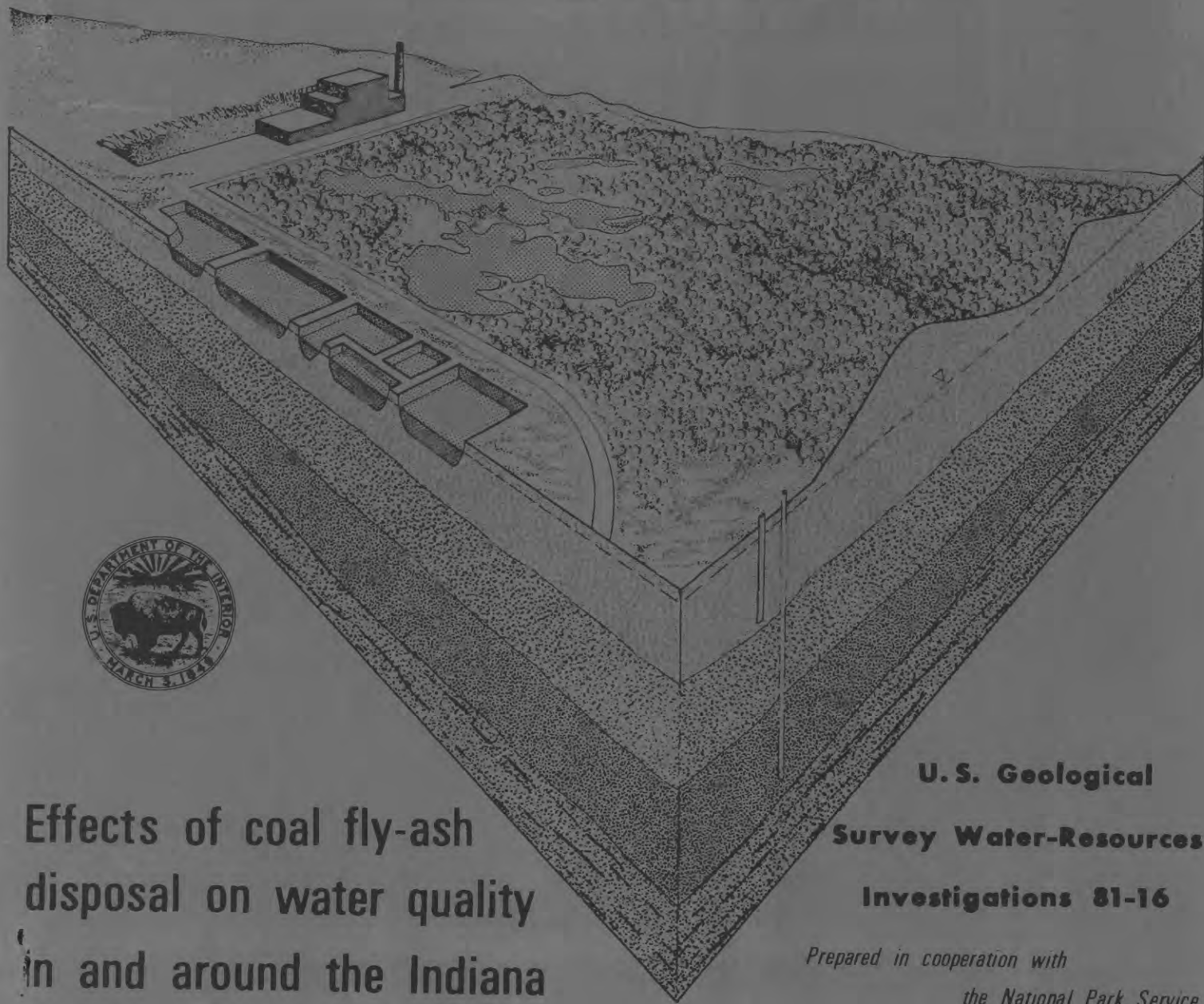


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Effects of coal fly-ash
disposal on water quality
in and around the Indiana
Dunes National Lakeshore, Indiana.

U. S. Geological
Survey Water-Resources
Investigations 81-16

*Prepared in cooperation with
the National Park Service*

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EFFECTS OF COAL FLY-ASH DISPOSAL ON WATER QUALITY
IN AND AROUND THE INDIANA DUNES NATIONAL
LAKESHORE, INDIANA

By Mark A. Hardy

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 81-16

Prepared in cooperation with the
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FACTORS FOR CONVERTING INCH-POUND UNITS TO
INTERNATIONAL SYSTEM OF UNITS (SI)

| <u>Multiply inch-pound unit</u> | <u>By</u> | <u>To obtain SI unit</u> |
|---|-----------|--|
| inch (in.) | 25.40 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| square foot (ft ²) | 0.929 | square meter (m ²) |
| square mile (mi ²) | 2.590 | square kilometer (km ²) |
| acre | 0.4047 | hectare (ha) |
| gallon | 3.788 | liter (L) |
| million gallons per day (Mgal/d) | 0.0438 | cubic meter per second (m ³ /s) |
| micromho per centimeter at 25° Celsius (μmho/cm at 25° C) | 1 | microsiemen per centimeter at 25° Celsius (μS/cm at 25° C) |

DATUM USED IN THIS REPORT

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

USE OF TRADE NAMES

Any use of trade names in this report is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

EFFECTS OF COAL FLY-ASH DISPOSAL ON WATER QUALITY IN AND AROUND THE INDIANA DUNES NATIONAL LAKESHORE, INDIANA

By Mark A. Hardy

ABSTRACT

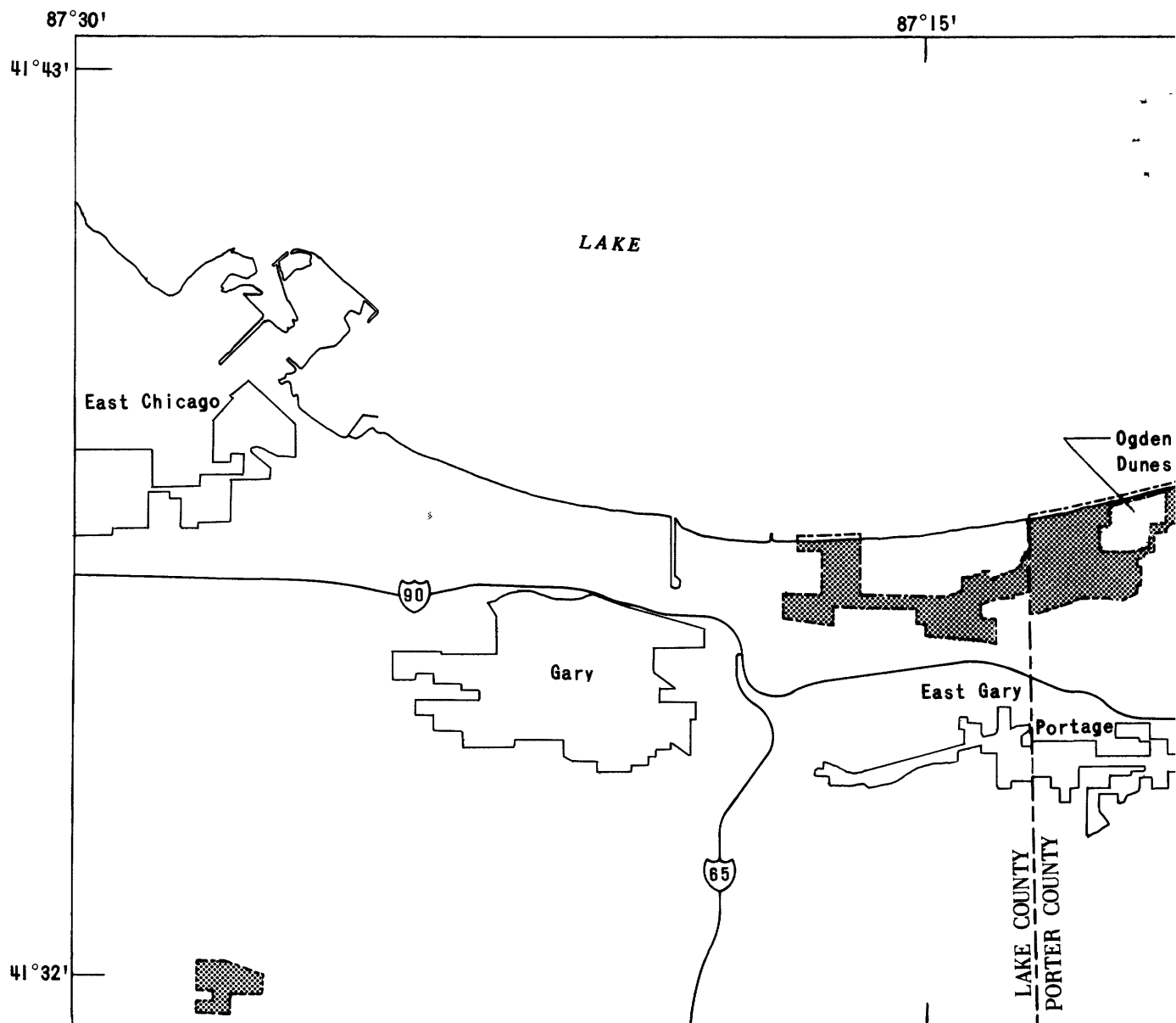
Dissolved constituents in seepage from fly-ash settling ponds bordering part of the Indiana Dunes National Lakeshore (the Lakeshore) have increased the concentrations of major ions (calcium, fluoride, potassium, and sulfate), trace elements (aluminum, arsenic, boron, iron, manganese, molybdenum, nickel, strontium, and zinc), and gross alpha and beta radioactivity in ground water and surface water downgradient from the settling ponds. Data collected from September 1976 through May 1978 suggest that concentrations of some dissolved trace elements may be greater beneath interdunal pond 2 than in the pond. The soil system downgradient from the settling ponds seems to have affected the concentrations of dissolved ions in the settling-pond seepage. Calcium concentrations were greater in ground water downgradient from the settling ponds than in the ponds. Where organic material was present downgradient from the settling ponds, concentrations of arsenic, fluoride, molybdenum, potassium, sulfate, and strontium were greater in the ground water than in the ponds. In contrast, the concentrations of cadmium, copper, nickel, aluminum, cobalt, lead, and zinc were less.

Leachate from an ash fill bordering the Lakeshore increased concentrations of boron, molybdenum, and potassium in surface water.

Although concentrations of chemical constituents were variable, data indicate that ground-water in a confined aquifer beneath the study area was not significantly affected by settling-pond seepage.

INTRODUCTION

The Indiana Dunes National Lakeshore (the Lakeshore) is located along the south shore of Lake Michigan in a heavily industrialized area of northwest Indiana between Gary and Michigan City, Ind. (fig. 1). The park consists of several parcels of land totaling about 12,000 acres. The Bailly Generating Station of the Northern Indiana Public Service Co. (NIPSCO) adjoins the park near Dune Acres, Ind. (fig. 2). Two coal-fired, 600-megawatt electrical generating units are operated at this station, and a nuclear generating unit (Bailly Nuclear 1) has been under construction since 1974. Fly ash produced by the coal-fired units is collected from smokestacks by electrostatic precipitators and is transported as a slurry to a series of settling ponds (ponds 10

