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POTOMAC RIVER SEDIMENT STUDY

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FLEET SUPPORT DEPARTMENT

Indian Head Technical Report 355

1 June 1972

POTOMAC WATER SEDIMENT STUDY

By

Marilyn E. Houser
Mae I. Fauth

Approved for public release,
distribution unlimited.

NAVAL ORDNANCE STATION
Indian Head, Maryland

B. W. FRESE, JR.
Captain, USNavy
Commanding Officer

JOE L. BROWNING
Technical Director

I

FOREWORD

The work described in this report was funded under Naval Ordnance Station Job Order 6603650 as part of the survey of possible pollution effects on the Potomac Estuary.

Sample collection and some technical support were provided by personnel from the Chesapeake Laboratory of the Environmental Protection Agency at Annapolis, Md.

The authors wish to express their appreciation to Mrs. Phyllis Wheeler of our laboratory who performed some of the analyses and to Mr. Johan A. Aalto, Director, Dr. Donald Lear, and Mr. Thomas Pheiffer, of the Chesapeake Laboratory, who reviewed the manuscript and offered helpful suggestions.

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Director, Propellant Chemistry Division

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ABSTRACT

Analyses of Potomac River sediments for approximately 20 metals have been made using atomic absorption spectrometry. Sample preparation involved extraction with water and nitric acid. The river area surveyed extended from Key Bridge to Piney Point, a distance of 96 river miles.

Data are presented for the following metals: aluminum, barium, cadmium, calcium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, nickel, potassium, silver, strontium, vanadium, and zinc. A few analyses were also made for mercury.

Lead content was highest at the Woodrow Wilson and Route 301 Bridges. Copper, chromium, and nickel concentrations at Woodrow Wilson Bridge and Piscataway Creek appear to be associated with major waste treatment plants whose outfalls are in the vicinity. High concentrations of manganese were found in an undeveloped section of the river.

INTRODUCTION

In order to evaluate the effect of the activities of the Naval Ordnance Station at Indian Head, Md., on the Potomac River Estuary, a study was made of the water and sediments of the lower river, particularly with reference to heavy metals. Two series of sediment samples were analyzed for approximately 20 metals and, for those sampling locations at which marked variation in metals content was noted, a third set of samples was analyzed for certain critical metals.

Previous work on water samples from areas adjacent to the Naval Ordnance Station had indicated that, while, in most cases, the amount of heavy metals in the estuary water was low, a buildup of such metals in the river bottom was a distinct possibility.

Because of the oscillatory motion of the water under the influences of tidal forces, sampling locations ranged from Key Bridge (26 miles upstream) to Piney Point (68 miles downstream). The section of the Potomac River upstream from Indian Head to Key Bridge is tidal but contains relatively fresh water. The transition zone from fresh to brackish water occurs in the region from Indian Head to the Route 301 Bridge. A list of sampling stations is given in Table I.

Both water and sediment samples were collected by personnel of the Chesapeake Laboratory of the Environmental Protection Agency. Surface samples for chemical analysis were taken by dipping a plastic bucket or large funnel into the river water with a minimum of agitation. Water samples were stored in 1-gallon plastic "cubitainers." Bottom samples were taken using a plastic Van Dorn sampler. These were stored in 1-pint glass jars with screw caps.

To determine if a seasonal effect existed, one set of samples was taken in August 1970 and another in December 1970. For sampling stations where marked differences in metals concentration occurred, a third series of samples was taken in April 1971. While primary interest was in the toxic metals such as lead, copper, chromium, mercury, nickel, cobalt, silver, manganese, zinc, and vanadium, various other metals were also determined. These included the following alkali and alkaline earth elements lithium, potassium, magnesium, calcium, barium, and strontium. Iron and aluminum were also determined. Since there is intrusion of salt water into the estuary, it was thought that sodium values would not be particularly meaningful. A number of elements tested for in the sediment samples were found to be either absent or were present in a concentration below the detection limit for the analytical methods used. These include arsenic, selenium, tin, bismuth, molybdenum, antimony, boron, lanthanum, tungsten, and zirconium.

Table I

SAMPLING LOCATIONS

Station	Location	Miles below Chain Bridge	Miles from Indian Head*
1	Key Bridge	3.35	+26.25
1A	Fletcher's Boathouse	1.49	+29.20
2	14th Street Bridge	5.90	+24.70
3	Haines Point	7.20	23.40
4	Bellevue	10.00	+20.60
5	Woodrow Wilson Bridge	12.30	+18.30
6	Broad Creek	15.20	+15.40
7	Piscataway Creek	18.35	+12.25
8	Dogue Creek	22.30	+8.30
9	Hallowing Point	26.90	+3.70
10	Indian Head	30.60	0.00
11	Possum Point	38.00	-7.40
12	Sandy Point	42.50	-12.10
13	Smith Point	46.80	-16.20
14	Maryland Point	52.40	-21.80
15	Nanjemoy Creek	58.55	-27.95
15A	Mathias Point	63.75	-33.15
16	Route 301 Bridge	67.40	-36.80
17	Machodoc Creek	73.45	-42.85
18	Kettle Bottom Shoals	76.60	-46.00
18A	Mouth of Wicomico River	82.00	-51.40
20	Kingcopsico Point	90.25	-59.65
21	Ragged Point	95.42	-64.82
22	Piney Point	99.20	-68.60
23	Point Lookout	107.41	-76.81
24	Smith Point	118.00	-87.40
25	Point Lookout	124.85	94.25

*+ = upstream - = downstream

It is known that many heavy metals are extremely toxic to marine life. A list of the range of concentrations of the more common metals which have toxic effects on marine life is given in Table II.(1) These values do not allow for synergistic effects or possible concentration effects in the various food chains.

Table II

TOXICITY OF METALS TO MARINE LIFE[1]

Metal	Chemical symbol	Threshold range of concentrations with toxic effects on marine life (mg l^{-1} or ppm)
Arsenic	As	1.0 to 7.6
Cadmium	Cd	0.01 to 10
Chromium	Cr	0.016 to 20
Cobalt	Co	10 to 25
Copper	Cu	0.02 to 3.0
Manganese	Mn	[illegible]
Mercury	Hg	0.004 to 0.2
Lead	Pb	0.1 to 1.0
Nickel	Ni	0.8 to 18.0
Silver	Ag	0.004 to 1.0
Zinc	Zn	0.11 to 11

[1] From Water Quality Criteria, edited by Jack E. McKee and Harold W. Wolf, Publication 3-A, California State Water Resources Control Board, April 1971.

The atomic absorption method of analysis which was used for this work is much more sensitive for some metals than for others. A list of the detection limits is given in Table III.

Table III

DETECTION LIMITS OF METALS ANALYZED

[Dry wt/1% Absorbance = ppm/1% Absorbance]

Symbol	Name	ppm/1% absorbance	Symbol	Name	ppm/1% absorbance
Ag	Silver	0.01	Li	Lithium	0.01
Al	Aluminum	0.01	Mg	Magnesium	0.005
As[1]	Arsenic	5.0	Mn	Manganese	0.01
B[1]	Boron	35.0	Mo[1]	Molybdenum	0.1
Ba	Barium	0.4	Ni	Nickel	0.05
Bi[1]	Bismuth	2.0	Pb	Lead	0.01
Ca	Calcium	0.01	Sb[1]	Antimony	2.0
Cd	Cadmium	0.01	Se[1]	Selenium	5.0
Co	Cobalt	0.01	Sn[1]	Tin	5.0
Cr	Chromium	0.01	Sr	Strontium	0.1
Cu	Copper	0.01	V	Vanadium	0.1
Fe	Iron	0.01	W[1]	Tungsten	25.0
Hg[1]	Mercury	5.0	Zn	Zinc	0.001
K	Potassium	0.01	Zr[1]	Zirconium	15.0
La[1]	Lanthanum	42.0			

[1] The concentration of these metals was found to be below the detection limit in all samples (prepared by digestion of 2 g sample, dry weight, with 10 ml concentrate of HNO_3 and diluted to 100 ml.)

Metal analyses were performed by the Chesapeake Laboratory of the Environmental Protection Agency. The samples were prepared according to [illegible] [illegible] ... sediment [illegible] ... [illegible] ... atomic absorption spectrophotometer ... [illegible] ... same procedure ... description.

ANALYTICAL METHODS

Since no standard procedures were available for the preparation of the sediment samples, a method was devised so that uniform preparation of samples for chemical analyses would be used. This method is described below. After the metals had been removed from the sediment samples, each sample was analyzed for approximately 20 metals using atomic absorption spectroscopy

Preparation and Procedure for Analysis of Sediment Samples

(1) Dry approximately 35 grams of the wet sample in a forced draft oven, or equivalent, at a maximum temperature of 105° C. Grind the dried sample in a mortar and pestle until fine, approximately 32 mesh, after discarding large pebbles, twigs, shells, bugs, etc.

(2) Quarter the sample at least twice, and transfer a portion into a weighed 100-ml beaker. Reweigh (Wt. A). Sample should be about 2 grams.

(3) If organic material determination is not desired, proceed to step (8).

(4) Add 30 ml of double distilled or deionized water to the sample and to a blank. Boil gently 10 minutes, cool, and filter by decantation through fine paper. Repeat twice more with 10 ml of water, using at least 50 ml of water. If the last filtrate shows any color, repeat with a third 10-ml aliquot of water. Collect and combine filtrates and take to volume in a 100-ml flask.

(5) Collect the residue, washing it into the original beaker with a minimum amount of water. Dry in the oven, cool, and weigh (Wt. B). Calculate % water solubles = 100(Wt. A - Wt. B)/Wt. A. Correct for weight loss or gain on the blank beaker.

(6) To the dried sample still in the original beaker, add 20 ml of acetone. Stir to wet all the sample, and allow to stand at least 30 minutes with frequent stirring. Filter by decantation through fine filter paper. Repeat until no color is observed in the filtrate—at least three washings. Combine the filtrates in weighed crucibles. Air dry until visible acetone is gone and then in the oven

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(105° C) for 1 hour. Cool and weigh (Wt. C). Calculate % organics = 100(Wt. C - Wt. B)/Wt. A. The dried organic residue can now be used for other tests, such as infrared analysis and elemental analysis.

(7) Collect the residue from the acetone filtration washing into the original beaker with a minimum of acetone. Dry, cool, and weigh (Wt. D).

(8) Add 30 ml of concentrated nitric acid to the sample and blank. Heat gently on a hot plate until reflux starts on the ribbed watch glass. Allow to heat at least 30 minutes.

(9) Cool slightly and filter by decantation through hardened filtered paper, such as Whatman No. 50, Millipore Epoxy filter membrane, or Millipore Versapor filter membrane. Wash the sides of the beaker down with a minimum amount of water add 10 ml of nitric acid, and heat 10 minutes. Repeat step (9) at least twice. If the last filtrate is still colored, repeat the step a fourth time; any further extractions are not deemed necessary. Collect and combine the filtrates and take to known volume (100 ml) with water. Appropriate dilutions are made of the acid extraction filtrates for analysis by atomic absorption spectroscopy.

(10) Combine and collect the residues from the acid extraction into the original beaker, dry, cool, and weigh (Wt. E). Calculate % acid soluble = 100(Wt. E - Wt. D)/Wt. A or, if steps (4), (5), (6), and (7) are omitted, calculate % acid solubles = 100(Wt. E - Wt. A)/Wt. A.

Atomic Absorption Analysis Method:

All atomic absorption spectrophotometric analyses were made using a Perkin-Elmer Model 303 with direct digital readout. Settings used for the individual metals were those recommended by the manufacturer. A platinum-titanium alloy nebulizer was used to minimize contamination in the presence of the strong nitric acid used as the solvent.

