at a location upstream of the main intake pumps. Only a small fraction of this intake water (~4%) is used for ash sluicing. The remainder is used for condenser cooling water and other miscellaneous processes. This new discharge location creates some degree of water reuse for ash sluicing. The degree of reuse depends on the mixing of the streams. For the purposes of this study, complete mixing will be assumed creating a very low degree of reuse. The ash pond effluent characteristics can then be assumed equal to those for the once-through system given in Table 32. The water quality characteristics shown in Table 38 will be assumed for the stream receiving the ash pond effluent from Plant J. These values are based on the 1976 data for the intake water to Plant J. They differ somewhat from the data given in Table 5 for the intake water during 1974 and 1975 mainly because of the precision involved in developing the average.

The significance level and precision for the data in Table 38 are not specified. For design purposes the values will be assumed to be absolute. In addition, some dilution factors and maximum allowable concentrations in the receiving stream must be specified. The dilution factor assumed for Plant J's ash pond effluent into the intake water stream is approximately 0.0435. It is based on an intake water flow of 1200 MGD and a maximum ash pond effluent flow of 50 MGD (~34,800 gpm). The maximum ash pond flow was assumed based on the highest reported value in Table 32. The calculations for the precision are the same as for Plant E. However, the value substituted for the sample mean, $\bar{X}$, in equation 2 for those elements which were divided into two data sets was calculated by averaging the means for the different sample periods. This had to be done as opposed to taking the mean of the entire data because there were more samples taken during the second period, therefore, baising the mean. But by assuming the events to be random within a subset of the data, the mean of the entire data set can be estimated by averaging the weighted subset means. In this case, the periods of the subsets were equal, therefore, the mean of the entire data set could be estimated by simply adding the subset means and dividing by 2. The geometric means were used for those parameters following a lognormal distribution.

Table 39 gives the allowable ash pond input concentration to the receiving stream and precision required by the monitoring program, assuming the maximum allowable average concentration in the receiving stream is based on maintaining the concentration in the receiving stream equal to or below the EPA proposed water quality criteria for domestic water supply intakes. Table 40 gives the same information for a monitoring program assuming the maximum allowable average concentration in the receiving stream is below or equal to the maximum value given in Table 38. The sampling frequencies associated with these precisions will be discussed in the following section.

TABLE 38. ASSUMED WATER QUALITY CHARACTERISTICS FOR
THE RECEIVING STREAM AT PLANT J

Element	Average Concentration (mg/l)	Maximum Concentration (mg/l)
Aluminum	0.45	0.60
Arsenic	0.006	0.010
Calcium	17.7	33
Copper	0.035	0.050
Dissolved Solids	81	140
Iron	0.5	0.84
Magnesium	4.7	8.4
Manganese	0.086	0.120
Selenium	0.002	0.002
Sulfate	17	26
Suspended Solids	6	12
Zinc	0.013	0.020

TABLE 39. REQUIRED PRECISION FOR THE MONITORING PROGRAM AT PLANT J
ASSUMING AN AVERAGE ALLOWABLE CONCENTRATION IN THE RECEIVING STREAM
EQUAL TO THE EPA PROPOSED WATER QUALITY CRITERIA

Element	Maximum Average Allowable Concentration In the Effluent (mg/l)	Required Precision
Arsenic	1.062	1.023
Iron	a	-
Selenium	0.194	0.186
Sulfate	5600	5515
Copper	23	3.02
Manganese	a	-
Zinc	120	119.95

a. Intake water exceeds the criteria.

TABLE 40. REQUIRED PRECISION FOR THE MONITORING PROGRAM AT PLANT J ASSUMING AN AVERAGE ALLOWABLE CONCENTRATION IN THE RECEIVING STREAM EQUAL TO THE MAXIMUM VALUE REPORTED FOR THE INTAKE WATER

Element	Maximum Average Allowable Concentration in the Effluent (mg/l)	Required Precision
Aluminum	4.05	3.35
Arsenic	0.102	0.063
Calcium	385	1.103
Dissolved Solids	1497	0.978
Iron	8.66	1.178
Magnesium	93.5	1.134
Selenium	0.002	a
Sulfate	233	147
Copper	0.40	1.26
Manganese	0.90	0.808
Suspended Solids	150	1.76
Zinc	0.18	0.13

[a]The reported ash pond effluent concentration exceeds the maximum average allowable concentration calculated by this method; therefore, the procedure developed in Section 4 for determining the number of samples to show compliance with a selected water quality criteria cannot be used.