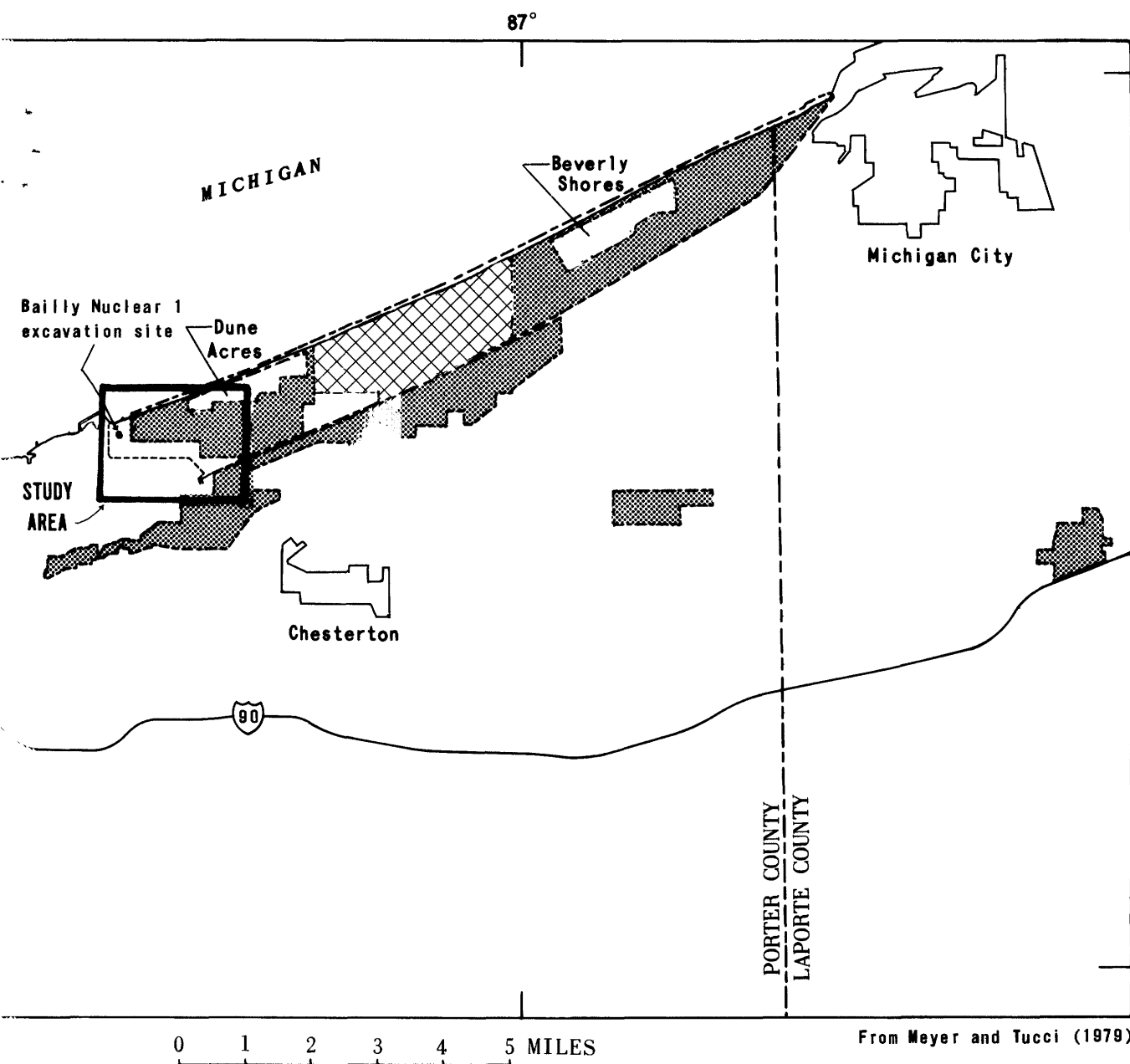


Base from National Park Service, Indiana Dunes
National Lakeshore, Lake, La Porte, and Porter
Counties, Indiana

EXPLANATION

- Indiana Dunes National Lakeshore
(Present and proposed areas)
- Indiana Dunes State Park

Figure 1.-- Location of study area and



Indiana Dunes National Lakeshore, Ind.



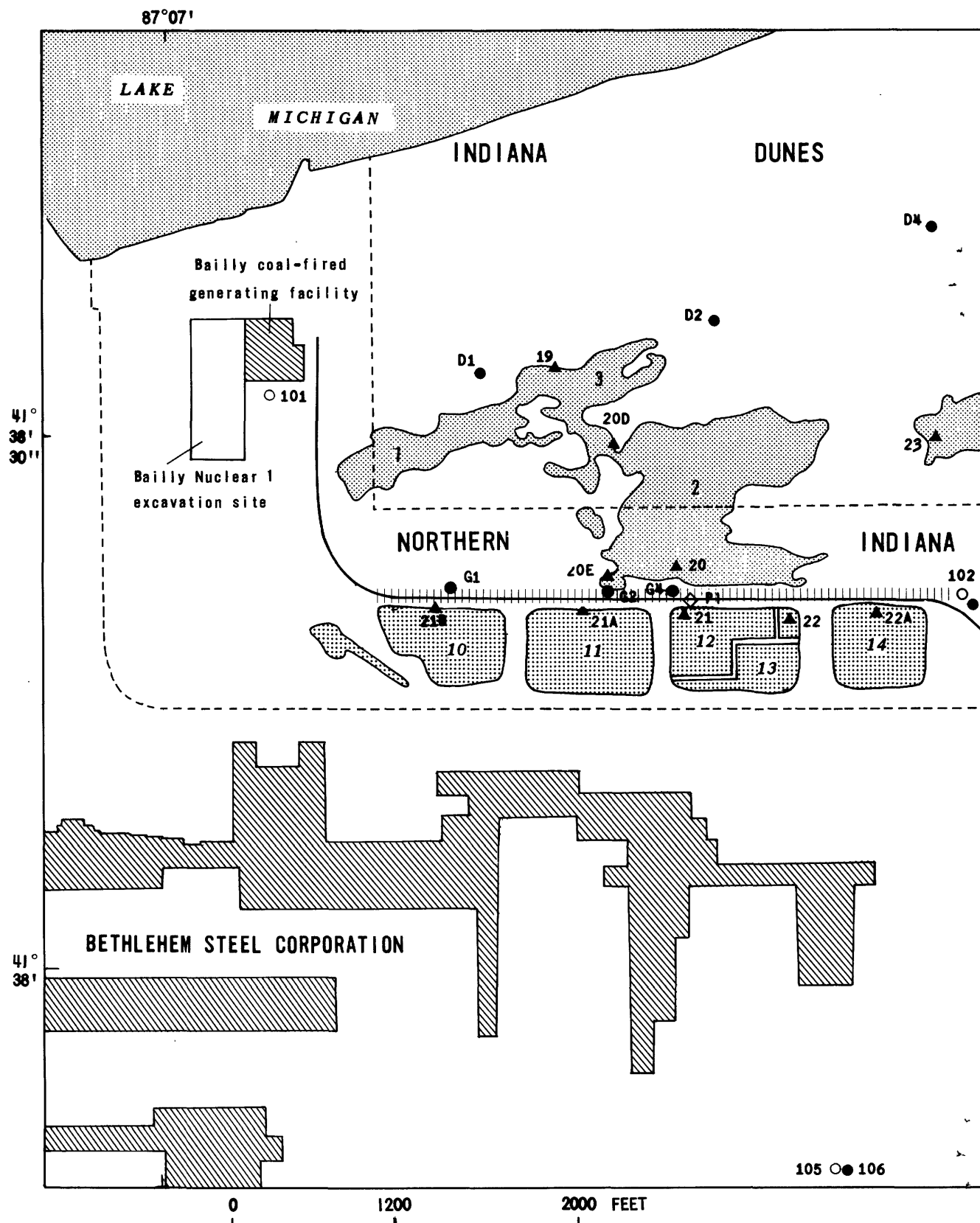
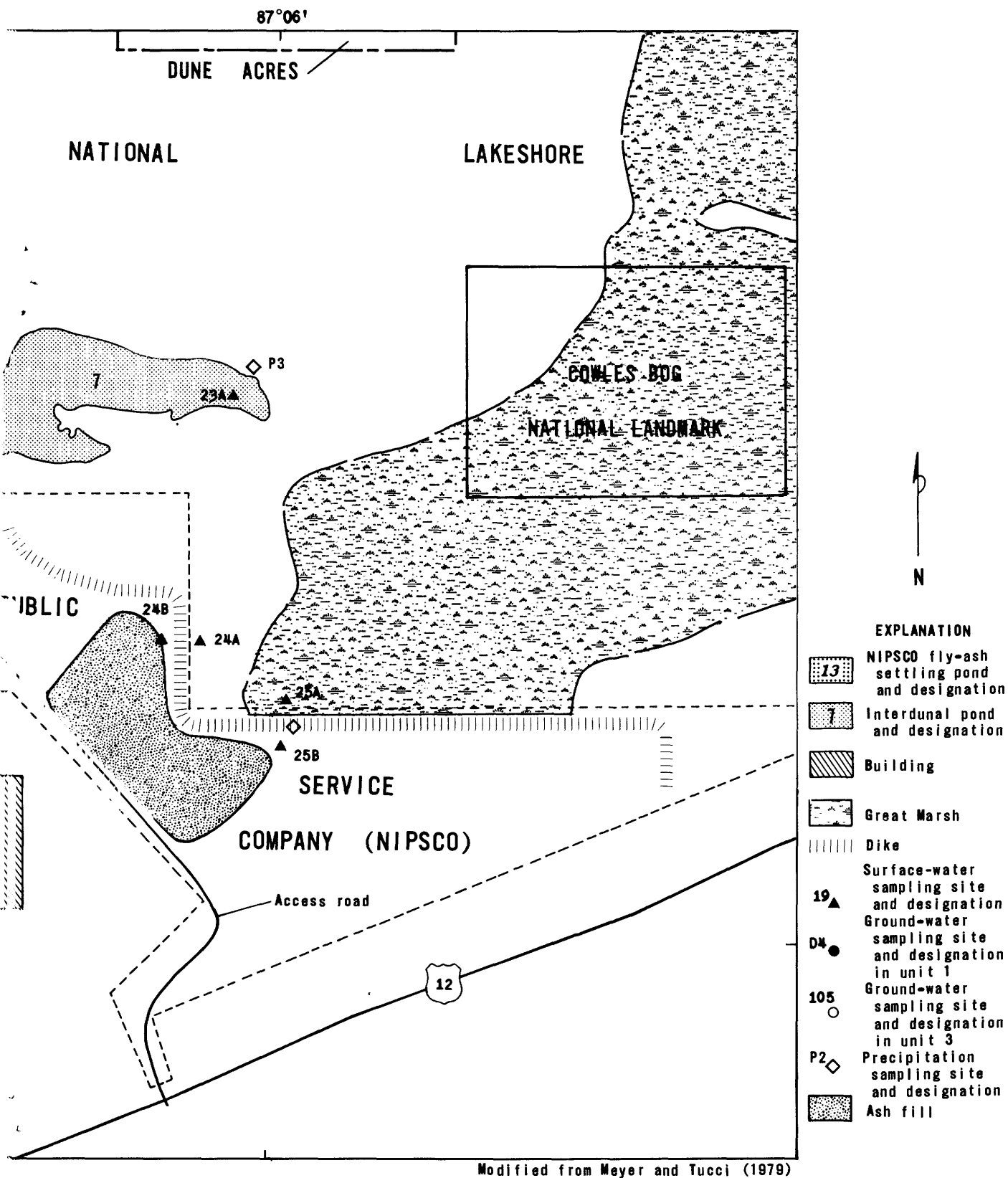


Figure 2.-- Locations of data-collection sites



and major physical features in the study area.

through 14, fig. 2). The settling ponds are periodically drained, and the accumulated ash is removed and is used to fill an area on the east side of NIPSCO's property.

Arihood (1975) found that the general water chemistry in pond 2 (fig. 2) was similar to that of the settling pond directly to the south but was different from that of interdunal ponds at the Lakeshore.

Because the National Park Service is obligated to manage National Lakeshore water resources, an assessment of surface- and ground-water quality in and around the ash-disposal areas was needed to determine whether ash disposal affects water quality.

A 2-yr data collection program was begun in 1976 to describe differences in surface- and ground-water quality in and around the ash ponds and the ash-fill area.

Physical Setting

The 3.8-mi² (square mile) study area is in Porter County in northwest Indiana (figs. 1 and 2). It is bounded by Lake Michigan on the north; steel mills and associated industries on the west; wetlands, dunes, and the town of Dune Acres on the northeast; and private homes, small farms, and additional park on the south. The study area is part of the Calumet Lacustrine Plain, an abandoned lake bottom formerly the site of Lake Chicago in late glacial time. The Calumet Lacustrine Plain is a compound lacustrine area in which successive stages of Lake Chicago are represented by terraced sand ridges. In many places these ridges are covered by sand dunes and interdunal wetlands of various types and developmental stages (Schneider, 1966, p. 50-51). The only surface drainages in the study area are manmade ditches that form part of the Dunes Creek drainage.

Land Features

Major physical features in the study area include the Bailly Generating Station, the Great Marsh, the interdunal ponds, the NIPSCO fly-ash settling ponds, an ash-fill area, dunes, and two dikes (one between the settling ponds and the interdunal ponds and the other between the ash fill and the Great Marsh). Most of the Great Marsh is a cattail marsh with a timbered swamp on the north edge. Cowles Bog National Landmark is within the Great Marsh. The boundaries of the bog are poorly defined, and, although officially named a bog, the soil, vegetation, and water-quality characteristics indicate that this area is probably better termed a fen (Boelter, 1977).