The standard reference solutions were made up in the same strength acid as the samples. Three different standard solutions were used; they were the following:

Standard A	ppm	Standard B	ppm	Standard C	ppm
Ca(+1% La_2O_3)	1			Ag	2
Cd	2	Al	10		
Co	2	Ba	2		
Cr	2	Bi	2		
Cu	2	K	1		
Fe	10	Ni	2		
Li	1	Se	2		
Mg	1	Sr	2		
Mn	1	V	2		
Mo	1				
Na	2				
Pb	2				
Zn	1				

The three different standard solutions were used instead of one standard for each metal. Tests showed the addition of 1% La_2O_3 for the determination of calcium affected the measurement of some of the metals; standards for those metals affected were made separately and labeled as Standard B. Silver standard was used alone as Standard C; some of the standard solutions, such as barium, sodium, and potassium, were the chloride salt, which would have precipitated the silver.

Dilutions of the initial 100-ml extraction volume (labeled Series A) were made where necessary. It was found that two series of 1- to 25-ml dilutions (final dilution factors of 2500 for Series B and 62,500 for Series C) allowed measurement of all 21 metals. (Only 19 metals were found in measurable quantities.)

Calculations were based on the weight of the dried sample. Where applicable, the parts per million (ppm) were converted to percentage by multiplying by the factor 0.0001 (1×10^{-4}).

$$\text{Total p[illegible]etal} = \frac{(\text{ppm in sample} - \text{ppm in blank})}{\text{dried sample wt. in grams}} \times \text{dilution factor.}$$

RESULTS AND DISCUSSION

Data for 19 metals for the various sampling stations are presented in Table IV. These results were obtained from the August 1970 and December 1970 samples of sediment. After it was found that considerable variation existed in the metals content for certain of the sampling locations, a third series of samples from these locations was taken in April 1971 and analyses made for toxic metals. These results are shown in Table V. A map of the Potomac Estuary showing the sampling points is given in Figure 1. Graphs of the concentrations of 18 of the metals at the various sampling locations are presented in Figures 2 through 19.

Examination of Table V reveals the following significant pieces of information:

(1) Lead content is highest at the Woodrow Wilson and Route 301 Bridges, both of which carry heavy traffic loads. The latter bridge has been in operation at least 15 years longer then the former so there has been more time for lead deposition to occur. Sources of lead may include the red primer paint coat and particulates from the combustion of leaded gasolines.

(2) Copper, chromium, and nickel concentrations at Woodrow Wilson Bridge and Piscataway Creek appear to be associated with major waste treatment plants whose outfalls are in the vicinity. Locations of these plants are shown in Figure 1.

(3) The spectacular rise in the copper concentration at the Route 301 Bridge is believed to be caused by the startup of a commercial power plant in the vicinity.

(4) The high concentration of manganese at Smith Point in an undeveloped section of the river was unexpected and may be due to precipitation at the salt intrusion in the deeper part of the river in this area.

(5) For the metals measured in April 1971, the concentrations were lower than in August and December of 1970. This may have been caused by hi ' -flow conditions during February and March of 1971, bringing about a more even distribution of metals downstream from Woodrow Wilson Bridge.

(6) The erratic behavior of calcium is believed to be due to processes involving intrusions of more alkaline water from Chesapeake Bay, transfer from the atmosphere, and variation in uptake by shell-forming organisms.

(7) There are significant increases in lead, cobalt, chromium, cadmium, zinc, nickel, silver, barium, aluminum, iron, and lithium in the area near the Woodrow Wilson Bridge in comparison with levels measured above and below this area.

The high values of manganese found in the sediments between 40 and 70 river miles below Chain Bridge may be related to changes in such factors as pH, redox potential, or chemical composition in the region of the salt wedge intrusion. Sedimentary processes involving precipitation and dissolution of manganese compounds are known to be highly complex and have been discussed in the geochemical literature. It may be that the location of the high manganese sediments merely represents one stage in the ultimate transport and deposition of manganese to the ocean depths.

Precipitation processes involving manganese in the marine environment have been discussed by Kuenen.(3) He states that while bacterial activity in the precipitation of manganese cannot be ruled out, it is likely that gradual oxidation of manganese in an alkaline environment leads to deposition. While manganese in the source rocks has an average value of 0.17%, it comprises only 0.01% in continental sediments and is apparently leached out and carried to the sea in solution.

Sedimentary processes affecting manganese have been discussed by Krauskopf.(4) Two species of bacteria have been found which prefer manganese to iron and these aid in the precipitation of manganese. The precipitation of manganese is known to be catalyzed by manganese dioxide. These processes explain the partial separation of iron and manganese in deposits from lakes and streams. Manganese carbonate and silicate are slowly soluble in weakly acid solutions; the oxides are stable under oxidizing conditions but dissolve in a reducing environment. Once it has been dissolved, manganese dioxide precipitates by a slight change in conditions. Krauskopf believes that this explains the small manganese accumulations in residual clays and stream channel deposits. The manganese dioxide precipitated in shallow water sediments is unstable because organic matter reduces it. Possible compounds of manganese are too soluble to remain in contact with sea water under ordinary conditions and, therefore, manganese supplied to the sea by streams gradually migrates to deeper water where the organic content is too small to keep manganese dioxide reduced.

Some implications for the Potomac Estuary may be found in the study of the distribution of metals in the bottom sediments, water, tubificid worms, clams, and fishes of the middle Illinois River made by Mathis and Cummings.(5) They found that, except for sodium, the concentrations of extractable metals were substantially lower in the water than in the sediments. The greatest difference in concentrations between sediments and water was obtained for copper, nickel, lead, chromium, zinc, cobalt, cadmium, and lithium. The metal concentrations in the bottom sediments of the Illinois River were, in most cases, significantly different from those of the three nonindustrial use streams. Those substantially higher in the sediments of the Illinois River include: copper, nickel, calcium, lead, chromium, zinc, and cadmium. Iron and cobalt were somewhat higher in the nonindustrial use streams. Except for lead, copper, and cobalt, which were higher in the Illinois River, metals concentrations were similar for the water of both the river and the nonindustrial streams.

The authors reported that organisms such as clams and worms, which live in the mud or at the mud-water interface, showed the highest metal concentrations of metals found in the bottom sediments more closely than did the fishes. Noncarnivorous fishes had significantly different concentrations of copper, nickel, iron, chromium, and zinc than carnivorous fishes, with the noncarnivorous fishes exhibiting the higher concentrations of these metals. Mathis and Cummings' results indicate that studies should be made of the long-range effects of metals accumulation in the bottom sediments on the biota of a region.

In conjunction with the expansion of the Blue Plains sewage treatment plant and proposals for dredging in that area of the river, additional information was desired on heavy metals concentrations in the vicinity of Goose Island (Figure 20). While the data obtained (Table VI) give a more detailed picture of metals concentrations in the sediments of a restricted area, a comparison of these results with the summary of toxic metals content of the sediments for the lower Potomac River (Table V) indicates that, for most of the metals, ranges in the river and at Goose Island are not significantly different. In the case of manganese, however, values at Goose Island (range, 200 to 1186 ppm) were lower than for the river sampling stations from Woodrow Wilson Bridge to the Route 301 Bridge (range, 918 to 4768 ppm).

The levels of mercury found for three stations further down the river range from 5 to 26 parts per billion while those for the sampling stations surrounding Goose Island were from 0.5 to 13 ppm. The highest value was obtained at the Blue Plains Channel and is evidently associated with treatment plant effluents. The reasons for the high concentrations of mercury in the sediments around Goose Island and the long-term effects of such concentrations need to be investigated.

To determine if there were local variations in the metals concentrations of either the water or the bottom sediments, samples of both were taken at a number of locations around and adjacent to the Naval Ordnance Station at Indian Head. Indian Head is 30.6 river miles below Chain Bridge and, therefore, any anomalous effects experienced in the metropolitan Washington area should have disappeared by the time the river reaches this area. Sampling locations are shown in Figures 21 and 22.

Analysis of the water samples indicated that chromium, cobalt, cadmium, arsenic, and silver were below the detection limit (Table VII). The range of manganese was 0 to 0.9 ppm, of copper 0 to 0.40 ppm, of lead 0 to 0.2 ppm. Lead was found to the extent of 0.1 ppm in the water of Mattawoman Creek at

Bumpy Oak Road, a location in the nontidal portion of the creek. Its presence here is evidently from agricultural runoff and possibly from lead particulates from the air.

Both water and sediment samples from the Indian Head area were analyzed for the anions fluoride, chloride, and perchlorate. Chloride was higher in the water samples while perchlorate and fluoride appear to be higher in mud samples A and A-1 of April 1970 (Table VIII). In most cases, there is no buildup of fluoride or perchlorate in the sediments. These two anions may occur in certain process streams and, since both calcium fluoride and potassium perchlorate are only slightly water-soluble, the fate of these two ions was of interest.

Examination of the results of the Indian Head sediments analysis for metals (Table IX) reveals that there has been extensive buildup of lead in the sediments adjacent to the areas where for many years propellants and other waste materials have been destroyed by burning. Other results different from those of the other areas of the river are the generally low levels of manganese, the presence of detectable amounts of cadmium and arsenic in most samples, and the erratic behavior of calcium.

In conclusion, it is apparent that while most of the metals present in the sediments are chemically bound and require both heat and low pH to convert them to soluble form, disturbance of the sediments—whether by turbulence, dredging, changes in chemical and physical environment, biological activity of organisms, or other factors—may induce redistribution and partial solution of some of these metals. Since a number of these metals are highly toxic, the long-term effects cannot presently be determined. It is highly desirable that further studies, particularly of the fate of lead, manganese, and several other heavy metals, be undertaken to elucidate the mechanism of metals deposition and dissolution in the estuarine environment.

Table IV

METALS CONTENT OF SEDIMENT SAMPLES[1]