ESTIMATED SAMPLING FREQUENCIES

The precision required to determine the minimum number of samples needed to show that the ash pond effluent for Plant J is in compliance with the effluent limitation for suspended solids was calculated to be 1.062. This value falls within the critical range of the deviation for suspended solids indicating the number of samples can be determined from Figure 20. For the 99 percent confidence level, this means two samples per sample period are required. Since the effluent limitation specifies that the concentration must not exceed an average of 30 mg/l for 30 consecutive days, the number of samples derived from Figure 20 represents a sampling frequency of two samples per 30 days or 24 samples per year assuming 30 days per month. This yields a sampling frequency of one sample every 15 days. This assumes, of course, that the variance obtained for the data over the period of the extensive sampling program and used to construct Figure 20, is equal to the variance had the period of the survey been any one month and the same number of samples been collected. This assumption is valid when the data are randomly distributed. Corresponding sampling frequencies for both the 95 and 80 percent confidence levels would be one sample per month.

The sampling frequency of one sample per 15 days (2 per month) for the 99 percent significance level is the same sampling frequency currently being required by the NPDES permit. The 24 suspended solids samples per year allows estimation of the yearly geometric mean within 36 percent of the true yearly geometric mean and estimation of the monthly geometric mean within 66 percent of the true monthly geometric mean.

The average value reported for pH for the period May 1 to October 31 can be shown to be within the range of six to nine within 99 percent confidence by collection of one sample during the period. However, the mean for the period from November 1 to April 30 was less than 6 and, therefore, the sampling frequency to show compliance, could not be determined. Sampling the pH one time during the period May 1 to October 31 estimates the average pH to within ± 1.2 pH units.

The above estimates are appropriate if the average is interpreted to mean the geometric mean when dealing with lognormal data. The geometric mean is always smaller than the arthimetic mean, thus, in effect, creating a slightly higher standard when transforming the standard to a logarthim value and comparing it with the geometric.

Table 41 shows the number of samples required per year to estimate the yearly mean (geometric mean for lognormal data) within 20 percent of the true mean for the 99, 95, and 80 percent confidence levels. For those elements which were divided into two sampling periods, the number of samples per period are given in parenthesis. A substantial sampling effort (greater than 52 samples per year) would be required to estimate the yearly mean within 20 percent for As, Fe, Se, suspended soilds, and zinc at the 99 percent confidence level, whereas a minimal effort (only 1 sample per year) would be required for calcium and dissolved solids. The remaining parameters would require between 3 and 42 samples per year at the 99 percent confidence level. More samples for Al and Fe should be collected during the period from November 1 to April 30 than during the rest of the year, while just the opposite is true for As and Se.

TABLE 41. NUMBER OF SAMPLES REQUIRED TO ESTIMATE THE YEARLY MEAN WITHIN 20% OF THE TRUE YEARLY MEAN FOR PLANT J

Element	Number of Samples Required Per Year[a]		
	99% SL	95% SL	80% SL
Aluminum	42(29,13)	22(15,7)	9(6,3)
Arsenic	66(18,48)	34(9,25)	13(4,9)
Calcium	1(1,0)	1(1,0)	1(1,0)
Dissolved Solids	1(1,0)	1(1,0)	1(1,0)
Iron	290(203,87)	148(104,44)	105(74,31)
Magnesium	3(2,1)	2(1,1)	1(1,0)
pH	4(3,1)	2(1,1)	1(1,0)
Selenium	30(7,23)	16(4,12)	6(1,5)
Sulfate	12(5,7)	7(3,4)	3(1,2)
Copper	9	5	2
Manganese	11	6	3
Suspended Solids	122	68	28
Zinc	116	64	26

a. Numbers in parenthesis indicate the number of samples required during the period November 1 to April 30 and May 1 to October 31, respectively.

SL = Significance level.

Table 42 gives the estimated sampling frequencies for the precisions given in Tables 39 and 40. Table 42 indicates that one sample per year for all parameters except Al, As, and Zn ensures within 99 percent confidence that the yearly average concentration in the receiving stream will not be increased (by the ash pond effluent) above the maximum value reported in the intake water for 1976. Arsenic, aluminum, and zinc would require two samples per year for the same assurance. Likewise, only one sample per year for all parameters ensures within 99 percent confidence that the receiving stream's yearly average concentration will not be increased (by the ash pond effluent) above the EPA proposed water quality criteria for domestic drinking water intakes. Therefore, establishing monitoring frequencies based on maintaining the average concentration in the receiving stream equal to or below the maximum value reported in the intake water in 1976 automatically ensures monitoring frequencies as great or greater than those based on maintaining the average concentration in the receiving stream equal to or below the EPA proposed water quality criteria for domestic water supply intakes.