Sand dunes parallel the Lake Michigan shoreline. Most of these dunes are stabilized by vegetation, but a few that lack vegetation are subjected to wind erosion. Interdunal wetlands of various stages of development occupy depressions between sand dunes. Many of these wetlands have organic bottom materials and dystrophic waters that are characteristically colored brown by dissolved humic materials.

The dikes are primarily constructed of sand from the surrounding area. Well logs indicate presence of limestone and slag fragments in some sections and a layer of fibrous organic-plant material about 20 ft (foot) beneath the dike surface at sites G1 and G2 (fig.2). This organic layer, only about 2 in. (inches) thick at site G1 but about 3.5 ft thick at site G2, probably extends under the settling ponds to the south of these wells.

Climate

The mean annual precipitation at Ogden Dunes, west of the study area, is 37 in. Mean monthly precipitation ranges from 2.06 in. in February to 4.50 in. in July. The mean annual temperature is 50.5° F (Fahrenheit). Mean daily temperature ranges from 18.4° in January to 82.6° F in July (Wayne Kiefer, Central Michigan University, written commun., 1975).

Geology

Meyer and Tucci (1979, p. 9-14) described four distinct unconsolidated units underlying the study area, which are numbered in descending order from 1 through 4. (See fig. 3.) The combined thickness of these units averages 180 ft. Unit 1 consists primarily of a tan, fine, well-sorted sand. The lower part of this unit consists of gray, fine-to-medium sand containing some gravel. Rosenshein and Hunn (1968) described the unit as slightly to moderately calcareous. Unit 2 is clay containing small amounts of silt and sand. This unit is absent in some areas south of the settling ponds. Unit 3 is a gray, fine-to-medium sand containing lenses of sandy clay, clay, and sand and gravel. It is absent in an area north of the nuclear excavation site, where unit 4 merges with unit 2. Unit 4 is a silt and clay till containing small lenses of sand and gravel.

Consolidated Paleozoic sedimentary rocks underlie the unconsolidated deposits. The uppermost formation is the Antrim shale, which is assumed to prevent any significant movement of water between the unconsolidated and consolidated deposits (Meyer and Tucci, 1979, p. 14).

Ground-Water Movement

Units 1 and 3 are aquifers. Units 2 and 4 act as semiconfining layers, and significantly less water flows through them than through units 1 and 3. The relation between the lithologic units and the surface- and ground-water systems is shown in figure 3 (Meyer and Tucci, 1979).

Water levels in unit 1 are illustrated in figure 4. The saturated thickness in this unit generally ranges from 0 to 35 ft (Meyer and Tucci, 1979, p. 9-14). The interdunal ponds are depressions intersecting the ground-water table in unit 1. Horizontal movement of ground water is perpendicular to water-level contour lines, generally northwest to Lake Michigan. However, seepage from the settling ponds, estimated by Meyer and Tucci (1979, p. 94) to be at least 2 Mgal/d (million gallons per day), has created a ground-water mound resulting in saturated ground-water flow in all directions away from the settling ponds in unit 1 and into interdunal pond 2. Although settling-pond seepage is indicated to be flowing toward pond 7 (fig. 4), no information is available to determine how this pond interacts with the local ground-water system.

Water levels in unit 3 are illustrated in figure 5. Movement of ground water in unit 3 is generally west and upward. Comparison of potentiometric heads in figures 4 and 5 shows that ground-water flow is downward from unit 1 to unit 3 in the immediate vicinity of the settling ponds.

Ash Disposal

The Bailly Generating Station is in the northwest corner of the study area. Coal combustion at the station produces a residue, composed primarily of inorganic material originally in the coal and incompletely burned organic matter. This residue consists of bottom ash, which collects in the bottom of the boiler, and fly ash, which is transported away from the boiler by the combustion gas. Most of the fly ash is collected by electrostatic precipitators, although some passes into the atmosphere (Ray and Parker, 1977, p. 28-31).

After collection, fly ash is sluiced to the fly-ash settling ponds, which are arranged in a straight line along the east-west boundary north of Bethlehem Steel Corp. (fig. 2). The ponds are numbered in figure 2 according to the scheme used by Meyer and Tucci (1979, p. 6-7). The ponds include two ash-settling systems. Primary ponds 10 and 11 receive the ash transported from the generating station, and an overflow pipe decants the pond water to secondary ponds (ponds 13 and 12, respectively) for further settling.

Water decanted from both secondary ponds goes into the forebay of the recirculating pump house for reuse in the sluicing system. Pond 14 is a relief surge pond and does not regularly receive discharge. Other discharges

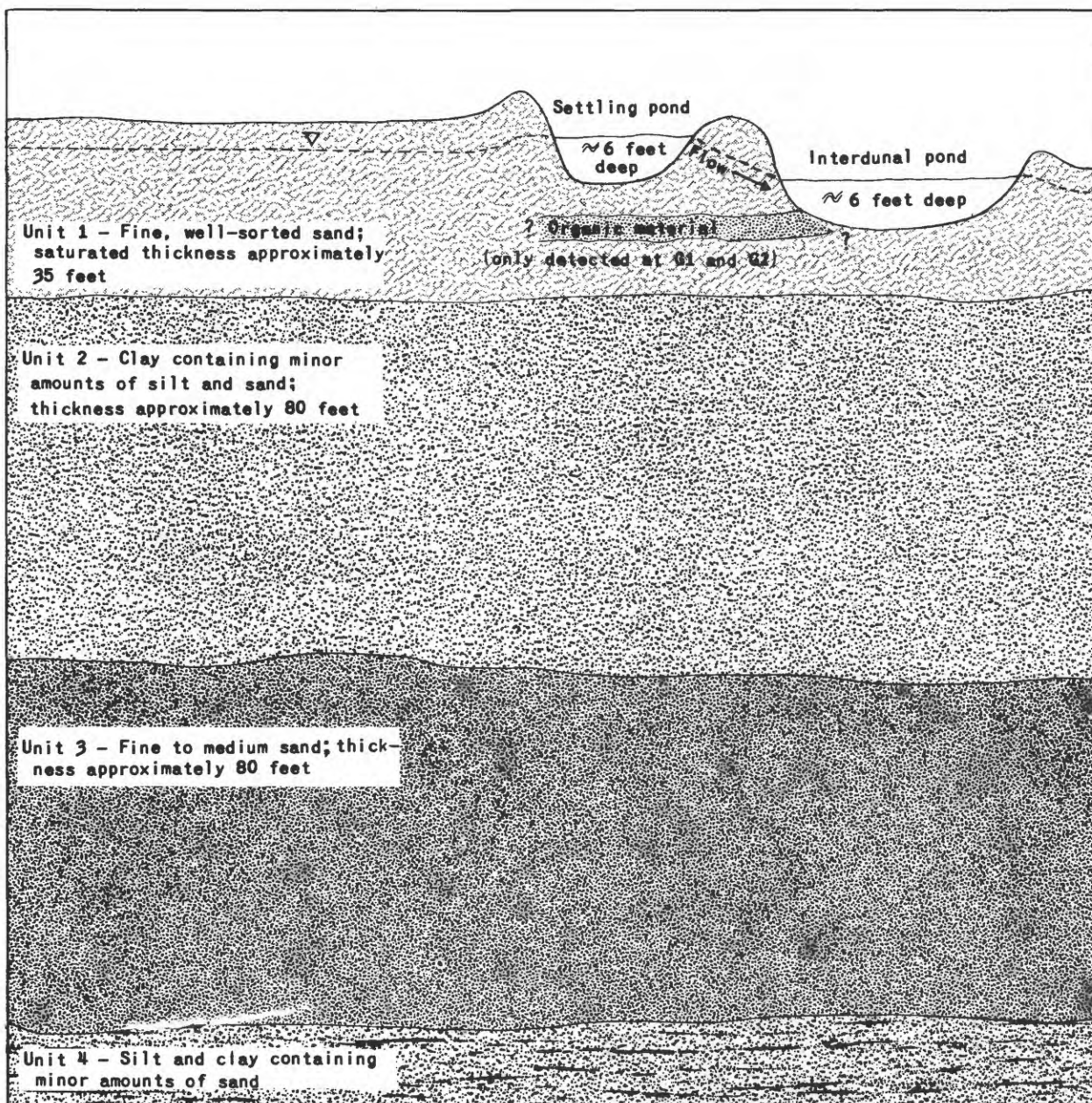
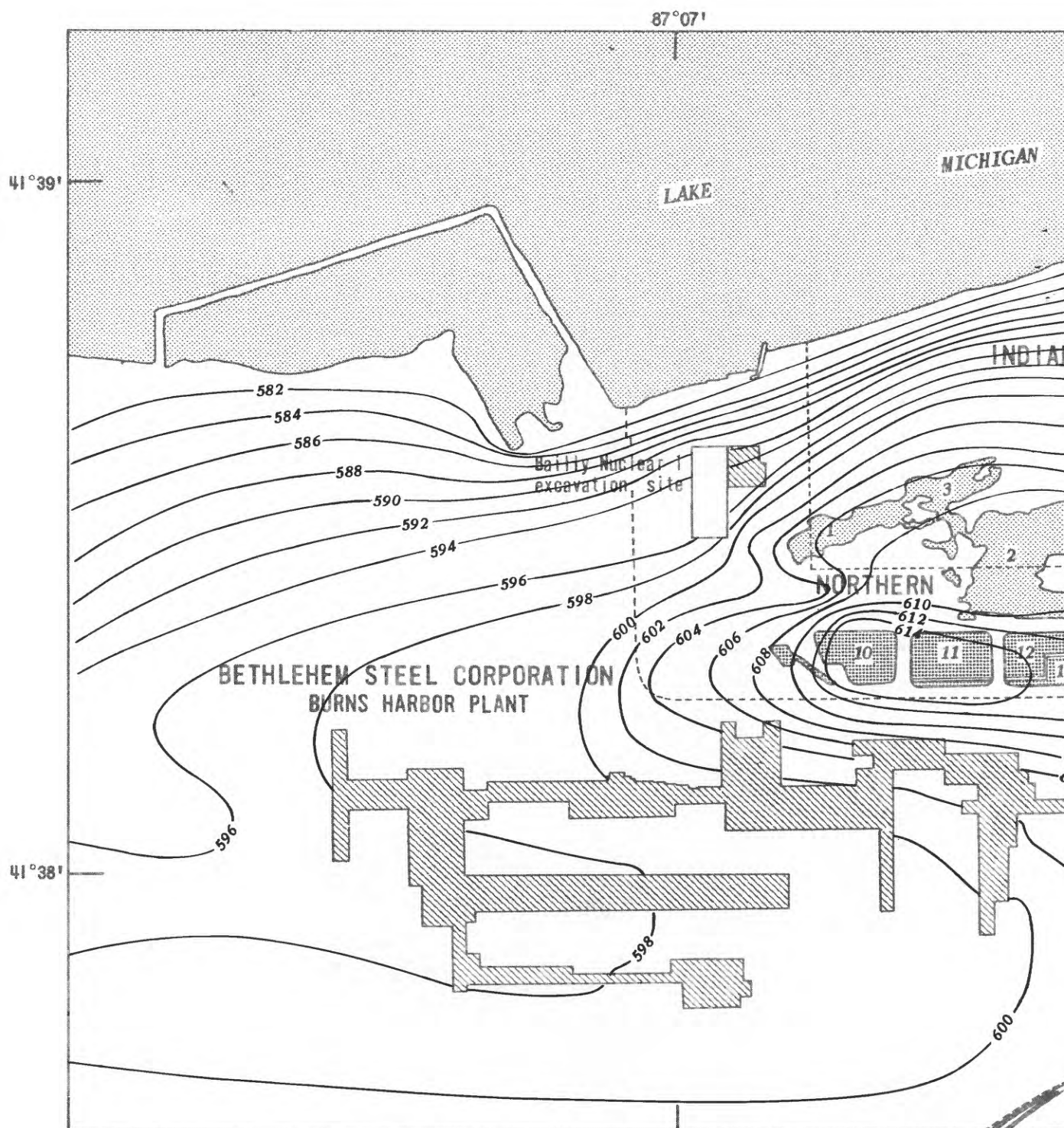
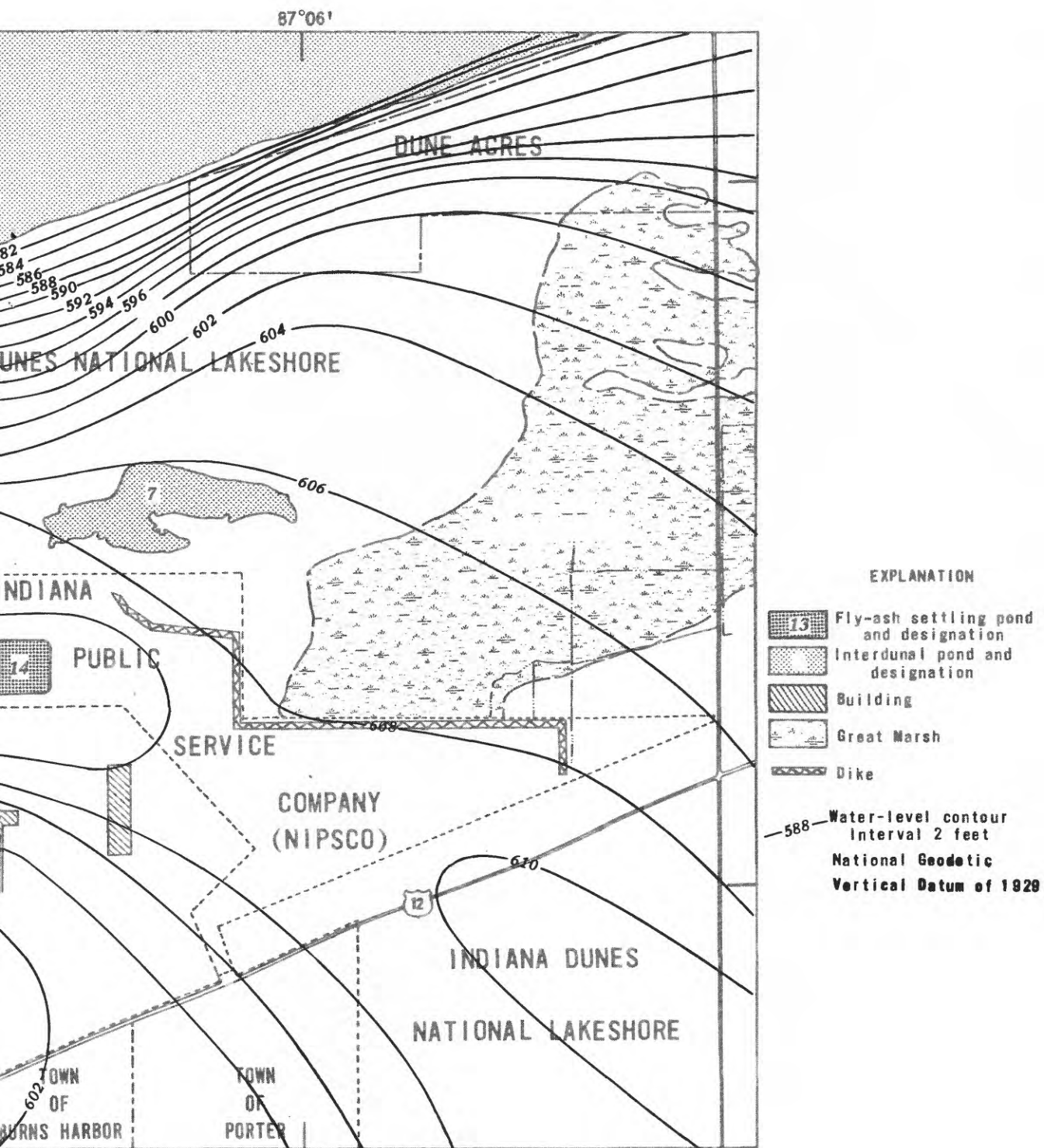