Station[2]	Date	Pb (ppm)	Cu (ppm)	Cr (ppm)	Ni (ppm)	Zn (ppm)	V (ppm)	Cd (ppm)	Hg (ppb)	Co (ppm)	Ag (ppm)	Mn (ppm)	Fe (%)	Al (%)	Li (ppm)	Ba (ppm)	Sr (ppm)	Mg (ppm)	K (ppm)	Ca (ppm)
1	Aug 70	33.95	11.95	21.98	21.9	114.5	●	0.20	-	9.96	0.6	438.1	1.792	0.946	10.0	54	6.2	4047.2	49.8	563
1	Dec 70	23.05	18.44	27.66	18.9	172.9	32	●	-	16.14	0.8	714.6	4.841	0.876	12.5	323	80.7	4322.3	1048.9	380
1A	Aug 70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1A	Dec 70	35.44	24.81	38.10	28.8	221.5	4	●	-	28.80	1.1	1129.8	3.627	1.451	15.1	576	230.4	4984.3	1373.4	1573
2	Aug 70	43.74	29.84	21.86	37.8	203.9	30	●	-	17.91	1.4	741.1	2.736	1.343	15.1	96	9.4	4829.5	123.3	876
2	Dec 70	34.74	27.30	43.67	33.3	273.0	30	●	-	29.28	0.8	1352.3	7.320	1.439	17.4	695	122.1	6203.3	1302.7	757
3	Aug 70	61.88	33.93	37.93	37.9	244.5	38	0.60	-	19.96	1.2	823.4	2.844	1.397	15.8	102	14.6	4940.2	159.7	878
3	Dec 70	47.28	37.34	60.96	28.8	909.7	33	●	-	25.52	3.1	886.1	4.194	1.193	14.2	662	81.3	4725.8	1098.8	248
4	Aug 70	62.76	56.87	64.72	43.1	318.7	49	0.59	-	23.53	3.7	1029.6	4.216	2.599	28.1	147	15.9	4971.4	191.2	495
4	Dec 70	49.27	37.94	70.95	31.0	702.1	44	●	-	29.56	3.4	1034.6	5.604	1.737	23.2	493	111.2	5542.6	1428.8	333
5	Aug 70	85.83	61.88	75.85	37.9	349.3	42	0.40	-	25.15	6.4	1312.4	4.241	2.096	23.0	178	14.7	4945.0	119.8	644
5	Dec 70	59.59	30.56	61.34	18.8	804.2	30	0.05	-	20.97	52.8	918.7	6.766	2.073	22.4	993	80.0	4965.9	1316.0	931
6	Aug 70	49.88	47.86	45.87	37.9	269.2	36	●	-	23.43	3.2	1740.0	3.739	1.645	17.8	114	10.0	4828.2	99.7	1720
6	Dec 70	59.58	35.25	56.10	22.8	384.6	50	0.94	-	27.31	3.5	1204.0	3.041	1.614	15.9	348	67.5	4344.2	1402.6	1080
7	Aug 70	51.86	63.82	49.86	47.9	279.2	28	●	-	19.95	3.2	1645.5	3.969	1.845	19.8	128	8.0	4841.7	99.7	439
7	Dec 70	38.86	27.69	41.29	21.9	692.2	10	●	28.20	23.31	2.8	1032.0	4.068	1.384	15.9	348	66.1	3642.9	1402.6	984
8	Aug 70	33.62	45.49	27.69	19.8	222.5	2	●	-	17.60	2.0	1473.1	2.917	1.335	12.3	82	12.9	4415.0	64.3	406
8	Dec 70	9.98	14.96	24.44	13.5	261.8	40	●	-	16.46	0.8	710.7	4.738	1.334	13.0	299	30.4	3740.5	910.2	362
9	Aug 70	35.96	41.96	25.97	22.0	219.8	22	●	-	15.98	3.6	1353.6	2.697	1.099	9.6	86	12.6	4290.5	40.0	406
9	Dec 70	33.50	24.88	47.38	23.0	442.6	24	●	4.89	23.31	1.8	1112.6	5.383	1.567	17.2	383	47.9	3888.1	885.3	477
10	Aug 70	35.89	45.87	25.92	18.0	239.3	16	●	-	13.96	3.2	1580.4	2.543	0.947	7.2	88	12.8	4068.0	24.3	489
10	Dec 70	37.86	27.45	37.39	23.7	804.6	43	●	4.94	20.35	2.0	1254.2	5.679	1.668	18.0	426	53.0	4437.0	1088.6	450
11	Aug 70	35.78	47.71	25.84	23.9	258.4	30	●	-	17.89	2.8	1709.7	3.678	1.441	15.3	88	15.9	4696.7	69.6	393
11	Dec 70	45.60	27.36	45.10	24.3	481.4	76	●	5.55	24.83	2.2	2102.8	8.646	1.685	18.8	455	65.9	4750.3	1482.1	393
12	Aug 70	35.71	47.61	31.74	27.8	277.7	14	●	-	17.85	2.4	2539.0	3.868	1.587	16.5	107	28.8	4691.2	74.4	1949
12	Dec 70	34.97	28.97	44.46	27.5	287.2	35	●	4.68	26.98	2.1	2897.6	3.029	2.086	30.5	699	107.9	5307.6	2048.2	267
13	Aug 70	35.95	37.95	29.96	36.0	244.7	18	●	-	19.97	1.8	4968.2	4.045	1.648	21.8	86	27.6	3225.6	109.9	170
13	Dec 70	49.10	14.23	21.05	14.7	208.5	20	●	-	17.66	1.4	3372.6	4.568	1.435	21.6	442	73.6	1398.1	1508.5	147
14	Aug 70	42.66	50.41	29.08	29.1	290.8	19	●	-	19.39	2.1	2060.1	4.217	1.597	21.5	66	19.0	4798.9	116.3	92
14	Dec 70	29.98	23.98	34.97	24.0	1061.7	60	●	-	27.48	1.8	2897.9	5.496	1.599	28.0	400	132.9	5933.1	1986.0	175
15	Aug 70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	Dec 70	5.00	21.50	30.50	23.6	212.5	55	●	-	25.00	1.8	2875.3	8.720	1.463	28.0	750	166.0	5625.6	2187.7	213
15A	Aug 70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15A	Dec 70	4.80	20.65	31.22	21.1	936.5	58	●	-	19.69	5	2329.2	6.513	1.249	21.6	528	156.6	5402.8	2269.2	168
16	Aug 70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	Dec 70	106.60	16.96	23.74	18.4	157.5	53	●	-	16.47	1.3	2035.1	7.177	1.102	20.4	485	356.6	5451.1	2289.5	9085
17	Aug 70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	Dec 70	58.79	23.03	39.68	25.5	894.1	49	●	-	21.56	1.6	2204.7	7.043	1.507	28.9	294	206.3	7348.9	3221.3	453
18	Aug 70	31.85	35.83	21.90	21.9	184.1	18	●	-	13.93	1.0	766.4	3.185	1.543	18.7	26	18.5	4611.5	169.1	130
18	Dec 70	24.46	22.50	35.22	21.5	379.1	49	0.05	-	19.06	0.9	525.9	5.503	1.517	30.8	636	192.3	7032.0	1834.4	330
18A	Aug 70	7.99	7.99	5.99	4.0	64.9	●	●	-	3.99	1.4	104.8	0.899	0.749	5.0	10	10.4	2026.6	15.0	929
18A	Dec 70	44.90	11.27	18.62	10.3	306.2	29	●	-	8.82	0.3	261.7	2.695	0.796	15.2	343	171.0	3368.1	2106.6	4297
20	Aug 70	19.88	25.85	15.91	19.9	298.8	14	●	-	7.95	0.4	457.3	2.734	1.342	17.3	16	38.2	4817.1	169.0	948
20	Dec 70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	Aug 70	19.80	39.59	15.54	25.7	133.1	24	●	-	9.90	●	623.6	3.019	1.346	16.2	18	18.6	4850.2	217.6	248
21	Dec 70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	Aug 70	●	7.50	5.93	4.0	54.3	10	●	-	5.93	●	74.1	0.741	0.790	3.4	4	1.6	2404.5	19.8	40
22	Dec 70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[1] ● - concentration below detection limit

[2] See Table I and Figure 1 for station locations

Table V

SUMMARY OF TOXIC METALS CONTENT OF SEDIMENTS[1]

Station	Location	Date	Pb (ppm)	Cu (ppm)	Cr (ppm)	Ni (ppm)	Zn (ppm)	V (ppm)	Cd (ppm)	Co (ppm)	Ag (ppm)	Mn (ppm)	Fe (%)	Hg (ppb)
5	Woodrow Wilson Bridge	Aug 70	85.83	61.88	75.85	37.9	345.3	42	0.40	25.15	6.4	1312.4	4.241	-
5	Woodrow Wilson Bridge	Dec 70	59.59	30.56	61.84	18.8	603.2	30	0.05	20.97	52.8	918.7	6.766	-
5	Woodrow Wilson Bridge	Apr 71	50.00	51.50	59.50	23.3	260.0	18	0.50	-	-	-	-	-
7	Piscataway Creek	Aug 70	51.86	63.82	49.86	47.9	279.2	28	●	19.95	3.2	1645.5	3.989	-
7	Piscataway Creek	Dec 70	38.86	27.69	41.23	21.9	692.2	10	●	23.31	2.8	1032.0	4.068	20.20
7	Piscataway Creek	Apr 71	42.50	17.50	20.50	16.0	130.9	13	●	-	-	-	-	-
16	Indian Head	Aug 70	35.89	45.87	25.92	18.0	239.3	16	●	13.96	3.2	1580.4	2.543	-
10	Indian Head	Dec 70	37.86	27.45	37.39	23.7	804.3	43	●	20.35	2.0	1254.2	5.679	4.94
10	Indian Head	Apr 71	25.08	30.50	26.00	21.3	205.6	3	●	-	-	-	-	-
11	Possum Point	Aug 70	35.78	47.71	25.84	23.9	258.4	30	●	17.89	2.8	1709.7	3.678	-
11	Possum Point	Dec 70	45.60	27.36	45.10	24.3	481.4	76	●	24.83	2.2	2102.8	8.646	5.55
11	Possum Point	Apr 71	42.50	32.75	28.25	27.0	207.5	8	●	-	-	-	-	-
13	Smith Point	Aug 70	35.95	37.95	29.96	36.0	244.7	18	●	19.97	1.8	4968.2	4.045	-
13	Smith Point	Dec 70	49.10	14.23	21.09	14.7	208.5	20	●	17.66	1.4	3372.6	4.568	-
13	Smith Point	Apr 71	47.50	27.25	25.50	23.3	192.5	5	●	-	-	-	-	-
15A	Mathias Point	Aug 70	-	-	-	-	-	-	-	-	-	-	-	-
15A	Mathias Point	Dec 70	4.80	20.65	31.22	21.1	936.5	58	●	19.69	1.5	2329.2	6.513	-
15A	Mathias Point	Apr 71	25.00	20.75	21.50	24.0	150.0	8	●	-	-	-	-	-
16	Route 301 Bridge	Aug 70	-	-	-	-	-	-	-	-	-	-	-	-
16	Route 301 Bridge	Dec 70	106.50	16.96	23.74	18.4	157.5	53	●	16.47	1.3	2035.1	7.177	-
16	Route 301 Bridge	Apr 71	172.50	731.25	84.50	36.0	212.5	20	●	-	-	-	-	-