The sampling frequencies listed in Tables 41 and 42 differ considerably. The frequencies based on the assumed allowable level of increase in the receiving stream are substantially lower than those required to estimate the mean within 20 percent. The sampling frequency used in the final monitoring program should, therefore, be a compromise between the frequencies given in Tables 41 and 42. As an aid in estimating the point of compromise, the deviation of the yearly sample mean from the true mean for the 99 percent confidence level is given for the following frequencies: yearly, quarterly, bimonthly (once every two months), monthly, biweekly (once every two weeks) and weekly (see Table 43). For those parameters which were assumed cyclic, the samples are not collected uniformly over the year, but the same number of samples are collected for the corresponding frequency. These frequencies were selected because they are the most widely used. The data given in Table 43 also indicates that the deviation of the sample mean from the true mean varies from parameter to parameter at each sampling frequency for the ash pond effluent parameters at Plant J.

EXAMPLE SAMPLING PROGRAM FOR PLANT J

An example sampling program for Plant J to meet NPDES requirements is shown in Table 44. It is based on the previous discussion and the following criteria:

1. The element must be required by the NPDES permit.

2. The 99 percent confidence level was assumed.

3. The precision used to estimate the sampling frequency was based on maintaining the average concentration in the receiving stream below or equal to the maximum concentration reported for the receiving stream in 1976 under the 7-day 10-year minimum flow. This justification for trace metals was assumed because biological studies performed for P.L. 92-500, Section 316, demonstrations indicated no adverse biological effects of the discharges from Plant E.

TABLE 42. ESTIMATED SAMPLING FREQUENCIES FOR THE MONITORING PROGRAM AT PLANT J ASSUMING ALLOWABLE AVERAGE CONCENTRATIONS IN THE RECEIVING STREAM EQUAL TO THE EPA WATER QUALITY CRITERIA AND MAXIMUM VALUE REPORTED FOR THE INTAKE WATER

| | Number of Samples Per Year[a] | |
Element	Precision Based on Water Quality Criteria[b]	Precision Based on Maximum Value Reported for the Intake Water[c]
Aluminum	d	1(1,0)
Arsenic	1(0,1)	2(0,2)
Calcium	d	1(1,0)
Dissolved Solids	d	1(1,0)
Iron	e	1(1,0)
Magnesium	d	1(1,0)
Selenium	1(0,1)	f
Sulfate	1(0,1)	1(0,1)
Copper	1	1
Manganese	e	1
Suspended Solids	d	1
Zinc	1	2

a. Values are for the 99% significance level. Numbers in parenthesis indicate the number of samples required during the period November 1 to April 30 and May 1 to October 31, respectively.
b. See Table 39 for the precision values.
c. See Table 40 for the precision values.
d. Criteria not proposed for drinking water intake supplies.
e. Intake water concentration exceeds criteria.
f. Intake water concentration exceeds effluent concentration.

TABLE 43. DEVIATION OF THE YEARLY SAMPLE MEAN FROM THE TRUE MEAN FOR THE 99% CONFIDENCE LEVEL AT VARIOUS SAMPLING FREQUENCIES

Parameter	Deviation from the True Mean[a]					
	Yearly	Quarterly	Bimonthly	Monthly	Biweekly	Weekly
Aluminum	62(1.129)	45(0.565)	40(0.461)	32(0.326)	24(0.222)	18(0.157)
Arsenic	67(0.078)	50(0.039)	45(0.032)	37(0.023)	28(0.015)	22(0.011)
Calcium	18(0.315)	9.6(0.158)	8.0(0.129)	6.1(0.091)	4.0(0.062)	2.9(0.044)
Dissolved Solids	4.0(0.091)	2.0(0.046)	1.7(0.037)	1.2(0.026)	0.8(0.018)	0.6(0.013)
Iron	58(0.326)	40(0.163)	36(0.133)	28(0.094)	21(0.064)	16(0.045)
Magnesium	27(0.303)	15(0.152)	13(0.124)	9.5(0.088)	6.5(0.059)	4.8(0.042)
pH	19(0.191)	10(0.096)	8.6(0.078)	6.2(0.055)	4.4(0.038)	3.0(0.026)
Selenium	58(0.011)	43(0.006)	33(0.004)	27(0.003)	22(0.0022)	16(0.0015)
Sulfate	46(73)	30(36)	26(30)	20(21)	14(14)	10(10)
Copper	42(1.20)	27(0.600)	23(0.489)	17(0.345)	12(0.235)	9(0.166)
Manganese	45(0.687)	29(0.344)	25(0.280)	19(0.198)	14(0.135)	10(0.095)
Suspended Solids	73(1.144)	58(0.572)	53(0.467)	44(0.330)	35(0.224)	28(0.159)
Zinc	73(0.134)	57(0.067)	52(0.055)	44(0.039)	34(0.026)	28(0.019)

a. Values are given as precent of deviation from true mean. Numbers in parenthesis indicate the deviation in mg/l or log mg/l.