Figure 3.-- Generalized diagram illustrating relation of surface water and the unconsolidated units in the study area.



Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968; 1973 NIPSCO Map No. MS-150, by Sargent and Lundy; and National Park Service, November 1978

Figure 4.-- Unconfined water level



Modification of figure 13 in Meyer and Tucci (1978)

in unit 1, October 26, 1976.

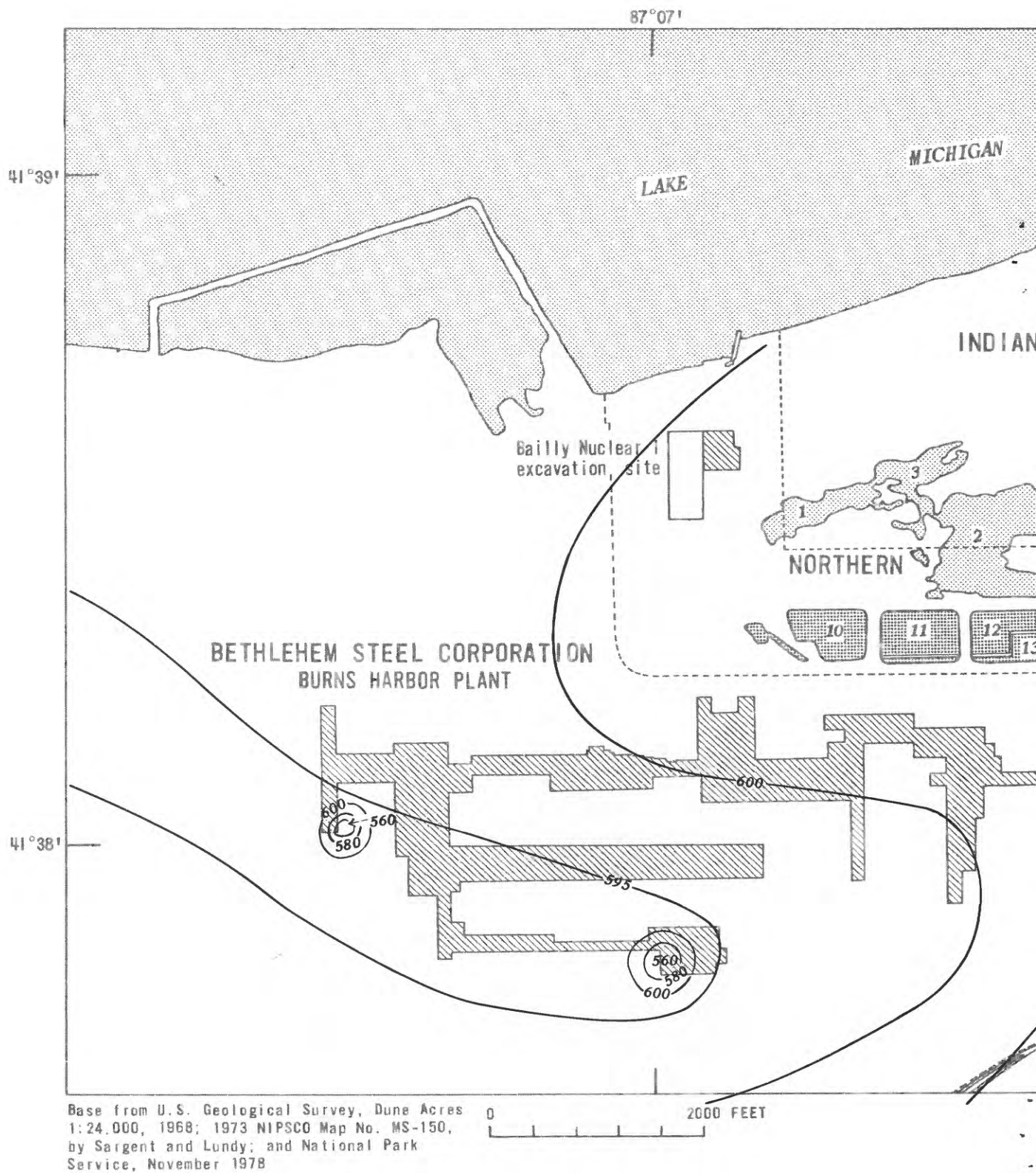
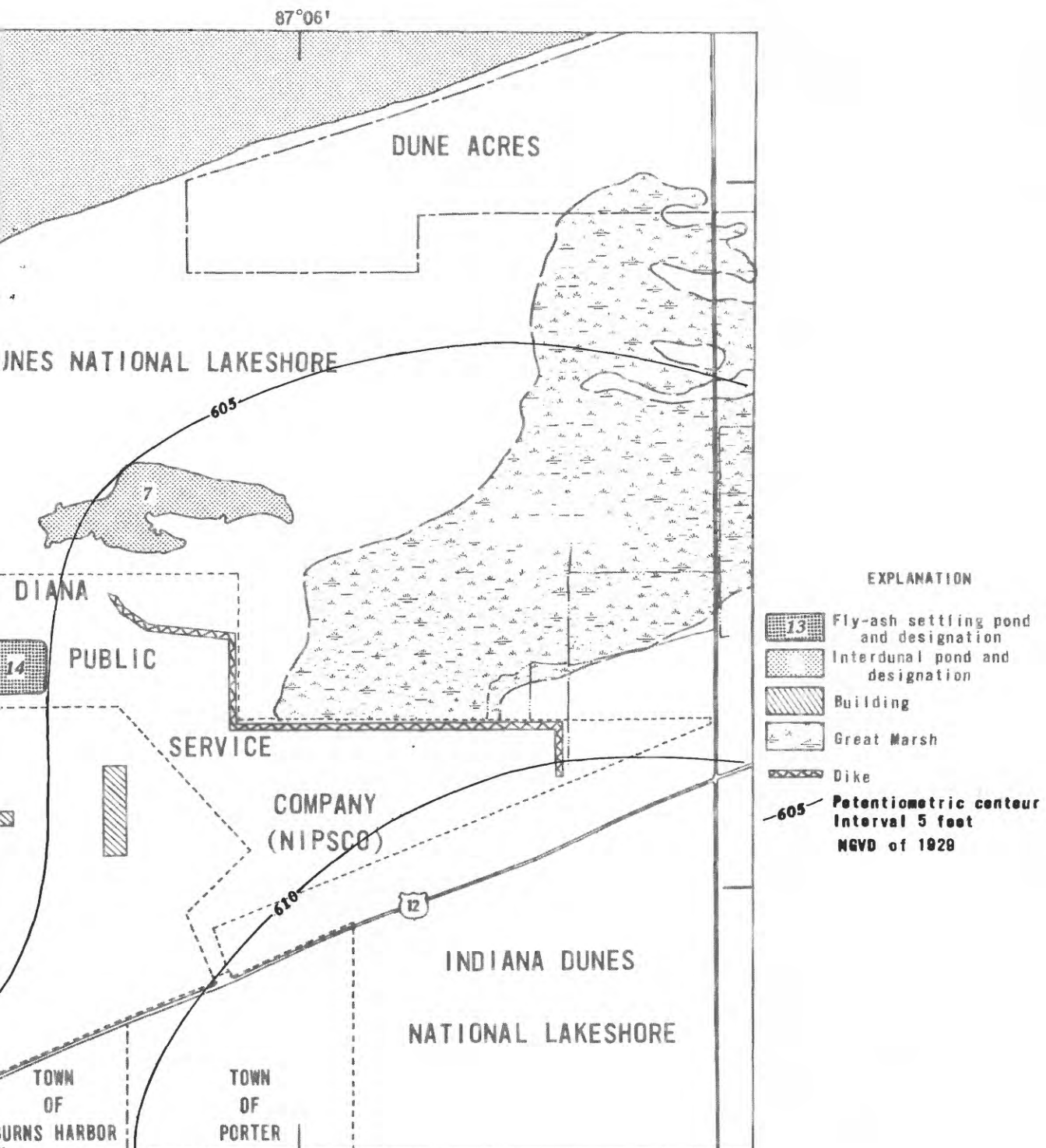


Figure 5.-- Potentiometric surface



Modification of figure 16 in Meyer and Tucci (1978)

of unit 3, October 26, 1976.

to the ash-pond systems include filter backwash, floor drains, ash-tank-seal water, and air-heater wash. Bottom ash from the generating station is transported to an area west of ash pond 10 and is deposited on the ground. Water flowing off the bottom ash is routed to the forebay for recirculation. Records identifying periods of use for each system are not regularly kept by NIPSCO (C. W. Kern, NIPSCO, written commun., Sept. 1978). However, discharge to primary pond 11 seemed to be more frequent than to primary pond 10.

The ash fill, a wetland area, is used to dispose of fly ash, bottom ash, some limestone fragments, and miscellaneous discarded materials. Grass has been planted on the south part of the fill but has not become well established. Only the north part of the fill was being used at the time of data collection.