[1] ● - [illegible] As, B, Be, La, Mo, Sb, Se, Sn, [illegible] and Zr

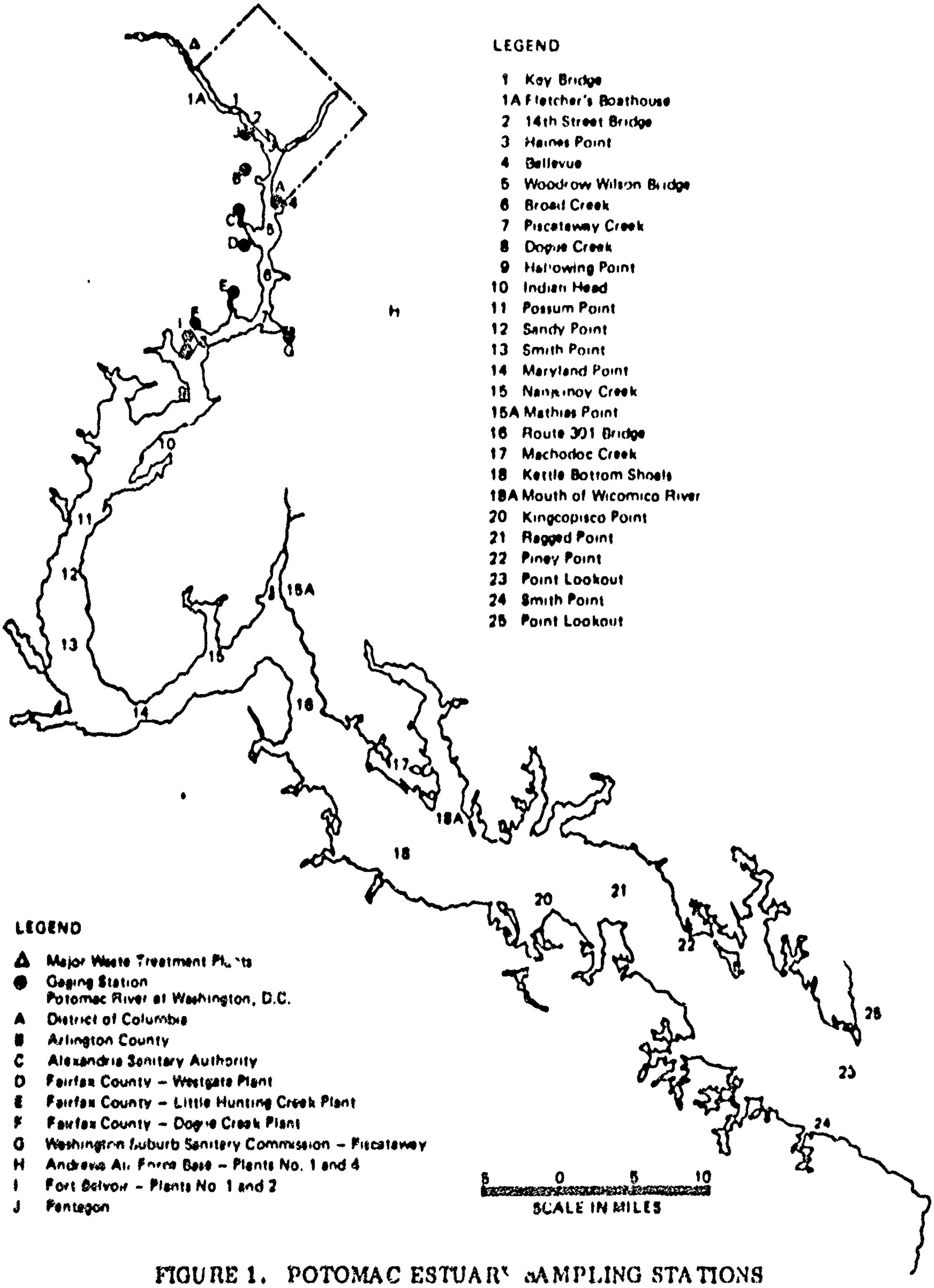

FIGURE 1. POTOMAC ESTUARY SAMPLING STATIONS

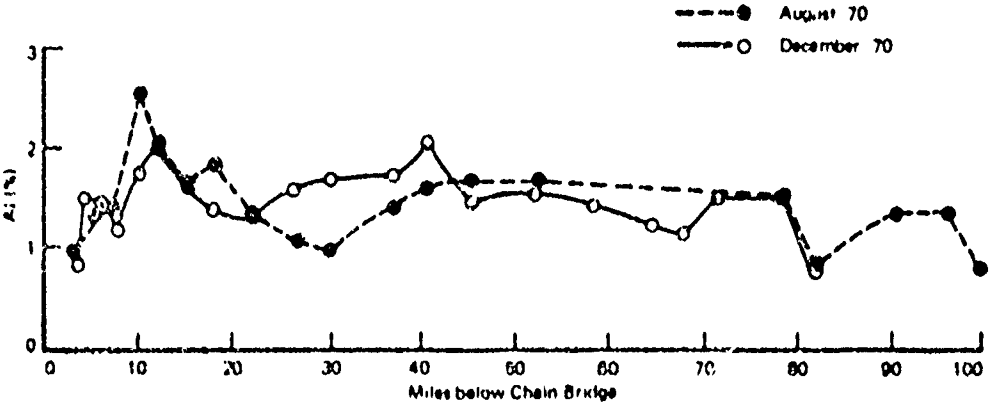

FIGURE 2. ALUMINUM

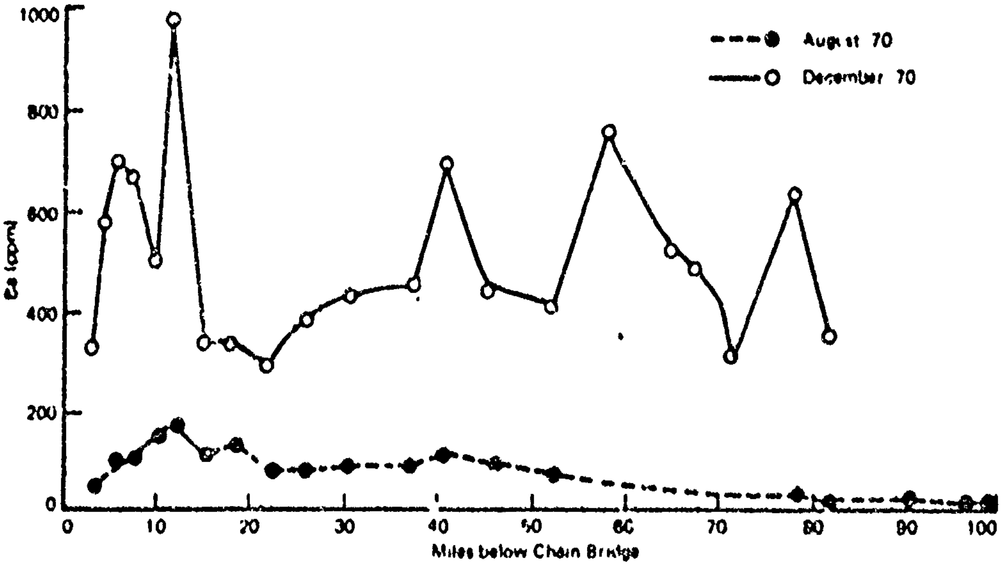

FIGURE 3. BARIUM

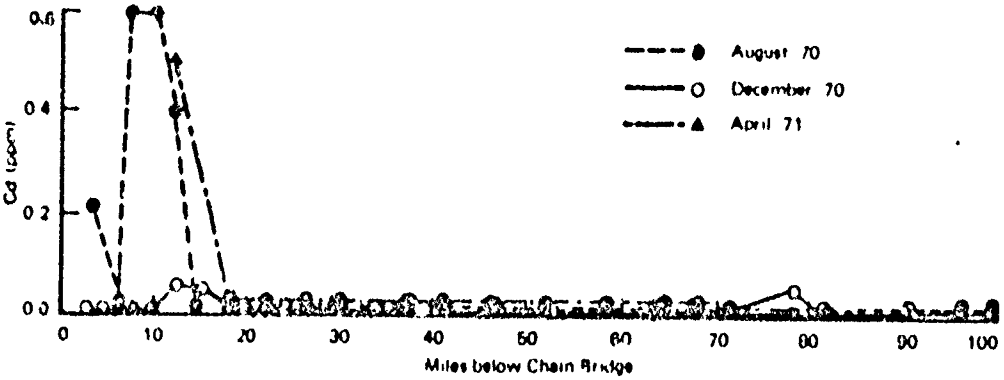

FIGURE 4. CADMIUM

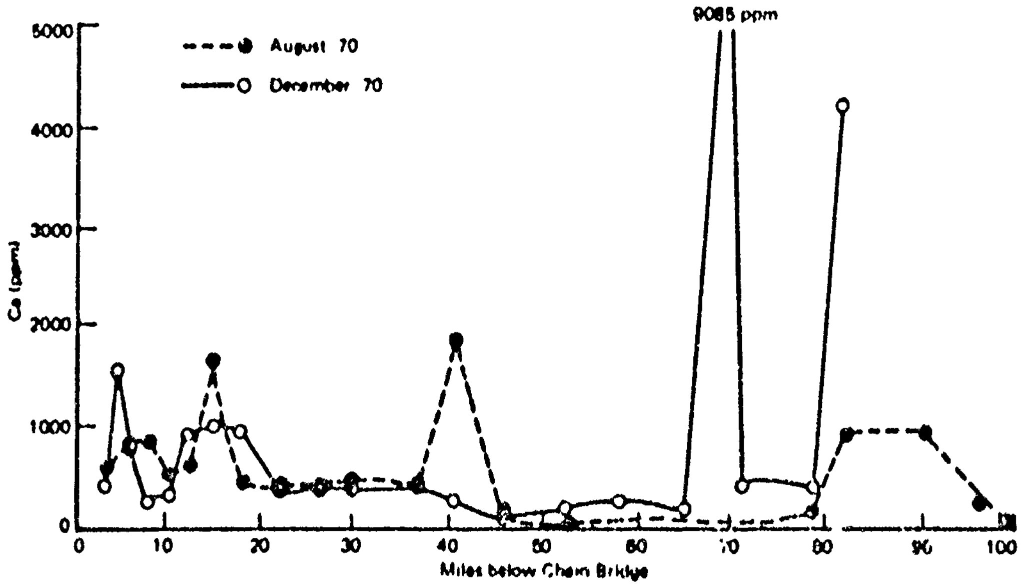

FIGURE 5. CALCIUM

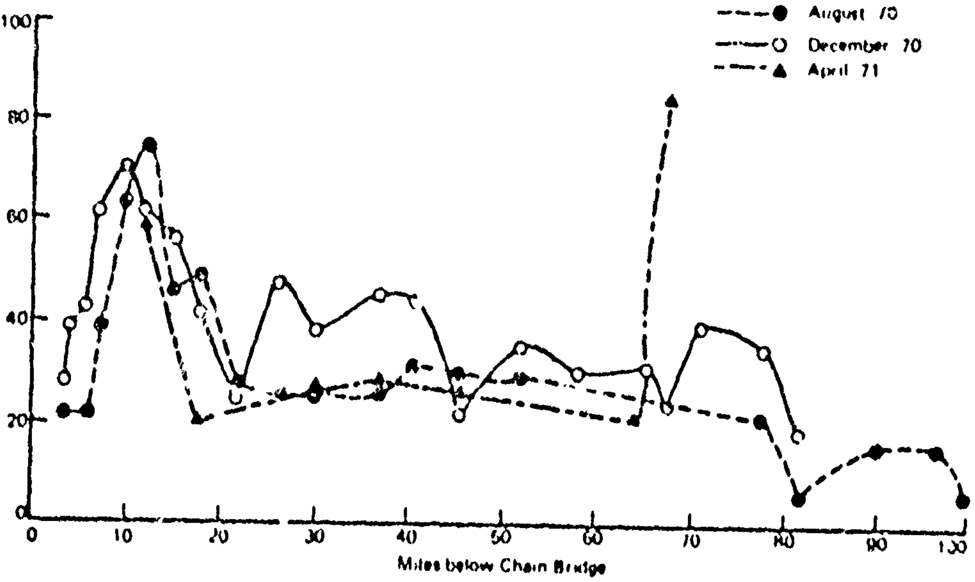

FIGURE 6. CHROMIUM

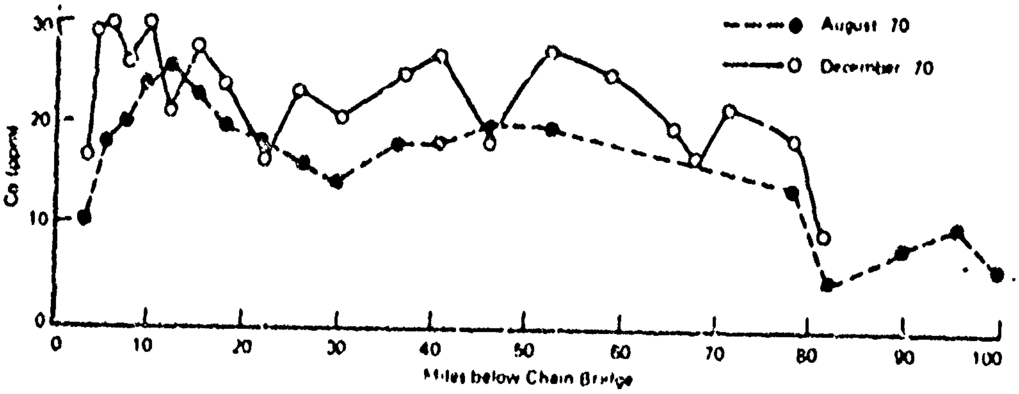

FIGURE 7. COBALT

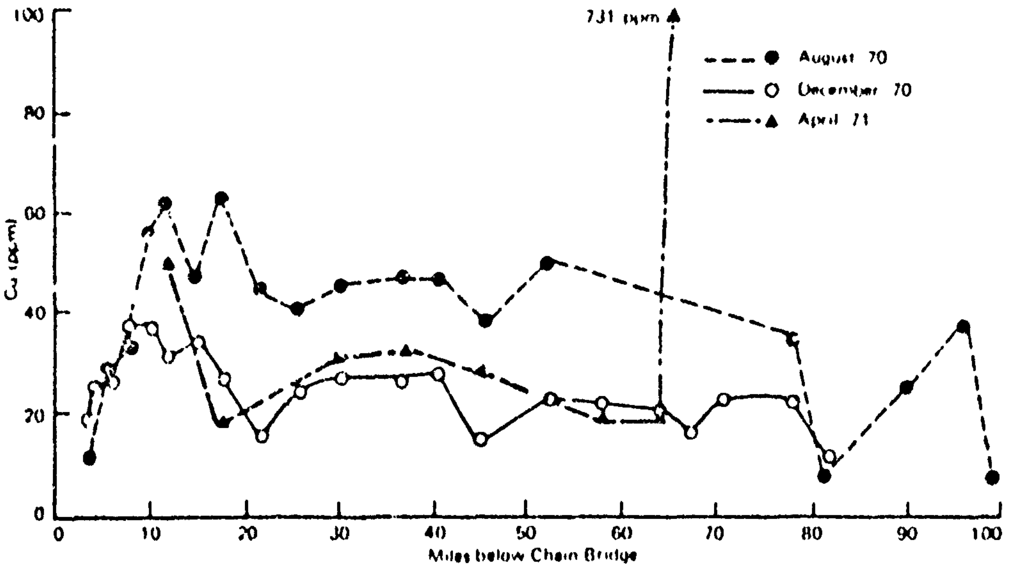

FIGURE 8. COPPER

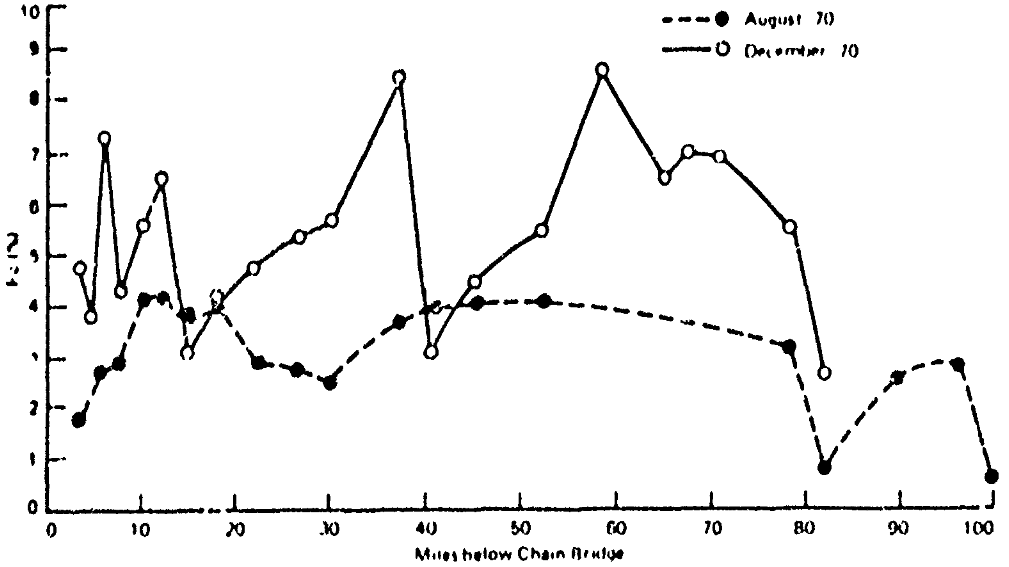

FIGURE 9. IRON

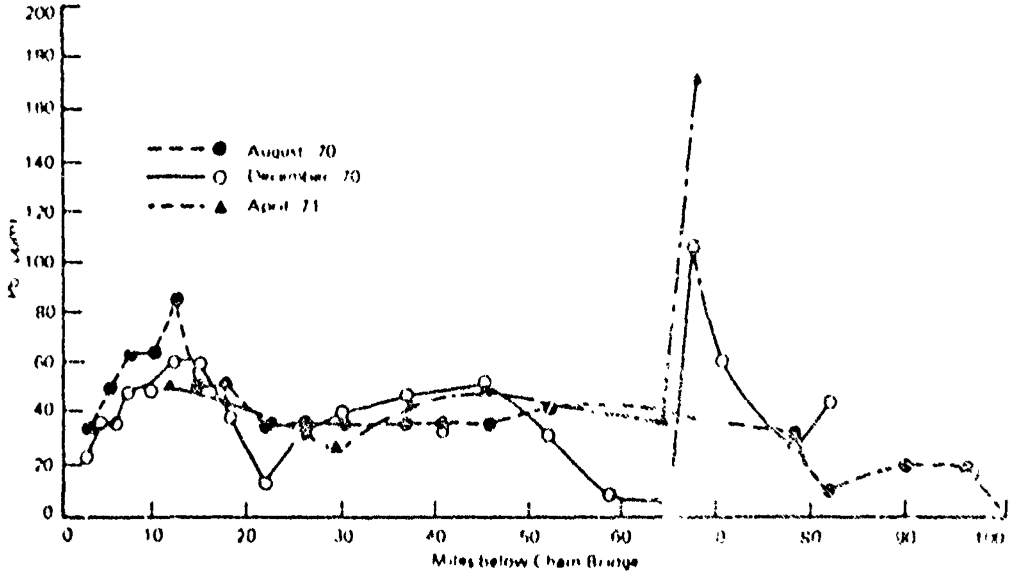

FIGURE 10. LEAD

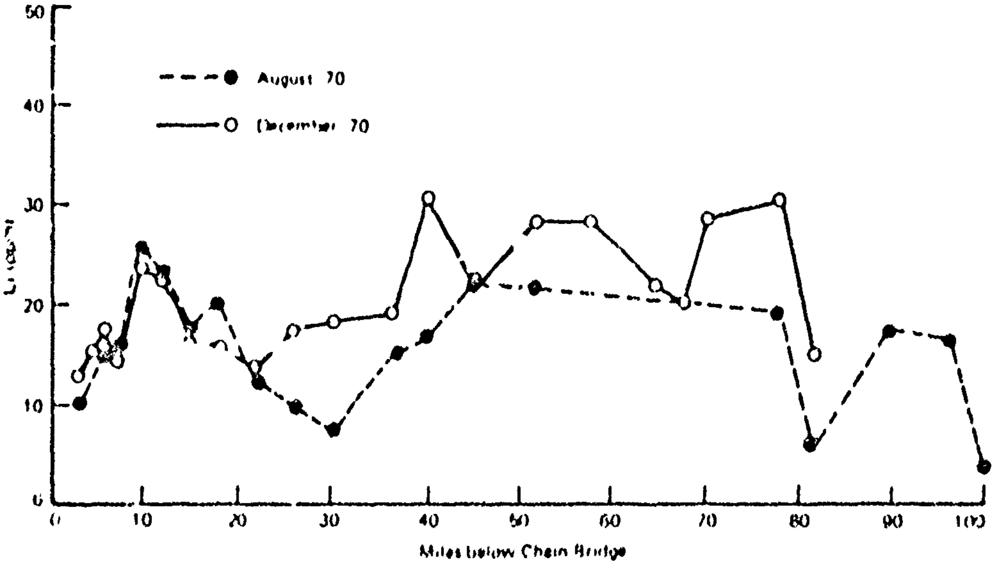

FIGURE 11. LITHIUM

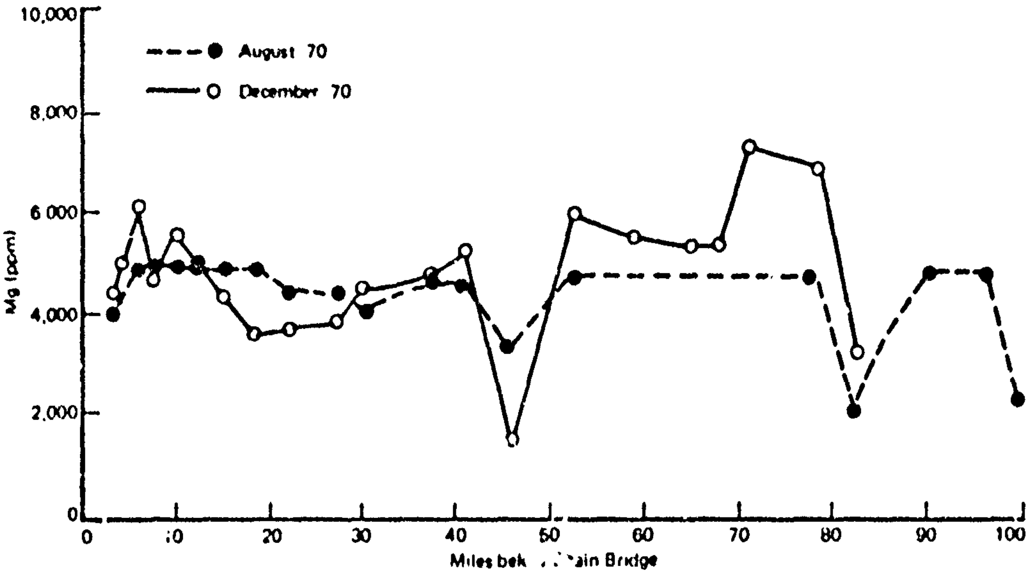

FIGURE 12. MAGNESIUM

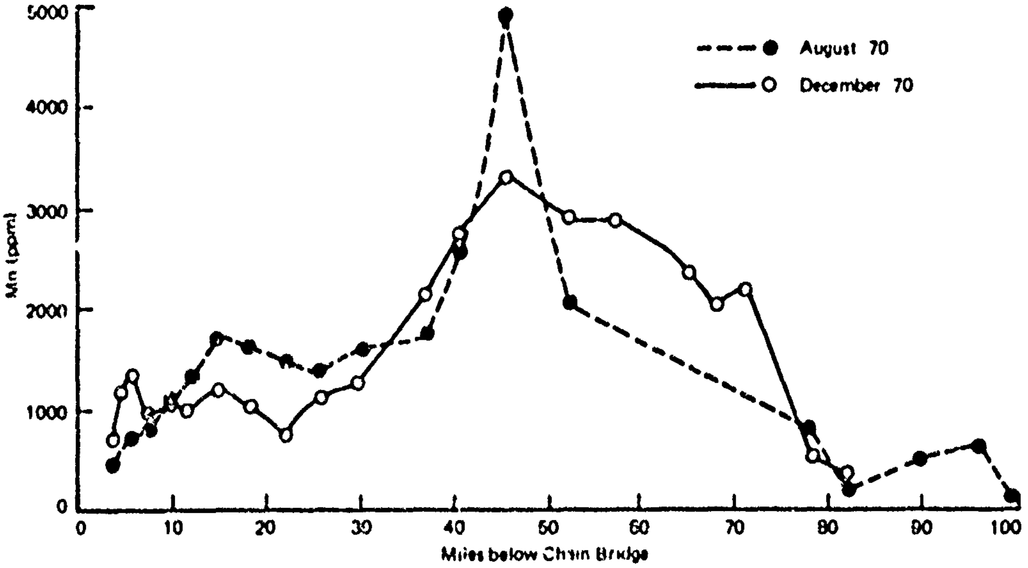

FIGURE 13. MANGANESE

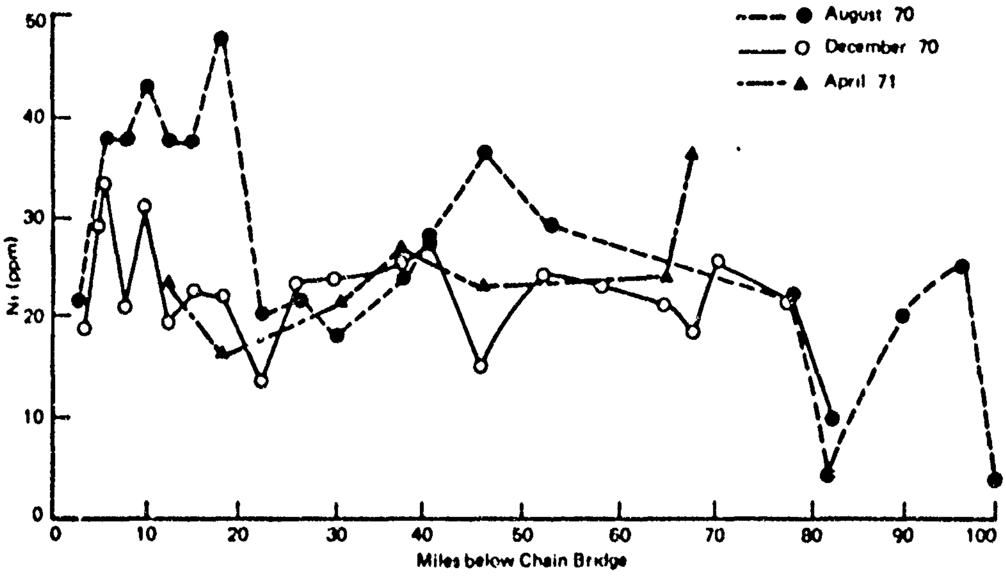

FIGURE 14. NICKEL

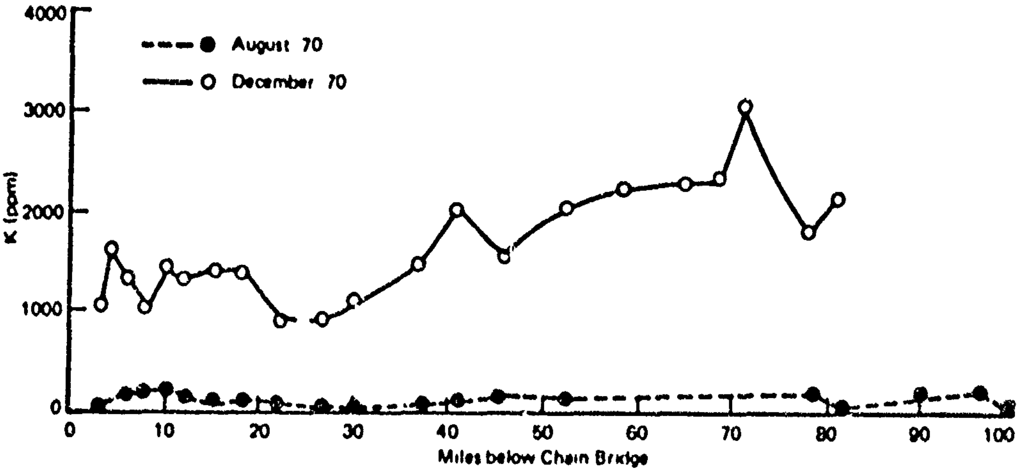

FIGURE 15. POTASSIUM