TABLE 44. EXAMPLE SAMPLING PROGRAM FOR PLANT J

	Sampling Frequency (No. per Period)[a]			
Element	November 1 to April 30	May 1 to October 31	January 1 to December 31	Precision[b] (% of true yearly mean)
Aluminum	0	0	0	-
Arsenic	0	2	2	59
Cadmium	0	0	0	-
Calcium	0	0	0	-
Chromium	0	0	0	-
Copper	c	c	1	42
Dissolved Solids	0	0	0	-
Iron	1	0	1	58
Lead	0	0	0	-
Magnesium	0	0	0	-
Manganese	c	c	1	45
Mercury	0	0	0	-
Nickel	0	0	0	-
pH	3	1	4	10
Selenium	1	3	4	43
Sulfate	0	0	0	-
Suspended Solids	c	c	24[d]	36
Zinc	c	c	2	66

a. The number given for the period January 1 to December 31 equals the sum of the other two periods.
b. At the 99% significance level.
c. Does not matter which period sample is collected.
d. The frequency should be one sample every 15 days.

4. If the average concentration in the effluent exceeded the maximum value reported for the intake water and the EPA proposed water quality criteria, then the frequency was established based on estimating the average within at least 50 percent of the true mean.

5. For those elements for which an effluent limitation has been set, the recommended frequency ensures an average which indicates if the effluent is in compliance.

6. Unless specified, the sample(s) can be collected any time during the averaging period.

7. If the data shows that the effluent concentration is below the detection limit, the element will not be included in the monitoring program even if required by the current NPDES permit.

The remaining discussion gives the justification for this program by element.

Aluminum

Aluminum is not recommented as part of the monitoring program because it is not required by the NPDES permit.

Arsenic

Two samples per year are recommended. Both samples should be taken during the period from May 1 to October 31. Monitoring of arsenic is required by the NPDES permit and two samples show with 99 percent confidence that the ash pond effluent does not increase the yearly average receiving stream concentration above 0.001 mg/l. They also allow estimation of the yearly average concentration in the effluent within 59 percent.

Cadmium

Cadmium is not recommended as part of the monitoring program because the data during 1974 and 1975 indicated that the concentration was below the detection limit.

Calcium

Calcium is not recommended as part of the monitoring program because it is not required by the NPDES permit.

Chromium

Chromium is not recommended as part of the monitoring program because the data during 1974 and 1975 and the data in this study indicated the concentration was below the detection limit.

Copper

One sample per year is recommended. Copper is required by the NPDES permit and one sample shows that the ash pond effluent does not increase the yearly average receiving stream concentration above 0.046 mg/l. It also allows the yearly mean in the effluent to be estimated within 42 percent.

Dissolved Solids

Dissolved solids is not recommended as part of the monitoring program because it is not required by the NPDES permit.

Iron

One sample per year is recommended. Iron is required by the NPDES permit. The concentration of iron in the intake water exceeds the EPA proposed water quality criteria for drinking water intake supplies; however, one sample shows that the effluent does not increase the yearly average receiving water concentration above 0.53 mg/l. It also allows estimation of the yearly average concentration in the effluent within 58 percent.

Lead

Lead is not recommended as part of the monitoring program because the data during 1974 and 1975 and the data in this study indicated the concentration was below the detection limit.

Magnesium

Magnesium is not recommended as part of the monitoring program because it is not required by the NPDES permit.

Manganese

One sample per year is recommended. Manganese is required by the NPDES permit and one sample shows that the ash pond effluent does not increase the yearly average receiving stream concentration above 0.11 mg/l. It also allows the yearly mean in the effluent to be estimated within 45 percent.

Mercury

Mercury is not recommended as part of the monitoring program because the data during 1974 and 1975 indicated that the concentration was below the detection limit.