Physical Characteristics of Ash

Bottom ash consists of heavy particles that collect in the bottom of coal-burning furnaces. These particles are generally gray or black and are angular. The diameter of fly-ash particles generally ranges from 0.5 to 100 μm (micron), and the color of the particles ranges from light tan, caused by high iron content, to gray black, caused by high carbon content.

Factors that determine the distribution of bottom and fly-ash fractions are the method of boiler firing, the ash-fusion temperature of the coal, and the type of boiler bottom. The method of boiler firing is probably the most important factor. Low coal-fusion temperatures and wet-bottom boilers both tend to increase the amount of bottom ash produced. (See Ray and Parker, 1977, p. 5-6.)

The total amount of ash produced is dependent on the amount of inorganic material dispersed throughout the coal and by inclusion of material above and below the coal seams during mining (Ray and Parker, 1977, p. 11).

Chemical Characteristics of Ash

Because the inorganic materials in coal are variable, so are the chemical characteristics of the ash produced. Carbon, hydrogen, oxygen, nitrogen, and sulfur are the major elements in coal, whose empirical formula ranges from $\text{C}_{75}\text{H}_{140}\text{O}_{56}\text{N}_2\text{S}$ to $\text{C}_{240}\text{H}_{90}\text{O}_4\text{NS}$. Chemical composition of the ash fractions is dependent on combustion conditions, efficiency of air-pollution-control devices, and chemical composition of the coal.

Oxides of silica, aluminum, iron, and calcium compose 95 to 99 percent of fly ash; magnesium, titanium, sulfur, sodium, and potassium compose 0.5 to 3.5 percent of the ash; and trace elements compose the remainder (Ray and Parker,

1977, p. 42). The concentrations of major elements are similar in bottom and fly-ash fractions, but concentrations of some trace elements in fly ash are as much as a hundredfold to a thousandfold greater than they are in natural soil concentrations (Davidson and others, 1974; Kaakinen and others, 1975; Klein and others, 1975; Lee and others, 1975). The most popular mechanism proposed to explain this phenomenon is the volatilization-condensation theory. This theory proposes that certain elements are volatilized when coal is burned and that, as the vapors cool in the discharge stack, some recondense on the surfaces of fly-ash particles. Trace-element concentrations on fly-ash particles have been demonstrated to be inversely related to particle size and subject to dissolution in water (Natusch and others, 1974; Kaakinen and others, 1975; Gladney and others, 1978).

In addition to inorganic materials, PCB's (polychlorinated biphenyls) and other polycyclic organic compounds have been found in stack emissions and have been assumed to form during coal combustion (Cowherd and others, 1975, p. 14).

The Bailly Generating Station generally burns Illinois and Indiana coals, whose sulfur content tends to be medium (1 to 3 percent) to high (greater than 3 percent), according to Magee and others (1973). Younger coals from these areas also tend to have higher boron concentration than the older coals (Ruch and others, 1974).

METHODS

Site Selection and Location

Surface Water

Surface-water sites (fig. 2) were selected to determine dissolved concentrations of various constituents in seven different areas: (1) the settling ponds (sites 21, 21A, 21B, and 22A); (2) the interdunal ponds downgradient from the settling ponds (sites 19, 20, 20D, and 20E); (3) surface water bordering the ash fill, where filling operations were intermittent (site 24B); (4) surface water across the dike from the filling operations (site 24A); (5) surface water bordering the ash fill, where active filling has ended (site 25B); (6) surface water across the dike from where active filling has ended (site 25A); and (7) interdunal pond 7 (sites 23 and 23A), which is considered a background interdunal pond. The surface-water site numbers are consistent with those used by Arihood (1975).

Ground Water

Ground-water samples were collected from wells installed for the ground-water hydrology study by Meyer and Tucci (1979). These sites (fig. 2) are designated by numbers prefaced by "G" or "D", or by three-digit numbers. This numbering system corresponds with that used by Meyer and Tucci (1979). In unit 1, samples were collected upgradient from settling-pond seepage (site 106), beneath the dike separating the interdunal ponds from the settling ponds (sites G1, G2, G4, and G6), and downgradient from interdunal pond 2 (sites D1, D2, and D4). In unit 3, ground-water samples were collected upgradient (sites 102 and 105) and downgradient (site 101) from settling-pond seepage. Samples from below the water-sediment interface of interdunal pond 2 (sites 20, 20D, and 20E) were collected to detect possible accumulations of trace elements beneath the pond.

Atmospheric Deposition

Atmospheric deposition samples were collected at three locations (fig. 2, sites P1, P2, and P3) to estimate atmospheric contributions of various inorganic constituents to the study area and to determine differences in atmospheric contributions between sites within the study area. P1 was used to estimate atmospheric contributions to interdunal pond 2, P2 was used to estimate possible contributions to the Lakeshore by windblown ash from the ash fill, and P3 was used as background for comparison of data from P1 and P2.

Sample-Collection Procedures

Surface Water

Surface-water samples were collected at most sites at approximately 5-week intervals. All surface-water samples were "grab samples" collected 5 to 10 ft from shore. In shallow wetland areas, collection of disturbed organic bottom materials was avoided. Because surface water did not always cover the organic materials at site 25A, samples could not always be collected. Measurements of temperature, dissolved oxygen, pH, and specific conductance in the interdunal ponds indicated that the ponds were not vertically stratified.

Ground Water

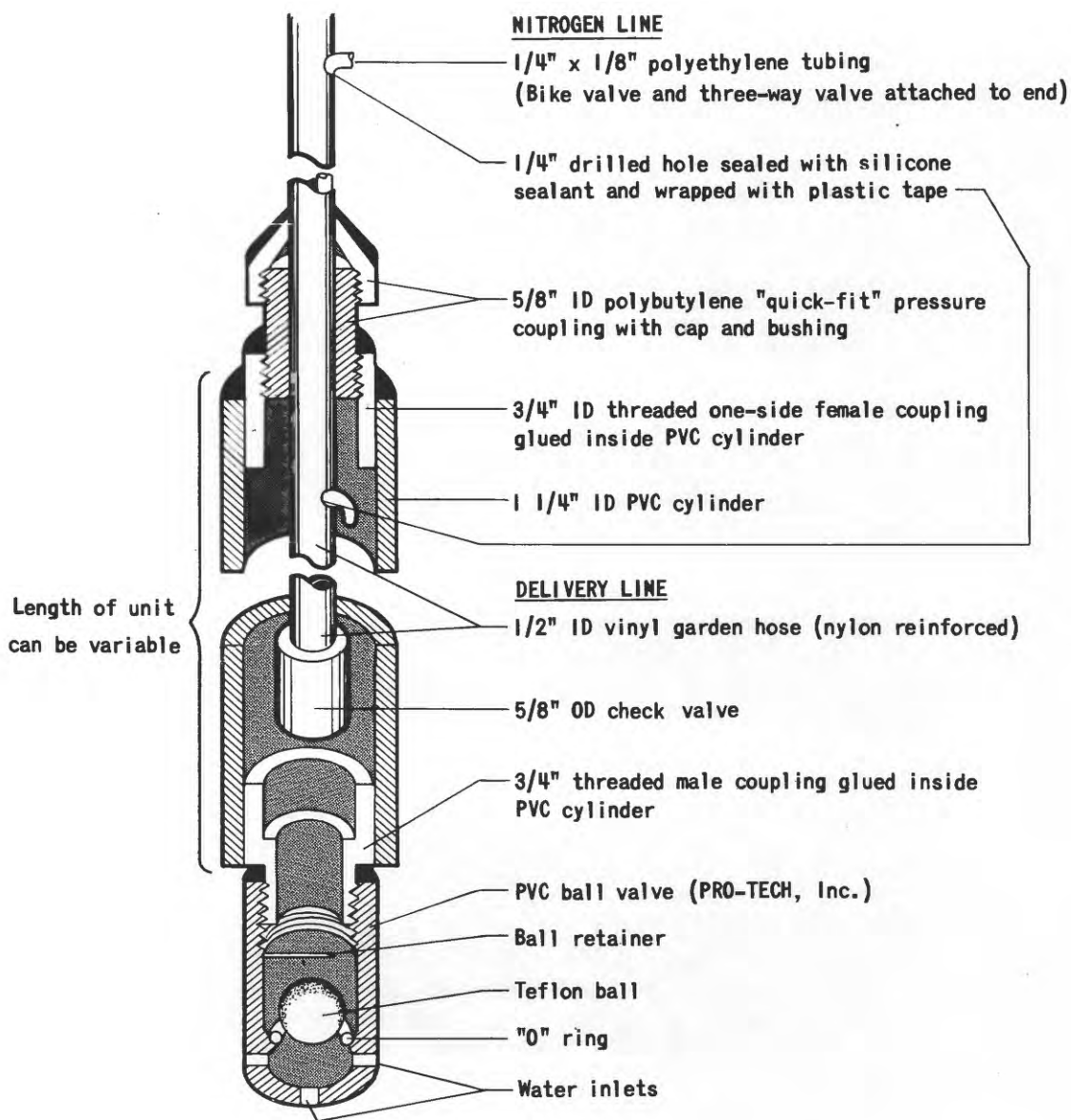
Ground-water samples were also collected at approximately 5-week intervals. From September 1976 through May 1977, a 4-ft length of PVC (polyvinyl chloride) pipe fitted with a ball valve on the bottom was used to collect samples. Several sampler volumes of water were removed before a sample was collected. For the remainder of the project (June 1977 through May 1978), a sampler (fig. 6) developed for this project was used to collect samples from all wells except the "D" wells so that samples represented ground water at equilibrium. This sampler allowed partial evacuation of the well casing and subsequent sampling of incoming water at the screened level. The "D" wells were sampled with a battery-powered peristaltic pump because the casings were too narrow for installation of the sampler. These wells were evacuated and were sampled as they recovered, so that samples represented ground water at equilibrium.

Various types of casings were used in the observation wells. In wells G1-G10, casings were constructed of low carbon steel, and, in wells 101, 105, and 106, casings were constructed of ABS plastic. All other casings were constructed of galvanized pipe. Although the water quality of samples from these wells is assumed to be representative of water quality in the area, the metallic casings could exert some control on water chemistry, particularly on concentrations of dissolved trace metals. For example, the low carbon steel may increase the concentration of iron in water, and the galvanized pipe may increase the concentrations of iron and zinc. Iron hydroxide associated with the metallic well screens could also remove dissolved trace elements by sorption (Jenne, 1968).

Water below the sediment interface of the ash ponds and interdunal ponds was sampled once with handmade PVC drive points that were pumped with a battery-powered peristaltic pump. Randomly drilled 1/64-in. holes in the bottom 3 in. of the drive point allowed ground water to move into it. After rinsings with nitric acid and deionized water, all drive points were driven to at least 2 ft below the pond bottoms. At site 20E, the drive point had to be driven through more than 6 ft of organic material before water freely entered it.

Atmospheric Deposition

Atmospheric deposition samples representing both wet and dry fallout were collected with two 16-cm (centimeter) Nalgene funnels mounted approximately 8 ft above the land surface and connected by tygon tubing to separate, calibrated, Nalgene bottles. One of the bottles contained 10 mL (milliliter) of a 1:5 nitric acid-deionized water solution to help prevent biological activity in the sample and sorption of metallic ions from the sample onto the Nalgene bottle. The sample collected in the other bottle (untreated) was used for determination of non-metals, total residue, and pH. The tygon tubing was



OPERATION OF SAMPLER

Water enters bottom of sampler when the nitrogen line is open. When pressure is applied by compressed nitrogen, the ball valve closes and water rises in the delivery line.

Figure 6.-- Sampler used for collecting ground water in the study area.

covered with opaque tape to prevent algal growth. Evaporation was minimized by putting a loop in the delivery line, forming a vapor trap, and by venting the sample bottles through bottles of deionized water. Acrylic "spikes" were placed around each funnel to discourage birds from landing on the funnels.

Frozen delivery lines were avoided by collecting precipitation samples from late November through early April in 34.9-cm diameter plastic acid-rinsed containers mounted approximately 5 ft above the land surface. This type of collection allowed more evaporation than the funnel system did.

Precipitation samples were analyzed when the volume was sufficient for analysis, usually between 1 and 5-month intervals. Thus, the samples do not represent the chemical quality of fresh precipitation.