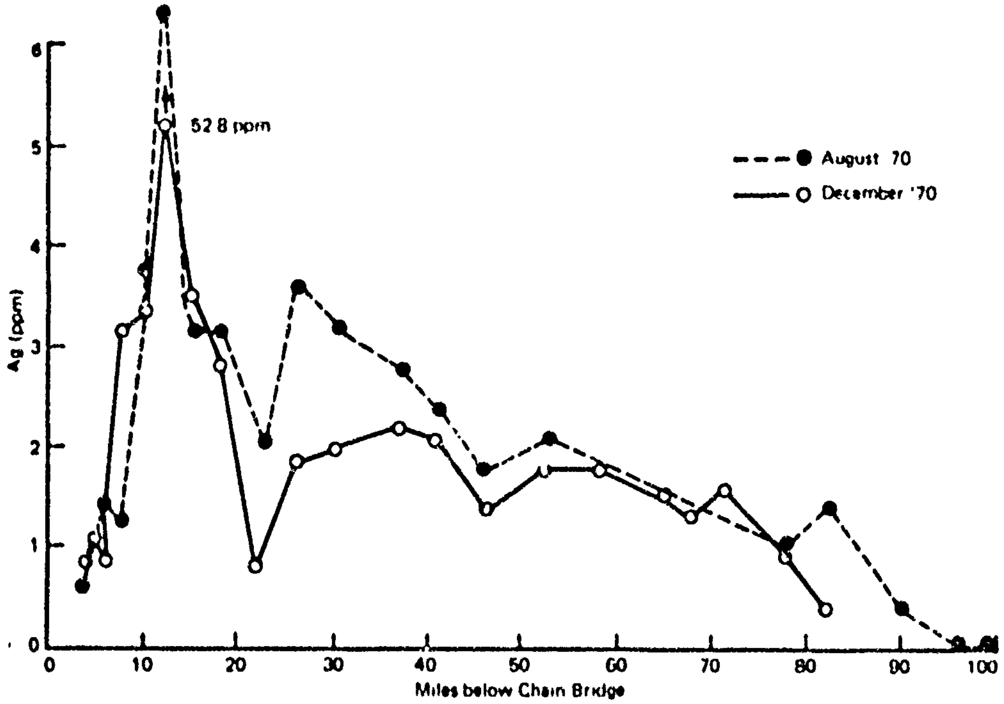

FIGURE 16. SILVER

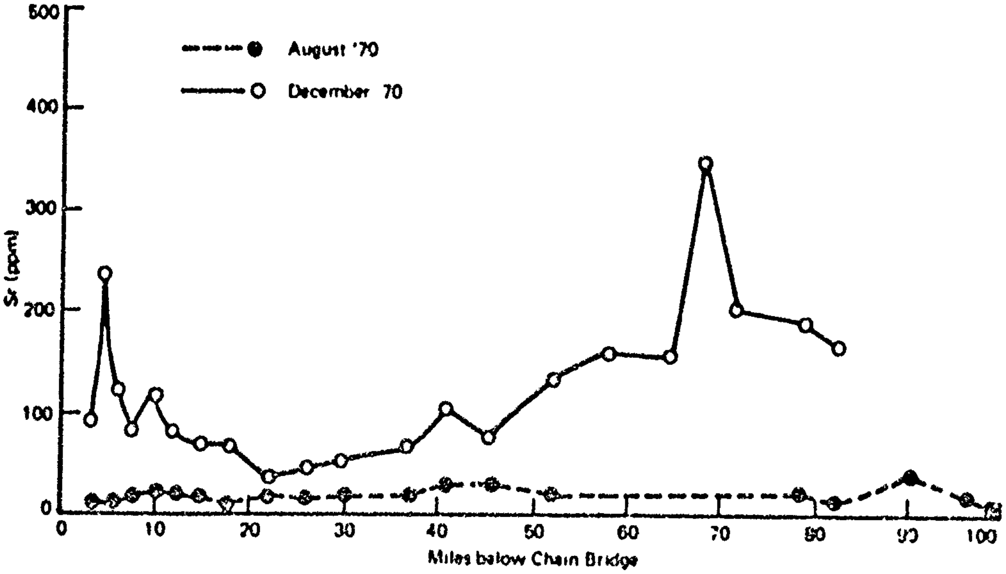

FIGURE 17. STRONTIUM

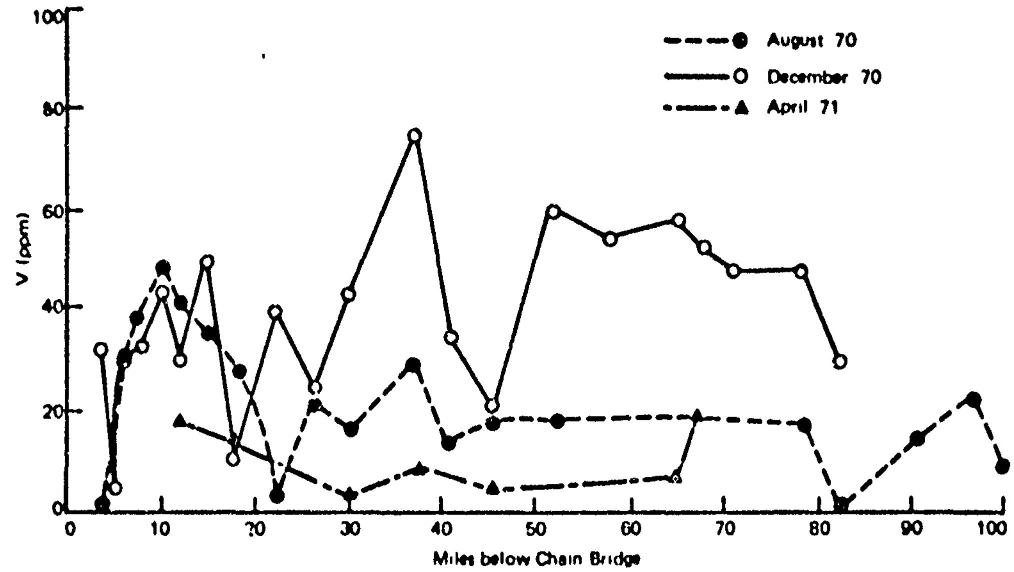

FIGURE 18. VANADIUM

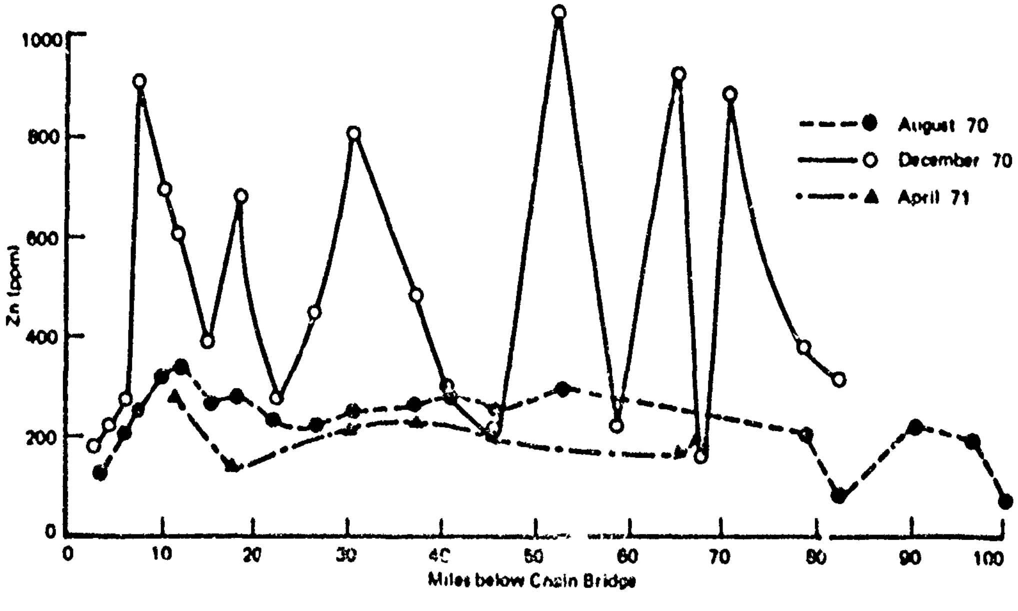

FIGURE 19. ZINC

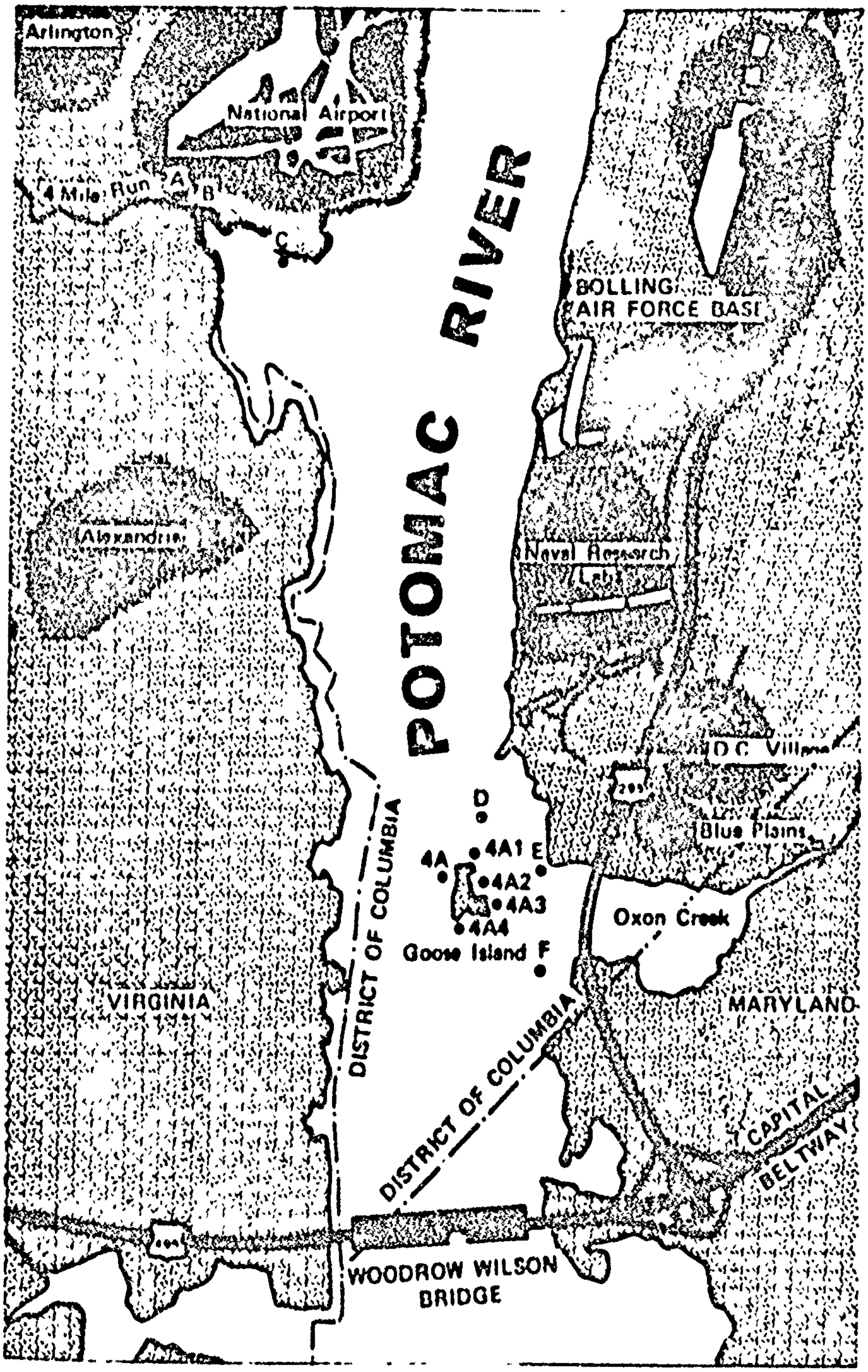

FIGURE 20. GOOSE ISLAND DREDGING STUDY

Table VI

GOOSE ISLAND DREDGING STUDY[1]

[ppm metal (µg/g dried wt.)]

Station[2]	Date	Pb (ppm)	Cu (ppm)	Cr (ppm)	Ni (ppm)	Zn (ppm)	V (ppm)	Cd (ppm)	Li (ppm)	Ba (ppm)	Sr (ppm)	Mg (ppm)	K (ppm)	Ca (ppm)	Hg (ppm)	Co (ppm)	Ag (ppm)	Mn (ppm)	Fe ( )	Al ( )	Volatiles at 105° C
4A	Dec 70	68.59	63.21	91.13	26.0	1555.6	49	0.08	15.7	196	125.9	4593.4	1114.7	6737	-	27.44	2.9	1139.2	1.195	1.543	-
4A	Feb 71	93.48	67.89	72.32	43.8	292.7	10	1.97	19.2	447	93.8	7994.6	738.0	347	13.1	29.03	8.9	848.7	3.352	1.968	65.94
4A1	Dec 70	19.93	21.92	25.38	13.5	161.9	15	●	6.5	747	40.4	1706.6	348.8	834	2.8	22.92	0.1	498.3	1.335	0.573	-
4A1	Feb 71	105.70	105.70	73.43	38.9	394.0	14	1.83	14.9	652	102.1	7651.2	480.5	69	2.4	23.06	11.5	660.6	2.823	1.634	60.17