Nickel

Nickel is not recommended as part of the monitoring program because the data during 1974 and 1975 and this study indicated that the concentration was below the detection limit.

pH

Four samples per year are recommended. Three of the samples should be collected during the period from November 1 to April 30 and one during the period from May 1 to October 31. The one sample during the period May 1 to October 31 is sufficient to show that the effluent is in compliance with the effluent limitation during the period. The remaining three samples, if spaced out evenly over the period, are sufficient to show that the effluent exceeds the limitation some time during the period. These four samples will allow estimation of the yearly mean to within 10 percent of the true mean.

Selenium

Four samples per year are recommended. Selenium is required by the NPDES permit. The concentration in the intake water is consistently at or below the minimum detectable limit of 0.002 mg/l, while the ash pond effluent was higher than that in the intake water. Therefore, this one sample allows estimation of the yearly average concentration in the effluent within 46 percent. It also shows with 99 percent confidence that the ash pond effluent does not increase the yearly average intake concentration above 23 mg/l.

Sulfate

Sulfate is not recommended as part of the monitoring program because it is not required by the NPDES permit.

Suspended Solids

Twenty-four samples per year at intervals of 15 days are recommended. This frequency shows with 99 percent confidence that the effluent is in compliance with the effluent limitation of 30 mg/l specified in the NPDES permit.

Zinc

Two samples per year are recommended. These two samples show that the ash pond effluent does not increase the yearly average receiving stream concentration above 0.019 mg/l. They also allow the yearly average effluent concentration to be estimated within 66 percent of the true mean.

SUMMARY

The example sampling program given in Table 44 requires a total of 35 analyses per year for 7 different elements whereas the NPDES permit requires a total of 156 analyses for 12 different elements. Under the recommended program, estimates of the yearly average were obtained for the following elements: As, Cu, Fe, Mn, Se, suspended solids, and Zn. The example program also excludes sampling for Cd, Cr, Pb, Hg, and Ni which are required by the NPDES permit, because past data showed them to be below the minimum detectable amount. The above totals exclude pH, flow, and oil and grease.

At the time of this writing the ash pond effluent at Plant J was considered to be in compliance with existing effluent limitations as defined in the NPDES permit for that plant. Special provisions or plant modifications specific for Plant J may be required in the future to ensure continued compliance.

SECTION 7

FUTURE APPLICATIONS

The procedure for designing a monitoring program outlined in
Section 4 and demonstrated in Sections 4 and 5 for ash pond effluents
has several limitations. First, the procedure relies on maintaining the
same type of operating conditions in the future as were used during the
period when the design data set was collected. If at some time after
design of the monitoring program, operating conditions change which
result in changes in the effluent characteristics, the monitoring pro-
gram may no longer be valid. Therefore, the monitoring program should
be closely evaluated if changes in the operating conditions occur.
Second, the procedure depends heavily on the establishment of effluent
limitations. Therefore, limitations should be established with full
understanding of the consequences of not complying with them. Third,
the procedure was primarily designed to indicate compliance with an
effluent limitation. In those cases where the effluent was not in
compliance, application of the procedure was difficult. Fourth, the
procedure cannot be generically applied to all ash pond effluents, but
must be applied individually to each effluent.

The monitoring program which results from the use of this design
procedure results in a program which is quite dynamic, requiring frequent
reexamination and reevaluation of data and assumptions and redevelopment
of the effluent sampling program. This plus the limitations listed
above significantly limit the attractiveness of the procedure. However,
in spite of these limitations, application of the procedure to the
effluents at Plants E and J indicated that the sampling effort for trace
metals could be substantially decreased (from 70 to 90 percent). There-
fore, it may prove beneficial to apply the procedure to the remaining
TVA ash pond effluents. In addition, the procedure should also be applied
to oil and grease samples to see if their frequency cannot be reduced.
Since each ash pond effluent is equipped with a continuous flow measure-
ment device which supplys a permanent record of the flow, there is no
advantage to applying this procedure to flow measurements. There may be
enough data collected since June 1976, as part of the NPDES program to
supply a data base for these designs. However, as pointed out in
Section 3, there are several factors within the operation of a power
plant which affect the ash pond effluent water quality characteristics.
Since TVA is making or will be making modifications through April 1979
to its coal-fired power plants and ash ponds in an effort to meet
environmental regulations, the ash pond effluent characteristics may
change. Therefore, the NPDES data collected during this period,
June 1976 to April 1979, may not be representative of the effluent
characteristics after these modifications are complete. It may be
necessary to wait until after the modifications are complete before
implementing the procedure discussed here.