Analytical Procedures

Temperature, pH, specific conductance, and dissolved-oxygen concentration of water were measured at all sites at the time of sample collection. Water samples were analyzed at the Geological Survey Central Laboratory in Doraville, Ga., for general inorganic constituents, selected trace elements, and dissolved-organic carbon by methods described by Brown and others (1970). Gross alpha and gross beta radioactivity of samples was measured by the methods of Thatcher, Janzer, and Edwards (1977). Potassium-40 radioactivity, in picocuries per liter, was estimated by multiplying the potassium concentration in milligrams per liter by 0.79 (Barker and Robinson, 1963, p. A30).

A fly-ash sample obtained from NIPSCO was analyzed for 27 constituents and properties. Contents of all constituents except chloride, fluoride, silica, and total sulfur were measured by the methods for bed-material analysis in Brown and others (1970, p. 69). Chloride concentration was determined by mixing a known weight of sample with deionized water and analyzing the supernatant solution by the Mohr titration method in Brown and others (1970, p. 69). Fluoride concentration was determined by mixing a known weight of sample with deionized water and sulfuric acid and distilling the mixture at 180°C. The distillate was analyzed for fluoride by the ion-selective method described in Brown and others (1970, p. 93). Silica was determined by converting silicates to soluble silica by sodium carbonate fusion as outlined in Jackson (1958, p. 302-303). The resultant solution was analyzed by the methods of Brown and others (1970, p. 139-140). Sulfur content was determined with a Leco induction furnace.

RESULTS AND DISCUSSION

A summary of all pertinent surface- and ground-water data are presented by site types (tables 3 and 5) and individual sites (tables 11 and 12.)

Statistical Analysis

An ANOV (analysis of variance) was used to determine if the average concentrations of dissolved chemical constituents for different groups of sites (settling ponds, dike, background ash-fill area, and background) and sites within groups were statistically significant at the 95-percent confidence level. The ANOV was done by the GLM (general linear model) procedure for unbalanced ANOV described by the Statistical Analysis System (Barr and others, 1976). Duncan's multiple-range test was used to identify population means that were significantly different from one another (Barr and others, 1976).

For application of statistical comparative tests, a data population should meet the following criteria: (1) The samples tested should come from normally distributed populations; (2) the samples should come from populations with identical variances; and (3) the samples should be obtained randomly; that is, the selection of any one sample should not influence the selection of any other member. The ANOV is robust with respect to the assumption of normality and equality of variance, and the validity of the analysis is affected little even by great deviations in population normality (Zar, 1974, p. 135).

Several characteristics of the data populations were examined for both untransformed data and data transformed by natural logarithm to determine which population was more normally distributed. This determination was based on the smallest difference between mean and median values and the central tendency of the second and third quartiles of data. The data set for each constituent providing the most normal population distribution was used for statistical analysis.

Compared with other multiple comparison tests, Duncan's multiple-range test is sensitive to smaller differences among population means. Therefore, an alpha level of 0.05 (95-percent confidence level) was used for determining significant differences.

Because pH is the negative logarithm of H^+ concentration, mean values are not representative of the central tendency of the data. Therefore, median pH values were used but could not be compared statistically.

Fly-Ash Analysis

Data presented for a chemical analysis of one NIPSCO fly-ash sample (table 1) represent concentrations "sorbed" on the ash particles (leachable rather than the total concentration of the fly ash). The pH represents active acidity but not the reserve acidity of the ash.

Table 1.--Chemical analysis of NIPSCO fly-ash sample

[Sample collected by U.S. Geological Survey
on April 5, 1978; all data except pH
are in milligrams per kilogram]

| Parameter | | Parameter | |
|-----------|---------|------------|-------|
| pH | 4.9 | Cadmium | 3 |
| Calcium | 12,000 | Chromium | 2 |
| Chloride | 11 | Cobalt | 10 |
| Fluoride | 92 | Copper | 30 |
| Magnesium | 770 | Iron | 4,600 |
| Potassium | 990 | Lead | 60 |
| Silica | 150,000 | Manganese | 60 |
| Sodium | 2,000 | Mercury | .2 |
| Sulfur | 10,000 | Molybdenum | 22 |
| Aluminum | 5,000 | Nickel | 10 |
| Arsenic | 100 | Selenium | .2 |
| Barium | 50 | Strontium | 70 |
| Beryllium | 3 | Zinc | 90 |
| Boron | 490 | | |

Unit 1 and Surface Water

General Water Chemistry

Generally, there are two types of water in the study area, calcium sulfate (in the settling ponds and downgradient from the ponds) and calcium bicarbonate (upgradient from the settling ponds). Stiff (1951) patterns representing water type distribution are presented in figure 7. The calcium bicarbonate water is probably caused by dissolution of calcareous materials in unit 1. Andrews and Anderson (1978) have also documented calcium sulfate type ground water downgradient from ash ponds. The wide variations of calcium and sulfate concentrations in and downgradient from the settling ponds compared with those upgradient from the ponds may be related to the variations in fly-ash and sluice-water chemistry.

Settling Ponds and Settling-Pond Seepage

The mean dissolved-solids concentration was significantly higher in the settling-pond samples than in background samples (table 2).

Constituents whose mean concentrations in the settling ponds were significantly greater than background concentrations include calcium, fluoride, potassium, sodium, and sulfate. Mean alkalinity concentrations in the settling ponds were significantly lower than mean background concentrations. Median pH values in the settling ponds were lower than background but were not tested statistically.

The two primary settling ponds (10 and 11) had significantly different mean concentrations of some major ions. Mean concentrations of calcium, potassium, and sulfate in pond 11 were significantly greater than those in pond 10. These differences between primary ponds might have been due to a greater amount of ash discharge to pond 11 than to pond 10; however, records documenting ash-pond use are not available.

Mean concentrations of calcium and sulfate in water beneath the dike were greater than those in the upgradient settling ponds. Calcareous materials in unit 1 could contribute additional calcium to the settling-pond seepage. Decomposition and biological respiration in the organic horizon beneath the dike probably increases the dissolution of calcareous materials in unit 1 by increasing the partial pressure of carbon dioxide, which lowers the pH of ground water. Decomposition of the organic material probably releases additional sulfur to the ground water, which is oxidized to sulfate.

Although this discussion indicates how water in the dike may act in general, water at site G4 had lower concentrations of calcium and sulfate than water at sites G1 and G2. The difference is probably due to the lack of

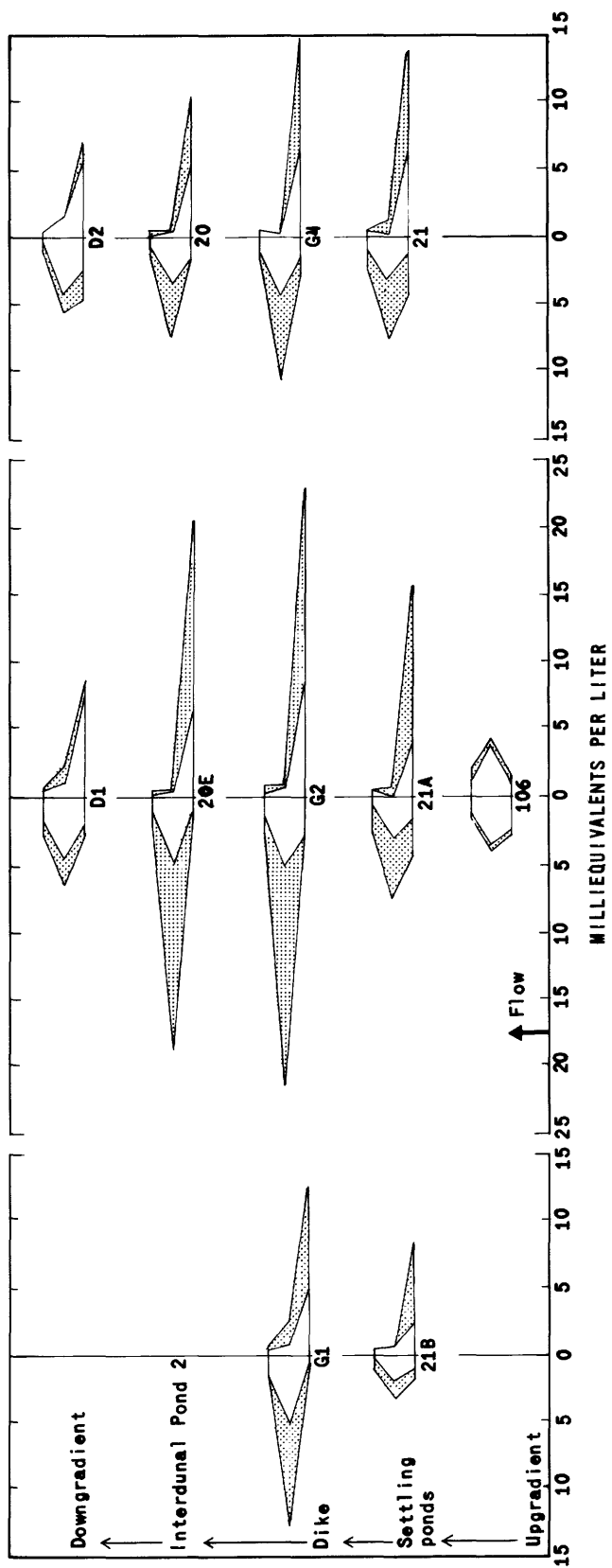
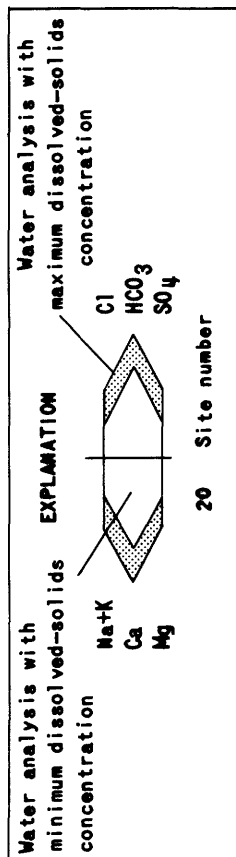


Figure 7.-- Stiff patterns representing analyses of water at Indiana Dunes National Lakeshore, September 1976 to May 1978.

Table 2.--Statistical summary of general water-quality data for major site types, September 1976-May 1978

[All data except pH are in milligrams per liter; samples collected and analyzed by U.S. Geological Survey; ND, not detectable]

| | Dis- solved solids concn. | pH ¹ | Alkalinity as CaCO ₃ | Silica ² | Calcium | Magnesium ² | Sodium | Potassium | Sulfate ² | Chloride | Fluoride | Dis- solved organic carbon |
|--|------------------------------------|-----------------|------------------------------------|---------------------|---------|------------------------|--------|-----------|----------------------|----------|----------|-------------------------------------|
| <u>Settling ponds</u> | | | | | | | | | | | | |
| Mean | 403 | 6.5 | 8 | 3.6 | 67 | 20 | 16 | 9.7 | 290 | 10 | 0.2 | 4.6 |
| Standard deviation | .5 | --- | 3.9 | 2.6 | .4 | 10 | .3 | .9 | 147 | .1 | .1 | 1.0 |
| Minimum value | 201 | 3.2 | ND | .7 | 41 | 11 | 7.8 | 2.4 | 88 | 7.8 | .1 | 1.0 |
| Maximum value | 1,040 | 8.1 | 64 | 12 | 170 | 54 | 28 | 43 | 730 | 13 | .8 | 65 |
| Number of observations | 65 | 57 | 65 | 65 | 65 | 65 | 65 | 65 | 65 | 65 | 59 | 28 |
| <u>Dike downgradient from settling ponds</u> | | | | | | | | | | | | |
| Mean | 698 | 6.9 | 25 | 8.5 | 140 | 20 | 16 | 20 | 480 | 13 | .4 | 7.8 |
| Standard deviation | .5 | --- | 2.9 | 3.9 | .7 | 12 | .3 | 1.0 | 255 | .6 | .6 | 1.3 |
| Minimum value | 380 | 4.7 | ND | .8 | 67 | 49 | 8.3 | 4.4 | 200 | 2.4 | ND | 1.1 |
| Maximum value | 1,760 | 8.5 | 120 | 17 | 500 | 50 | 25 | 68 | 1,200 | 90 | 3.8 | 72 |
| Number of observations | 50 | 52 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 41 |
| <u>Downgradient from settling ponds</u> | | | | | | | | | | | | |
| Mean | 543 | 6.9 | 27 | 4.8 | 100 | 22 | 15 | 15 | 380 | 10 | .3 | 5.9 |
| Standard deviation | .5 | --- | 1.2 | 3.5 | .6 | 6.5 | .5 | .8 | 151 | .2 | .1 | .5 |
| Minimum value | 99 | 5.9 | ND | .1 | 15 | 5.4 | 3.0 | .5 | 41 | 4.9 | ND | 2.9 |
| Maximum value | 1,480 | 9.4 | 120 | 15 | 370 | 35 | 46 | 48 | 970 | 13 | .7 | 19 |
| Number of observations | 61 | 57 | 62 | 61 | 62 | 61 | 61 | 61 | 62 | 61 | 61 | 31 |
| <u>Ash fill</u> | | | | | | | | | | | | |
| Mean | 286 | 7.1 | 150 | 8.1 | 58 | 23 | 9.9 | 5.6 | 74 | 12 | .3 | 14 |
| Standard deviation | .5 | --- | 1.1 | 5.0 | .6 | 10 | .3 | .5 | 66 | .3 | .2 | .8 |
| Minimum value | 98 | 6.1 | 12 | .1 | 13 | 5.0 | 4.6 | 2.4 | 9.6 | 6.1 | .1 | 3.7 |
| Maximum value | 621 | 8.3 | 360 | 22 | 130 | 45 | 18 | 19 | 300 | 22 | 1.1 | 43 |
| Number of observations | 54 | 57 | 54 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 38 |
| <u>Background³</u> | | | | | | | | | | | | |
| Mean | 213 | 6.9 | 83 | 7.4 | 40 | 18 | 5.7 | 2.0 | 66 | 7.1 | .1 | 9.4 |
| Standard deviation | .7 | --- | 1.1 | 5.4 | .8 | 9.3 | 1.3 | .2 | 28 | 1.1 | .1 | .8 |
| Minimum value | 79 | 6.1 | 24 | ND | 15 | 6.1 | 2 | .7 | 13 | 4.3 | ND | 2.0 |
| Maximum value | 442 | 8.3 | 220 | 14 | 85 | 32 | 12 | 4.1 | 130 | 14 | .2 | 28 |
| Number of observations | 35 | 36 | 35 | 35 | 35 | 35 | 23 | 35 | 35 | 23 | 35 | 19 |