4A2	Dec 70	34.04	37.93	57.87	19.5	571.4	49	0.09	10.2	456	68.6	3951.3	753.8	1532	3.9	29.18	4.0	1033.4	5.380	0.936	-
4A2	Feb 71	45.74	43.45	37.05	24.2	386.5	5	1.23	9.2	148	46.8	4996.7	114.3	32	2.7	21.04	2.7	468.8	1.344	0.995	47.29
4A3	Dec 70	42.70	55.98	72.59	23.3	854.0	43	0.11	13.3	759	118.1	4151.3	1008.2	261	3.5	22.30	60.5	889.6	4.566	1.269	-
4A3	Feb 71	49.08	57.92	46.63	32.9	279.8	5	1.47	10.3	397	70.0	6957.6	368.1	48	2.0	30.92	2.5	736.3	3.191	1.178	45.47
4A4	Dec 70	37.33	54.58	75.58	25.2	699.8	23	0.08	14.9	746	115.2	156.6	1306.3	233	5.0	21.46	15.2	1038.0	5.307	1.598	-
4A4	Feb 71	72.99	90.02	63.74	37.0	326.0	15	1.56	12.2	596	89.4	7554.0	243.3	79	1.3	23.36	6.8	693.4	2.737	1.180	56.53
4X	Dec 70	37.89	24.63	30.79	20.8	163.4	14	0.52	9.0	184	34.6	3990.2	355.2	69	2.2	14.68	1.4	367.1	1.776	0.876	30.31
4X1	Feb 71	37.43	29.95	26.20	18.3	196.8	4	1.17	8.0	222	38.5	4644.1	234.0	5	0.5	10.76	20.6	362.6	1.462	0.912	36.02
A	Jan 71	139.97	53.49	26.49	26.0	110.0	5	2.05	6.5	194	47.4	4973.9	249.9	23	-	15.50	2.0	200.0	1.344	2.337	42.49