If the reduction in the NPDES monitoring program, once the procedure is implemented, is as significant for the entire TVA system as for Plants E and J, the cost savings in routine monitoring should be directed towards more short-term, extensive surveys or studies to better quantify the effects of power plant operations on the ash pond effluent water quality and development of better methods of treating or using water in power plants.

REFERENCES

1. "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Steam-Electric Power Generating Point Source Category," U.S. Environmental Protection Agency, Report No. EPA-440/1-74-029-a, (October 1974).

2. Freund, John E. Modern Elementary Statistics, 3rd Edition, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1967.

3. Standard Methods for the Examination of Water and Wastewater, 14th ed., American Public Health Association, American Water Works Association and Water Pollution Control Federation, 1975.

4. U.S. Environmental Protection Agency, Handbook for Monitoring Industrial Wastewater, August 1973.

5. Daniel, Wayne W. and James C. Terrell, Business Statistics Basic Concepts and Methodology, Houghton Mifflin Company, Boston, MA, 1975.

6. Sherwani, Jabbar K. and David H. Moreau, Strategies for Water Quality Monitoring, Water Resources Research Institute of the University of North Carolina, June 1975. Report No. 107.

7. Berthouex, Paul M. and Dennis L. Meinert, Water Quality at Selected Locations in the Tennessee Valley with Recommendations for Monitoring, Tennessee Valley Authority, Chattanooga, Tennessee, 1977.

8. Miller, Irwin and John E. Freund, Probability and Statistics for Engineers, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965.

9. Snedecor, George W. and William G. Cochran, Statistical Methods, Sixth Edition, Iowa State University Press, Ames, Iowa, 1967.

10. Box, George E. P. and Gwilym M. Jenkins, Time Series Analysis Forecasting and Control, Holden-Day, Inc., 500 Sansome Street, San Francisco, CA, 1976.

11. Quality Criteria For Water, U.S. Environmental Protection Agency, Washington, DC 20460, September 1976.

APPENDIX A

APPENDIX A

ANALYTICAL PROCEDURES USED BY REFERENCE

	Parameter	Procedure	Reference	MDA(µg/l)
1.	Aluminum	Atomic absorption - Direct	EPA, pp. 81, 92	200
2.	Arsenic	Digestion and Colorimetric	SDDC SM, pp. 62, 65	5
		Atomic absorption - Gaseous Hydride*	EPA, pp. 81, 95	2
3.	Cadmium	Atomic absorption - Extracted	EPA, pp. 81, 89, 101	1
4.	Chromium	Atomic absorption - Extracted	EPA, pp. 81, 89, 105	5
5.	Copper	Atomic absorption - Direct	EPA, pp. 81, 108	10
6.	Iron	Atomic absorption - Direct	EPA, pp. 81, 110	50
7.	Lead	Atomic absorption - Extracted	EPA, pp. 81, 89, 112	10
8.	Manganese	Atomic absorption - Direct	EPA, pp. 81, 116	10
9.	Magnesium	Atomic absorption - Direct	EPA, pp. 81, 114	1000
10.	Calcium	Atomic absorption - Direct	EPA, pp. 81, 103	1000
11.	Mercury	Digestion and Flameless Atomic absorption	EPA, p. 134	0.2
12.	Nickel	Atomic absorption - Direct	EPA, pp. 81, 141	50
13.	Selenium	Atomic absorption - Gaseous Hydride	EPA, p. 95	<1

	Parameter	Procedure	Reference	MDA(μg/l)
14.	Silica, Dissolved	Colorimetric-automated Molybdosilicate (Technicon Auto Analyzer)	EPA, p. 274 Automated by TVA	100
15.	Zinc	Atomic absorption - Direct	EPA, pp. 81, 155	10
16.	Residue, Total Filterable	Gravimetric - Glass Fiber Filtration	EPA, p. 266	10
17.	Residue, Total Nonfilterable	Gravimetric - Glass Fiber Filtration	EPA, p. 268	1

EPA - <u>Methods for Chemical Analysis of Water and Wastes</u>, 1974, Environmental Protection Agency, Water Quality Office, Cincinnati, Ohio.

SM - <u>Standard Methods for the Examination of Water and Wastewater</u>, 13th Edition, 1971, American Public Health Association, New York, New York.

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*This procedure used for the analysis of all samples collected after October 12, 1976.