¹Median values of pH.²Indicates statistical information calculated from nontransformed data.³Chloride and sodium data for background are based only on sites 23 and 23A because site 106 is probably affected by road salting.

organic material at site G4. Mean concentrations of calcium and sulfate in surface water bordering the dike where organic material was present (4.3 and 8.5 times background, respectively, at site 20E) are higher than mean concentrations farther east in the pond, where there was no organic material (calcium concentration 2.5 and sulfate concentration 5.5 times background, at site 20).

Concentrations of calcium and sulfate at the ground-water sites farthest downgradient from the settling ponds (sites D1 and D2, fig. 7) were less variable than the concentrations at sites upgradient. This condition suggests mixing and dispersion of leachate with regional ground water and (or) physical and chemical reactions of leachate with the aquifer materials.

Dissolution of sulfur oxides on fly-ash particles, an acid-producing reaction, may decrease alkalinity concentration and pH. Stiff patterns in figure 7 indicate that bicarbonate concentrations in the settling ponds and downgradient from them are lower than bicarbonate concentrations of the upgradient ground water (site 106). The mean alkalinity concentrations for the settling ponds (8 mg/L) and downgradient from the ponds (27 mg/L) were significantly less than the mean background concentrations (83 mg/L). The median pH value for the settling ponds (6.5) was also lower than background (6.9). Median pH values in the dike and downgradient from the settling ponds, the same as background, indicate calcareous materials in the dike to be effective neutralizers of the settling-pond leachate.

The pH in the settling ponds ranged from 3.2 to 8.1. The variation may be caused by variation of bicarbonate and other buffering agents in sluicing water, acid-producing reactions with the ash (such as dissolution of sulfur oxides), and base-producing reactions with the ash (such as dissolution of alkaline metal oxides). Chu, Ruane, and Krenkel (1978) suggested that the pH of ash-sluicing water is primarily determined by the relative quantities of alkaline earth metal oxides and sulfate dissolved from ash. The relationship between pH and the ratio of calcium plus magnesium to sulfate is shown in figure 8. The lowest pH values of ponds 11 and 12 (3.3 and 3.2, respectively) correspond with the lowest ratios, but data are scattered at higher pH values. Although more low pH data are needed to establish a meaningful correlation, these data do suggest that the low pH values in the settling ponds might be caused by low ratios of alkaline earth metal oxides to sulfur oxides on the fly ash, possibly caused by ash of high sulfur content.

Fluoride, potassium, and sodium are the other major ions having higher mean concentrations downgradient from the settling ponds than background (3, 7.5, and 2.6 times, respectively). The high concentrations indicate movement of these ions into the Lakeshore water resources.

Mean chloride, fluoride, and potassium concentrations beneath the dike are higher than mean concentrations in the settling ponds. These higher concentrations suggest accumulation of the ions or an additional source of the ions in the aquifer. The mechanism causing the higher concentrations beneath the dike is not known. However, higher concentrations of these ions at sites G1 and G2 than at G4 suggest that processes in the organic material might be responsible.

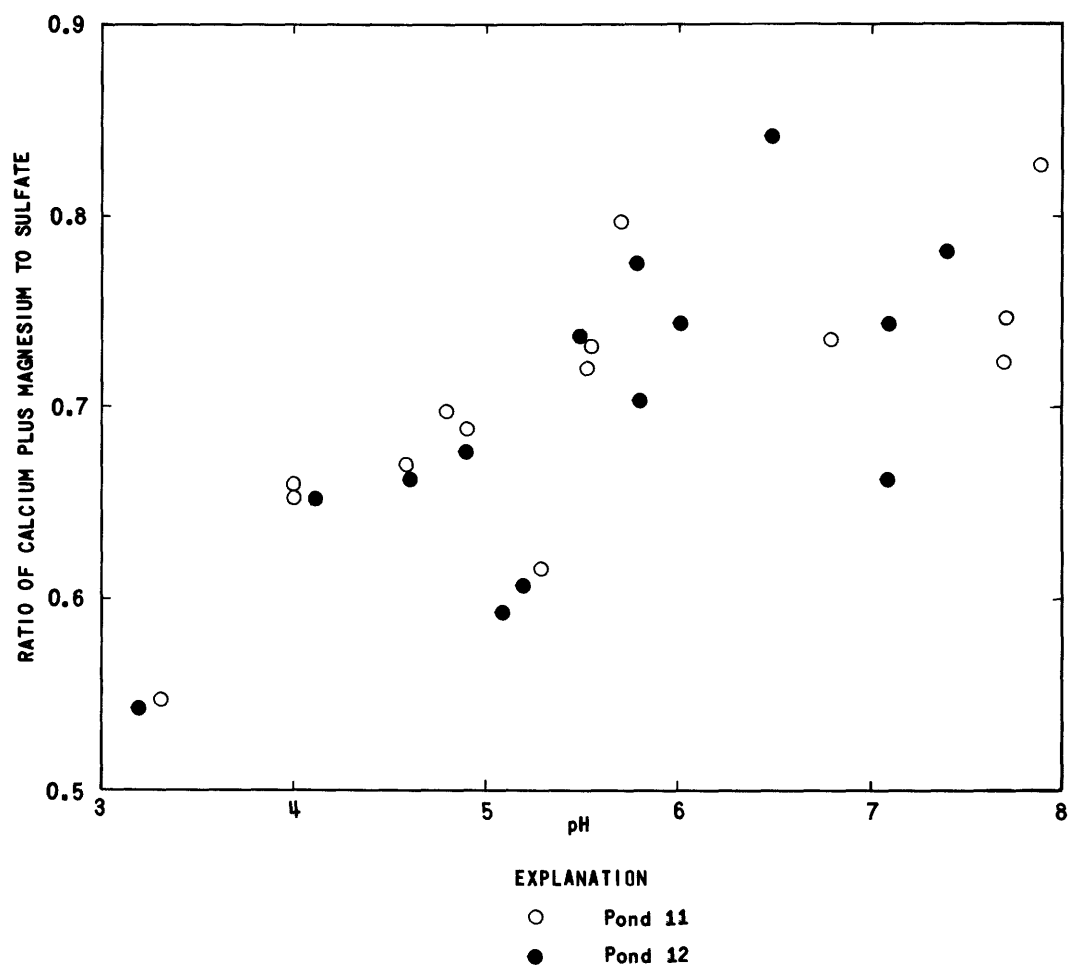


Figure 8.-- Relation between pH and the ratio of calcium plus magnesium to sulfate in settling ponds 11 and 12 at Indiana Dunes National Lakeshore, September 1976 to May 1979.

Ash Fill

Mean potassium concentrations in surface water bordering the ash fill (sites 24B and 25B) were two to four times the mean background concentrations, probably because of ash-fill leaching. In contrast, Martens and Beahm (1976) found that fly ash has little or no potassium available for plant growth after settling-pond leaching.

Interstitial water transported with the ash may be a source of potassium and sulfate because mean concentrations of each at site 24B, where there is active filling, are approximately double those at site 25B, where there is no active filling.

Ash-fill leaching resulted in mean potassium concentrations in the Lakeshore surface water (sites 24A and 25A) that were 2.5 to 3 times mean background concentrations.

Mean fluoride concentrations on the east side of the fill, at sites 25A and 25B, are 4 to 5 times the mean background concentration. The reason for this enrichment at only the east side of the fill is not known.

Atmospheric Deposition

Concentrations and calculated loads of major chemical constituents in samples of bulk atmospheric precipitation are presented in table 3. Loads were based on the volume of precipitation in the samplers. The volume of precipitation recorded at the Ogden Dunes precipitation station (National Oceanic and Atmospheric Administration, 1977a, b, and c) was used for load calculation where sample loss due to plugged delivery lines was suspected.

Loads of major constituents varied temporally and spatially. Loads were highest along the NIPSCO access road (site P1). Activities around this site, such as traffic on the access road, may suspend particulates in the atmosphere and cause the chemical loading around site P1 to exceed the loading at the other two sites. Windblown material from the ash fill did not seem to increase chemical loading on NPS property because loading at P2 did not exceed loading at P3, the background site.

Information on atmospheric loading of major ions in northwest Indiana was not available for comparison with data collected in the study area. However, concentrations of all major constituents in precipitation samples were lower than or within background concentration ranges for surface and ground waters. Consequently, precipitation did not seem to contribute significant amounts of major ions to the study area.

Trace Elements

Leaching of trace elements from fly-ash disposal areas is of concern because some organisms have a narrow tolerance range for certain trace elements. Compared with concentrations of major ions, relatively low concentrations of some trace elements can be toxic. In addition to affecting the survival of a particular plant or animal species, sub-lethal concentrations can alter biologically related processes, such as nitrification in soil systems (Liang and Tabatabai, 1978).

Means, standard deviations, and ranges of trace elements within major site types are presented in table 4.