B	Jan 71	39.15	140.46	43.56	59.7	181.1	5	1.76	22.5	698	118.7	7536.7	244.7	115	-	37.19	0.5	1186.8	3.395	1.970	65.41
C	Jan 71	49.77	48.78	40.32	38.3	72.2	10	1.29	16.9	431	90.0	7889.0	248.0	79	-	25.38	0.5	771.5	2.489	2.016	53.43
D	Jan 71	54.91	49.92	35.94	40.9	34.9	10	1.70	15.0	379	78.6	8323.7	249.0	85	-	23.46	0.5	711.3	2.683	2.097	49.82
E	Jan 71	89.68	171.38	35.37	36.9	47.3	20	1.69	15.4	608	117.6	6090.5	124.0	175	-	21.92	2.0	572.9	7.037	1.806	51.00
F	Jan 71	59.91	75.39	54.42	48.4	84.9	20	2.05	18.5	699	91.4	8175.2	249.0	36	-	29.46	2.0	711.4	2.964	2.359	51.81

[1] ● [illegible]

[2] 4A [illegible]
4A1 Back of Goose Island [illegible]
4A2 Back of Goose Island [illegible]
4A3 Back of Goose Island [illegible]
4A4 South of Goose Island [illegible]
4X [illegible] Marsh
A 4 Mile Run
B Mouth of 4 Mile Run
C [illegible] 4 Mile Run [illegible]
D [illegible]
E [illegible]
F [illegible]

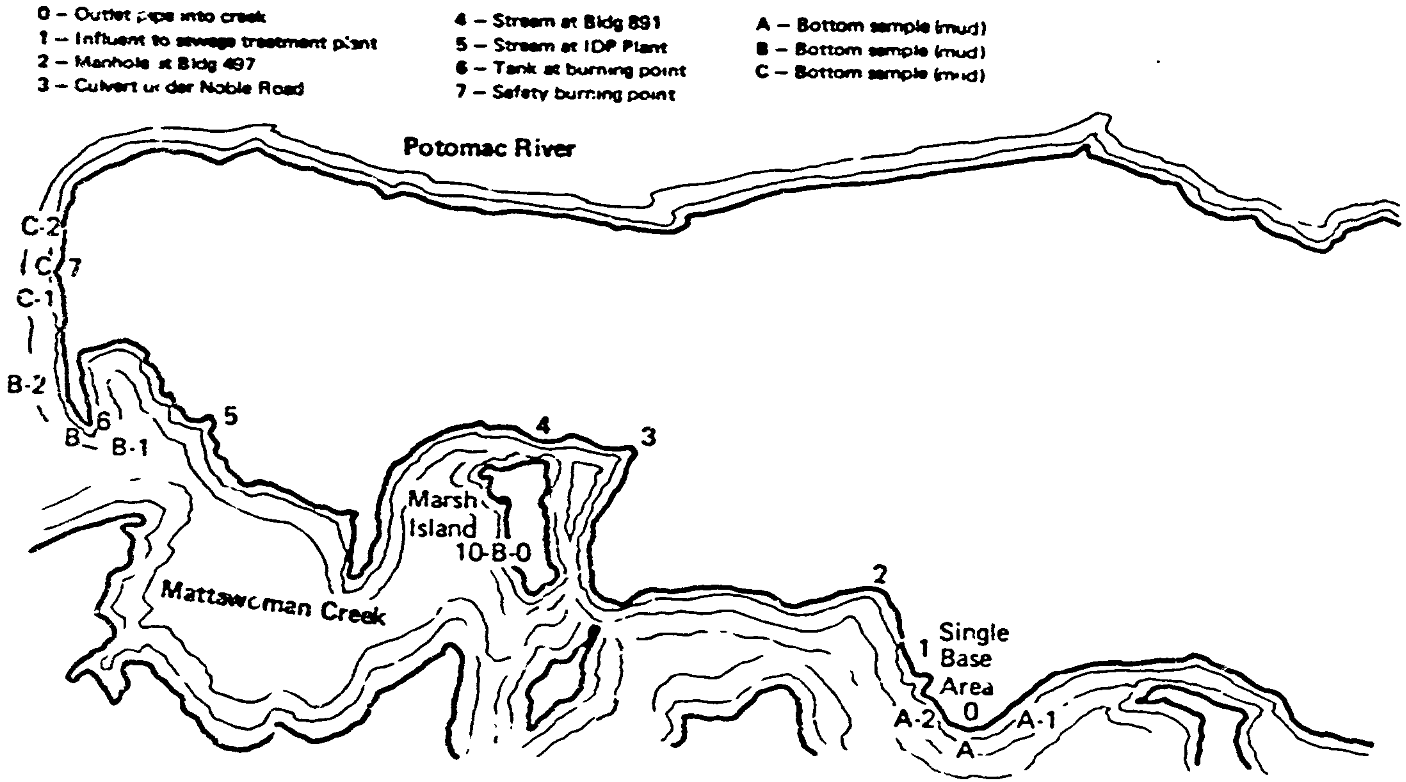

FIGURE 21. SAMPLING LOCATIONS AT NAVAL ORDNANCE STATION, INDIAN HEAD, MD.