APPENDIX B

QUALITY CONTROL DATA FOR TVA
WATER QUALITY LABORATORY

TABLE B-1

SHORT TERM SINGLE OPERATOR DATA
BASED ON SEVERAL REPLICATES
ANALYZED AT LEAST THREE DIFFERENT CONCENTRATION LEVELS

Parameter	Equation for Standard Deviation $(So=Mx+b)$	Concentration Range & Units	Range of Bias
Cu	0.00945 x +4.50	10 - 536 µg/l	0 to 14%
Zn	0.00652 x +2.93	11 - 519 µg/l	-2 to 10%
Cr	0.0454 x +2.71	20 - 110 µg/l	-3 to 0%
Ni	0.0133 x +8.82	226 - 1150 µg/l	+10 to +14%
Pb	0.00843 x +2.47	15 - 149 µg/l	-26 to +3%
Hg	0.0163 x +0.079	1.13 - 5.71 µg/l	+5 to +38%
As*	-0.0211 x 1.68	10 - 48.5 µg/l	-3 to 0%
As**	0.0429 x +0.357	2 - 10 µg/l	-20 to -3.6%
Cd	0.0106 x +0.395	0.9 - 21.7 µg/l	-10 to +14%
Se	0.0571 x +0.100	5 - 20 µg/l	-1 to +1%
Be	0.00184 x +3.92	47 - 515 µg/l	-6 to +3%
Sb***	0.002 x 70	5,000 - 15,000 µg/l	-4 to -3%
Al	0.0577 x +47.4	657 to 5,200 µg/l	0 to 18%
Ca	-0.00106 x +0.635	22.5 to 38.5 mg/L	-11 to -10%
Fe	0.00985 x +6.34	220 to 2,150 µg/L	-3 to 6%
Mg	0.0387 x -0.134	6.8 to 8.6 mg/L	-3 to 10%
Mn	0.0155 x +3.96	29 to 547 µg/L	0 to 12%
SiO_2	0.0453 x -0.268	7.4 to 11.2 mg/L	-1 to 2%
Residue, Total Filterable	0.000 x +3.5	39 to 189 mg/L	-22 to -6%
Residue, Total Nonfilterable	0.0334 x +0.864	4 to 84 mg/L	Not Obtainable
Sulfate	0.0250 x +1.12	26 to 34 mg/L	-15 to 3%

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*From 3/76 to 10/12/76 arsenic was analyzed by the silver diethyl dithiocarbamate method.

**From 10/12/76 to present arsenic was analyzed by the gaseous hydride method.

***Data from EPA manual.

TABLE B-2

LONG-TERM QUALITY CONTROL CHART DATA
BASED ON OBSERVATIONS FROM MARCH 1976 TO JUNE 1977*

Parameter	Observations #	% Relative Standard Deviation		
		Mean Concentration (µg/l)	Mean %RSD	Average % Bias
Cu	120	280	0.96	0.93
Zn	140	310	0.98	0.75
Cr	180	51	3.98	0.39
Ni	120	570	2.26	1.22
Pb	200	53	5.22	2.36
Hg	110	1.9	3.28	2.01
As**	55	25	4.77	1.21
As***	60	7.4	5.38	1.98
Cd	169	7.9	2.63	0.75
Se	100	9.0	4.95	2.75
Be	69	250	0.93	0.65
Sb	16	1,900	0.81	1.52
Al	61	1,390	1.77	0.715
Ca	147	12.26	0.67	0.52
Fe	151	670	1.53	1.13
Mg	145	2.65	0.83	0.49
Mn	150	99	0.84	0.18
Silica	123	4.75	0.68	3.94
Residue, Total Filterable	245	441	4.98	0.979
Residue, Total Nonfilterable	496	449	7.76	--
Sulfate	232	10.3	3.00	-1.10

*For the parameters below Sb, the data are based on observations from 8/76 to 9/77.
**From 3/76 to 10/12/76 arsenic was analyzed by the silver diethyl dithiocarbamate method.
***From 10/12/76 to present arsenic was analyzed by the gaseous hydride method.