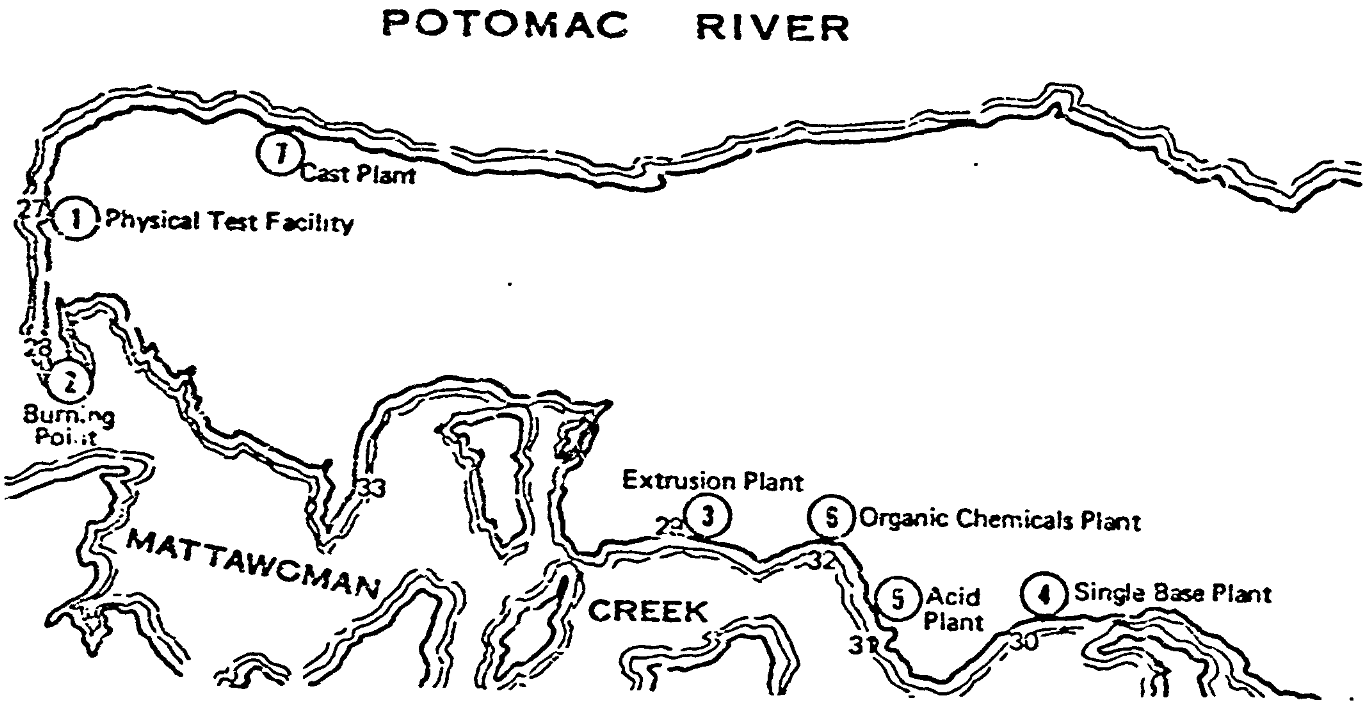

FIGURE 22. SEDIMENT SAMPLING LOCATIONS AT NAVAL ORDNANCE STATION, INDIAN HEAD, MD.

Table VII

METALS CONTENT OF WATER SAMPLES AT NAVAL ORDNANCE STATION[1]

Collection date	Location[2]	Pb (ppm)	Zn (ppm)	Mn (ppm)	Cr (ppm)	Cu (ppm)	Co (ppm)	Cd (ppm)	As (ppm)	K (ppm)	Li (ppm)	Ca (ppm)	Ag (ppm)	Mg (ppm)	Fe (ppm)	F (ppm)	Cl (ppm)	ClO₄ (ppm)
3/16/70	Water 1	0.1	0.06	0.06	●	0.02	●	●	●	4.7	●	6.4	●	1.77	1.33	-	-	-
	Water 2	0.2	0.04	0.01	●	0.01	●	●	●	1.4	●	1.4	●	0.14	0.18	-	-	-
	Water 3	0.1	0.04	0.02	●	●	●	●	●	2.3	●	12.1	●	3.95	0.35	-	-	-
	Water 4	0.1	0.08	●	●	0.02	●	●	●	2.4	●	6.1	●	2.38	0.66	-	-	-
	Water 5	0.1	0.09	0.9	●	0.01	●	●	●	2.0	●	25.5	●	5.25	0.39	-	-	-
	Water 6	0.1	0.06	●	●	0.01	●	●	●	1.8	●	24.0	●	5.60	0.15	-	-	-
4/16/70	Water 8	0.1	0.10	0.01	●	0.01	●	●	●	2.0	●	13.0	●	6.5	0.3	0.70	17.0	3.1
	Water 1	●	0.30	0.06	●	0.01	●	●	●	2.0	●	10.0	●	5.6	0.7	0.63	24.7	4.2
	Water 2	●	0.26	0.06	●	0.03	●	●	●	2.5	0.01	31.0	●	3.3	●	1.54	43.8	5.3
	Water 3	●	0.44	0.01	●	0.03	●	●	●	3.0	●	11.0	●	6.9	0.3	0.15	65.7	2.1
	Water 4	0.1	0.16	0.10	●	0.01	●	●	●	3.5	●	11.0	●	7.4	0.5	0.26	82.4	1.6
	Water 5	0.1	0.69	0.06	●	0.04	●	●	●	3.5	●	20.0	●	7.5	0.4	0.09	14.9	2.3
	Water 6	●	0.22	0.01	●	0.03	●	●	●	3.5	●	17.0	●	7.2	0.4	0.02	11.2	1.7
	Water 7	●	0.22	0.01	●	0.03	●	●	●	0.1	●	17.0	●	7.2	0.4	0.02	11.9	1.9
	Water I[3]	●	0.33	0.01	●	0.10	●	●	●	3.0	[illegible]	24.0	●	8.0	0.2	0.34	21.1	1.6
	Water II[3]	0.1	0.21	0.02	●	0.40	●	●	●	4.0	●	20.0	●	7.0	0.9	0.04	12.2	1.4
5/13/70	Water, Bumpy Oak	0.1	0.03	●	●	●	●	●	●	1.2	●	4.0	●	1.5	0.3	0.06	8.9	0.2
	Water, Sewer No. 2	●	0.05	0.02	●	0.02	●	●	●	10.3	●	3.5	●	1.3	0.5	0.65	67.9	0.8
5/19/70	Water 10	0.1	0.05	●	●	0.03	●	0.01	●	2.03	●	27.5	●	5.0	0.4	0.17	19.7	0.8
	Water 10-B-6	0.1	0.05	●	●	●	●	0.01	●	1.90	●	12.0	●	2.5	0.4	0.11	25.5	0.5
	Water 11	0.1	0.20	●	●	●	●	0.01	●	2.18	●	28.5	●	4.5	0.1	0.13	19.7	0.6
6/10/70	Water 10 (A)	0.1	0.02	●	●	●	●	0.01	●	2.96	●	35.0	●	7.0	0.06	0.19	15.0	0.1
	Water 10-B-6 (A)	0.1	0.01	●	●	●	●	0.01	●	2.09	●	24.5	●	4.5	●	0.24	25.5	0.3
	Water 11 (A)	0.1	0.03	●	●	●	●	0.01	●	2.33	●	23.0	●	5.5	●	0.14	25.2	0.1

[1] ● = concentration below detection limit

[2] Locations shown on Figures 1 and 2

[3] Samples supplied by Public Works Department, no information as to location available.

Table VIII

METALS CONTENT OF SEDIMENT SAMPLES AT NAVAL ORDNANCE STATION[1]

Collection date	Location[2]	Pb (ppm)	Zn (ppm)	Mn (ppm)	Cr (ppm)	Cu (ppm)	Co (ppm)	Cd (ppm)	As (ppm)	K (ppm)	Li (ppm)	Ca (ppm)	Ag (ppm)	Mg (ppm)	Fe (%)	F (ppm)	Cl (ppm)	ClO$_4$ (ppm)
3/16/70	Mud A	258	373	30	22	16	●	6.5	●	331	4.3	215	●	300	4.0	-	-	-
	Mud B	1776	162	37	22	20	22	●	18	1031	4.4	2	31	●	2.2	-	-	-
4/16/70	Mud A	631	197	35	36	72	29	2	20	610	7	273	2	987	3.86	2.47	5.8	20.1
	Mud A-1	222	270	28	18	78	14	5	6	1154	5	4588	●	1649	3.45	3.33	14.4	11.3
	Mud A-2	●	49	20	14	14	14	4	6	351	3	258	●	45	3.95	0.06	1.1	3.7
	Mud B	582	63	16	8	15	5	1	15	601	3	2	1	240	1.85	0.18	2.6	2.7
	Mud B-1	600	91	75	9	120	11	1	22	400	1	1	●	218	1.75	0.15	1.3	2.1
	Mud B-2	120	16	48	8	●	8	○	●	88	1	6	●	302	1.76	0.15	1.9	2.2
	Mud C	18	36	73	7	●	36	2	●	87	1	345	●	90	0.91	0.22	1.4	1.6
	Mud C-1	1498	115	66	13	595	8	1	●	94	1	48	1	201	1.83	0.37	2.0	0.8
	Mud C-2	10	11	44	4	●	5	2	28	31	1	8	●	55	0.78	0.08	0.5	0.8
5/13/70	Mud, Bumpy Oak	10	20	33	17	2	1	0.5	●	1913	2	1	●	1294	1.81	0.004	23.4	-
5/19/70	Mud 10	50	295	101	43	44	47	1.2	9	1848	23	5	0.6	4869	4.35	0.06	24.7	-
	Mud 10-B-0	19	75	81	21	16	28	0.7	9	1100	17	3	●	2274	2.60	0.02	19.9	-
	Mud 11	50	277	100	35	42	47	1.1	9	1275	24	4	●	4674	4.10	0.03	44.7	-
6/10/70	Mud 10 (A)	60	333	1687	50	52	24	0.6	●	179	28	249	4	4846	4.28	-	-	-
	Mud 10-B-0 (A)	55	254	604	37	37	16	0.8	●	228	31	86	10	4618	3.71	-	-	-
	Mud 11 (A)	64	328	1740	44	52	22	0.8	●	219	34	199	3	4886	4.47	-	-	-

[1] ● = concentration below detection limit

[2] Locations shown on Figures 1 and 2

Table IX

SUMMARY OF TOXIC METALS CONTENT OF SEDIMENTS AT NAVAL ORDNANCE STATION[1]

Mud sample[2]	Date sampled	Concentration (dried sample) (ppm)								
		Pb	Zn	Mn	Cr	Cu	Co	Cd	Ni	Ag
Mattawoman Creek										
A	3 16 70	258	373	30	22	16	●	6 5	-[3]	●
B	3 16 70	1776	162	33	22	20	22	●	-[3]	11
A	4 16 70	431	197	65	36	72	29	2	-[3]	2
A-1	4 16 70	222	270	28	18	78	14	5	-[3]	●
A-2	4/16/70	●	49	20	14	14	11	4	-[3]	●
B	4/16/70	582	63	16	8	15	5	1	-[3]	1
B-1	4/16/70	600	91	75	9	120	11	1	-[3]	
B-2	4/16/70	120	16	48	8	●	8	●	-[3]	●
C	4/16/70	18	36	73	7	●	36	2	-[3]	1
C-1	4/16/70	1498	115	68	13	595	8	1	-[3]	●
C-2	4/16/70	10	11	44	4	●	5	2	-[3]	●
Station 10-B-0	5/19/70	19	75	81	21	16	28	0 7	-[3]	●
Station 10-B-0	6 10/70	55	254	604	37	37	16	0 8	-[3]	10
Station 10-B-0	7/8/70	56	199	642	24	66	14	1 4	-[3]	11
27	12/8-9/70	●	335	104	●	2	4	●	1	●
28	12/8-9/70	203	40	127	6	34	7	●	3	1
29	12/8-9/70	737	1535	472	47	242	12	10	36	18
30	12/8-9/70	14	163	113	14	56	8	●	10	3
31	12/8-9/70	139	1006	435	15	41	18	●	36	5
32	12/8-9/70	●	35	58	2	7	6	●	3	1207
33	12/8-9/70	●	55	51	●	2	2	●	1	1
Potomac River										
Station 10	5 19/70	50	295	101	43	44	47	1 2	-[3]	1
Station 11	5/19/70	50	277	100	35	42	47	1.1	-[3]	●
Station 10	6/10/70	60	333	1687	50	52	24	0 6	44	4
Station 11	6/10/70	64	328	1740	44	52	22	0.8	-[3]	3
Station 10	7/8/70	34	75	425	18	16	6	●	18	1
Station 10	8/18-20/70	36	239	1580	26	46	14	●	18	3
Station 11	8/18-20/70	36	258	1710	26	48	18	●	24	3
Station 11	12/8-9/70	60	604	656	62	31	21	0 01	19	38
Station 11	12/8-9/70	5	209	1398	21	14	18	●	15	2

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[1] ● = concentration below detection limit (usually less than 0.05 ppm)

[2] Locations shown on Figures 1, 21 and 22

[3] Not determined

REFERENCES

(1) Jack E. McKee and Harold W. Wolf, *Water Quality Criteria*, Publication 3-A, California State Water Resources Control Board. April 1971.

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