TABLE B-3

COMPARISON OF SHORT-TERM SINGLE OPERATOR DATA WITH THAT
PREDICTED FROM LONG-TERM QUALITY CONTROL CHART DATA

Parameter	Mean Value (µg/l) from Control Charts	Standard Deviation	
		(µg/l) So Predicted****	(µg/l) So Found*****
Cu	280	7.14	2.69
Zn	310	4.95	3.04
Cr	51	5.02	2.03
Ni	570	16.4	12.9
Pb	53	2.92	2.77
Hg	1.9	0.110	0.118
As*	25	1.15	2.98
As**	7.4	0.674	0.398
Cd	7.9	0.479	0.208
Se	9.0	0.414	0.446
Be	250	4.39	2.33
Sb	1,900	73.4***	15.4
Al	1,390 µg/L	128	24.6
Ca	12.3 mg/L	0.622	0.082
Fe	670 µg/L	12.9	10.3
Mg	2.65 mg/L	0.000	0.022
Mn	99 µg/L	5.50	0.83
SiO$_2$	4.75 mg/L	0.000	0.032
Residue, Total Filterable	441 mg/L	3.5	23.0
Residue, Total Nonfilterable	449 mg/L	15.9	34.8
SO$_4$	10.3 mg/L	1.38	0.31

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*From 3/76 to 10/12/76 arsenic was analyzed by the silver diethyl
dithiocarbamate method.

**From 10/12/76 to present arsenic was analyzed by the gaseous
hydride method.

***Data from EPA manual.

****So predicted is found by using mean value from control charts to
solve equation for standard deviation for short-term single operator
data in Table I.

*****So found is product of long-term RSD and mean value from control
charts.

APPENDIX C

APPENDIX C

WATER QUALITY CRITERIA FOR DOMESTIC WATER
SUPPLY INTAKES PROPOSED BY EPA

Element	Domestic Water Supply (EPA) mg/l
Reference	9
Aluminum	No criteria
Arsenic	0.05
Barium	1.0
Beryllium	No criteria
Cadmium	0.01
Chloride	250
Chromium	0.05
Copper	1.0
Iron	0.3
Lead	0.05
Manganese	0.05
Mercury	0.002
Nickel	No criteria
Selenium	0.01
Silver	0.05
Sulfate	250
Zinc	5

APPENDIX D

APPENDIX D

STUDENT t VALUES[1]

n	degrees of freedom	99% CI	95% CI	80% CI
12	11	3.106	2.201	1.363
13	12	3.055	2.179	1.356
20	19	2.861	2.093	1.328
21	20	2.845	2.086	1.325
25	24	2.797	2.064	1.318
32	31	2.745	2.040	1.309
33	32	2.741	2.038	1.309
34	33	2.736	2.036	1.308

1. Taken from CRC Standard Mathematical Tables, 19th ed., edited by Samuel M. Selby, The Chemical Rubber Co., 18901 Cranwood Parkway, Cleveland, Ohio 44128, page 610.

APPENDIX E

APPENDIX E

EXAMPLE CALCULATION OF THE ALLOWABLE INPUT TO THE STREAM AND THE ASSOCIATED PRECISION ASSUMING THE MAXIMUM AVERAGE ALLOWABLE CONCENTRATION IN THE STREAM IS EQUAL TO OR LESS THAN THE EPA WATER QUALITY CRITERIA

Element: As
Sample Mean in the Effluent: 0.017 mg/l
Average Concentration in the
   Receiving Stream: 0.004 mg/l
Water Quality Criteria: 0.05 mg/l
Maximum Ash Pond Flow: 67 cfs
7-day Minimum Flow in the
   Receiving Stream: 7880 cfs

$$\text{Maximum average allowable concentration in the effluent} = \frac{7880(0.05) - 7813\,(0.004)}{67}$$

$$= 5.4$$

Required Precision $= 5.4 - 0.017$
                      $= 5.383$

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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		6. PERFORMING ORGANIZATION CODE
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		11. CONTRACT/GRANT NO. IAG-D5-E-721
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16. ABSTRACT The report describes a procedure for designing an effective monitoring program for fossil-fueled power plant ash pond effluents. Factors that influence effluent characteristics and are important in designing such a monitoring program were determined following a review of plant operating characteristics and ash pond effluent characteristics of TVA's fossil-fueled power plant system. A statistical procedure for determining the sampling frequency of chemical characteristics in ash pond effluents was then developed. Two ways to determine precision are described: Method 1 involves selecting a precision value to estimate the population mean within a given percentage; Method 2 involves calculating a precision value by subtracting an estimate of the population mean from either the ash pond effluent limitation established by EPA or a desirable water quality criterion. Method 2 gives the number of samples required to show that the effluent is in compliance with the effluent limitation or below the water quality criteria. The method chosen to compute the precision depends on the purpose of the monitoring program. The procedure was demonstrated for two TVA ash pond systems.

17.	KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Monitors Design Ponds Fly Ash Effluents	Waste Disposal Electric Power Plants Fossil Fuels Chemical Analysis Water Quality	Pollution Control Stationary Sources Ash Ponds	13B 14B 08H 21B	10B 21D 07D

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