Table 3.--Major constituents in and pH of bulk precipitation

[Samples collected by U.S. Geological Survey; ND, not detectable; for residue and constituents, upper number is concentration, in milligrams per liter, and lower number is load, in milligrams per square meter per month]

| Precipitation and constituents | Site P1 | | | | | | Site P2 | | | Site P3 | | | | | |
|---|--------------------|--------------------|---------------------|----------------------|--------------------|--------------------|---------------------|--------------------|--------------------|-------------------|-------------------|---------------------|----------------------|----------------------|---------------------|
| | Collection period | | | | | | Collection period | | | Collection period | | | | | |
| | 4-20-77 to 6-28-77 | 6-28-77 to 8-19-77 | 8-19-77 to 10-12-77 | 10-12-77 to 11-23-77 | 11-23-77 to 4-3-78 | 11-23-77 to 4-3-78 | 9-22-77 to 11-23-77 | 11-23-77 to 4-3-78 | 11-23-77 to 4-3-78 | 4-20-77 to 7-1-77 | 7-1-77 to 8-19-77 | 8-19-77 to 10-13-77 | 10-13-77 to 11-23-77 | 11-23-77 to 12-21-77 | 12-21-77 to 4-3-78 |
| Precipitation (in.) | 5.0 | 6.5 | ¹ 11.7 | 3.0 | 2.2 | 3.8 | 3.8 | 1.75 | 5.3 | 7.5 | 5.3 | ¹ 11.7 | 3.5 | 2.7 | S a m p l e r |
| pH | 5.5 | 6.1 | 4.8 | 6.9 | 6.5 | 5.7 | 5.7 | 5.6 | 5.6 | 5.5 | 5.6 | 4.4 | 5.7 | 4.8 | |
| Specific conductance (µmho/cm at 25° C) | 59 | 46 | 27 | 6.1 | 324 | 33 | 33 | 224 | 33 | 33 | 33 | 25 | 27 | 53 | |
| Residue (total) | 42 2,300 | 360 30,000 | 26 4,300 | 65 3,500 | 608 7,700 | 32 3,000 | 32 3,000 | 426 4,300 | 26 2,100 | 17 1,400 | 13 2,100 | 28 1,800 | 56 4,100 | | v a n d a l i z e d |
| Calcium | 2.2 97 | 3.8 360 | 2.6 430 | 8.0 440 | 52 660 | 4.3 400 | 4.3 400 | 25 250 | .7 45 | 4.1 330 | 2.5 190 | 2.9 190 | 5.4 400 | | |
| Chloride | 1.0 55 | .7 58 | .4 66 | .1 5.4 | 7.3 92 | .1 9.4 | .1 9.4 | 5.3 54 | .7 56 | .4 32 | .2 33 | .1 6.5 | 1.0 74 | | |
| Magnesium | 1.0 44 | .8 76 | .5 83 | 1.5 81 | 10 130 | .6 56 | .6 56 | 4.7 48 | .6 39 | .5 40 | .4 31 | .5 33 | 1.1 81 | | |
| Potassium | 0.5 22 | .4 38 | .4 66 | .5 27 | 1.1 14 | .3 28 | .3 28 | 1.2 12 | .4 26 | .5 40 | .3 23 | .5 33 | .1 7.4 | | |
| Silica | 0.9 50 | 1.1 92 | .8 132 | 2.0 110 | 6.5 82 | .6 56 | .6 56 | 2.9 30 | .8 64 | .5 40 | .4 65 | .7 46 | 1.6 120 | | |
| Sodium | 1.0 44 | .3 29 | ND 0 | .3 16 | 3.8 48 | .3 28 | .3 28 | 3.0 31 | .5 32 | .3 24 | .2 39 | .4 26 | .5 37 | | |
| Sulfate | 9.1 500 | 7.9 660 | 4.5 740 | 8.6 470 | 100 13,000 | 6.7 630 | 6.7 630 | 69 700 | 5.7 460 | 7.4 600 | 3.5 570 | 5.4 350 | 11 810 | | |

¹Precipitation at Ogden Dunes station.

Table 4.--Statistical summary of trace-element concentrations for major site types, September 1976-May 1978

[Concentrations are in micrograms per liter; samples collected and analyzed by U.S. Geological Survey; ND, not detectable]

| | Alumi- num | Arsenic | Barium ¹ | Beryl- lium | Boron | Cad- mium ¹ | Chro- mium | Co- balt ¹ | Cop- per | Iron | Lead | Mer- cury | Manga- nese | Molyb- denum | Nick- el | Sele- nium | Stron- tium | Zinc |
|--|---------------|---------|---------------------|----------------|--------|---------------------------|---------------|--------------------------|-------------|--------|------|--------------|----------------|-----------------|-------------|---------------|----------------|-------|
| <u>Settling ponds</u> | | | | | | | | | | | | | | | | | | |
| Mean | 280 | 3 | 200 | 0 | 1,300 | 81 | 3 | 13 | 45 | 250 | 7 | <0.5 | 140 | 18 | 67 | 0 | 330 | 460 |
| Standard deviation | 9 | 1 | 100 | 0 | 2 | 172 | 3 | 8 | 6 | 11 | 4 | .2 | 1 | 4 | 1 | 0 | <1 | 2 |
| Minimum value | ND | ND | ND | ND | 90 | ND | ND | 5 | ND | ND | ND | ND | 10 | ND | 13 | ND | 130 | 30 |
| Maximum value | 32,000 | 15 | 300 | ND | 8,300 | 800 | 18 | 21 | 310 | 47,000 | 200 | .5 | 410 | 1,600 | 250 | ND | 740 | 1,800 |
| Number of observations | 35 | 35 | 16 | 6 | 43 | 35 | 6 | 4 | 25 | 59 | 35 | 6 | 59 | 35 | 35 | 4 | 35 | 35 |
| <u>Dike downgradient from settling ponds</u> | | | | | | | | | | | | | | | | | | |
| Mean | 97 | 4 | 100 | <10 | 2,300 | 16 | 3 | 3 | <1 | 590 | 1 | <.5 | 170 | 24 | 7 | 0 | 390 | 40 |
| Standard deviation | 4 | 3 | 144 | 3 | 1 | 48 | 2 | 5 | 1 | 3 | 2 | .2 | 1 | 6 | 3 | 0 | <1 | 10 |
| Minimum value | ND | ND | ND | ND | 260 | ND | ND | ND | ND | 30 | ND | ND | 20 | 1 | ND | ND | 150 | ND |
| Maximum value | 2,200 | 230 | 500 | 30 | 8,800 | 250 | 10 | 12 | 21 | 14,000 | 63 | .6 | 770 | 1,700 | 250 | ND | 1,200 | 2,300 |
| Number of observations | 45 | 45 | 21 | 9 | 42 | 45 | 9 | 6 | 33 | 50 | 45 | 9 | 50 | 45 | 45 | 6 | 45 | 45 |
| <u>Downgradient from settling ponds</u> | | | | | | | | | | | | | | | | | | |
| Mean | 51 | 2 | 100 | 0 | 2,400 | 2 | 1 | 6 | <1 | 230 | 1 | .1 | 270 | 110 | 15 | 0 | 410 | 30 |
| Standard deviation | 2 | 1 | 134 | 0 | 1 | 4 | 2 | 5 | <1 | 4 | 1 | .2 | 4 | 2 | 1 | 0 | <1 | 3 |
| Minimum value | ND | ND | ND | ND | 150 | ND | ND | ND | ND | 10 | ND | ND | 10 | 4 | 2 | ND | 190 | ND |
| Maximum value | 300 | 48 | 500 | ND | 12,000 | 15 | 10 | 10 | 5 | 4,600 | 10 | .5 | 3,900 | 1,100 | 55 | ND | 880 | 570 |
| Number of observations | 37 | 37 | 19 | 7 | 45 | 37 | 7 | 3 | 25 | 61 | 36 | 7 | 61 | 37 | 37 | 3 | 37 | 37 |
| <u>Ash fill</u> | | | | | | | | | | | | | | | | | | |
| Mean | 50 | 4 | <100 | 0 | 1,100 | <1 | 1 | 0 | 1 | 670 | 1 | <.5 | 230 | 18 | 3 | 0 | 250 | 10 |
| Standard deviation | 2 | 1 | 74 | 0 | <1 | 1 | 2 | 0 | 1 | 3 | 1 | .2 | 3 | 5 | 2 | 0 | 1 | 4 |
| Minimum value | ND | ND | ND | ND | 80 | ND | ND | ND | ND | 40 | ND | ND | 10 | ND | ND | ND | 10 | ND |
| Maximum value | 340 | 32 | 200 | ND | 2,900 | 7 | 10 | ND | 18 | 5,700 | 8 | .5 | 2,100 | 800 | 16 | ND | 530 | 280 |
| Number of observations | 47 | 46 | 28 | 7 | 48 | 46 | 7 | 4 | 24 | 53 | 46 | 7 | 53 | 46 | 46 | 4 | 46 | 46 |
| <u>Background</u> | | | | | | | | | | | | | | | | | | |
| Mean | 22 | <1 | <100 | <10 | 220 | 8 | 1 | <1 | <1 | 90 | 1 | <.5 | 40 | 2 | 2 | 2 | 120 | 10 |
| Standard deviation | 3 | <1 | 80 | 2 | 2 | 42 | 2 | <1 | <1 | 6 | 1 | .2 | 5 | 2 | 1 | 3 | <1 | 4 |
| Minimum value | ND | ND | ND | ND | 30 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 80 | ND |
| Maximum value | 110 | 5 | 300 | 10 | 840 | 220 | 10 | 1 | 2 | 2,700 | 7 | .5 | 1,500 | 23 | 10 | 5 | 220 | 170 |
| Number of observations | 28 | 28 | 16 | 6 | 28 | 28 | 6 | 3 | 18 | 35 | 28 | 6 | 35 | 28 | 28 | 3 | 28 | 28 |

¹Indicates statistical information calculated from nontransformed data.

Settling Ponds and Settling-Pond Seepage

Dissolved trace elements significantly enriched in the settling ponds include aluminum, arsenic, barium, boron, cadmium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, strontium, and zinc. Concentrations of these elements generally followed no temporal trends. Aluminum and lead concentrations of settling pond 11 (site 21A) were highest (32,000 and 200 µg/L, respectively), where pH was less than 3.5.

Mean concentrations of aluminum, cadmium, nickel, and strontium were higher in pond 11 than in pond 10. These differences might have been caused by differences in ash chemistry and (or) quantities of ash discharged to the two primary ponds.

Trace elements whose concentrations were increased downgradient from the settling ponds by the seepage included aluminum, arsenic, boron, iron, manganese, molybdenum, nickel, strontium, and zinc (by 2.3, 2, 11, 2.5, 6.8, 55, 7.5, 3.4, and 3 times, respectively). Although enriched in the settling ponds, concentrations of barium, cadmium, cobalt, copper, and lead were not enriched downgradient from the settling ponds.

Trace-element concentrations downgradient from the settling ponds exceeded recommended limits (table 5) several times. Whether these elements significantly affect resident flora and fauna is not known.

Effect of unconsolidated materials on trace-element transport.---Not all the trace elements that were enriched in the settling ponds were similarly enriched in the ground-water system.

Mean concentrations of boron, iron, and manganese in each settling pond and in ground water downgradient from the ponds were not statistically different. Of these elements, only boron is normally present in water as an anion, borate (Cox and others, 1978; Hem, 1970, p. 188), which would not be exchanged or sorbed abundantly in soils (Rhoades and others, 1970). Iron and manganese are normally present as multivalent cations and are abundant in soils.

The mean concentrations of nickel, zinc, and molybdenum in settling ponds 10-12 and in ground water downgradient from the ponds are plotted in figure 9. The mean nickel concentration of each settling pond is greater than that of ground water downgradient from the ponds. Mean concentrations of cadmium and copper display the same trend as that of nickel. Although the mean concentration of cadmium in ground water at site G1 was not lower at 95-percent confidence than that of cadmium in the settling pond upgradient (site 21B), the mean concentration of cadmium in that settling pond was already similar to the mean background concentration of cadmium. Precipitation (Hem, 1970, p. 201-202; Kopp and Kroner, 1967, p. 18) and sorption by iron and manganese hydroxides (Hem, 1972; Jenne, 1968) are common removal mechanisms of these metals in soil. Similarly, Theis and Richter (1979) concluded that dissolved cadmium and nickel are adsorbed by iron and manganese oxides, whereas copper is precipitated as hydroxides and carbonates.

Table 5.--Trace elements in the Indiana Dunes National Lakeshore water resources, downgradient from the settling ponds, whose concentrations exceeded recommended limits, September 1976-May 1978

[Concentrations are in micrograms per liter; samples collected and analyzed by U.S. Geological Survey]

| Element | Mean concentration | Minimum concentration | Maximum concentration | Recommended limit | Percent of samples having concentrations greater than or equal to limit | Water use subject to limit | Comments |
|------------|--------------------|-----------------------|-----------------------|-------------------|---|------------------------------------|---|
| Boron | 2,400 | 150 | 12,000 | ¹ 750 | 93 | Irrigation | Some plants having a narrow tolerance range for boron require a certain amount for healthful growth but display toxic effects at slightly higher concentrations. The limit is based on the fact that sensitive crops have displayed toxic effects at concentrations of less than 1,000 µg/L. |
| Cadmium | 2 | ND | 12 | ¹ 15 | 8 | Protection of freshwater organisms | |
| Molybdenum | 110 | 4 | 1,100 | ² 10 | 95 | Irrigation | Some plants can concentrate molybdenum in their tissue. The limit is based on the ability of some plants to accumulate molybdenum to concentrations toxic to cattle and sheep. |
| Zinc | 30 | ND | 570 | ¹ 200 | 16 | Protection of freshwater organisms | Reported LC50 (lethal concentration for 50 percent of the population) values for various fish species ranged from 90 to 25,000 µg/L. An LC-50 concentration of 20,100 µg/L was reported for bluegills, a resident species in the interdunal ponds (Texas Instruments, Inc., 1978). The limit would be 200 µg/L. |

¹Limit by U.S. Environmental Protection Agency, 1976b.

²Limit by National Academy of Sciences and National Academy of Engineering, 1972, p. 314.

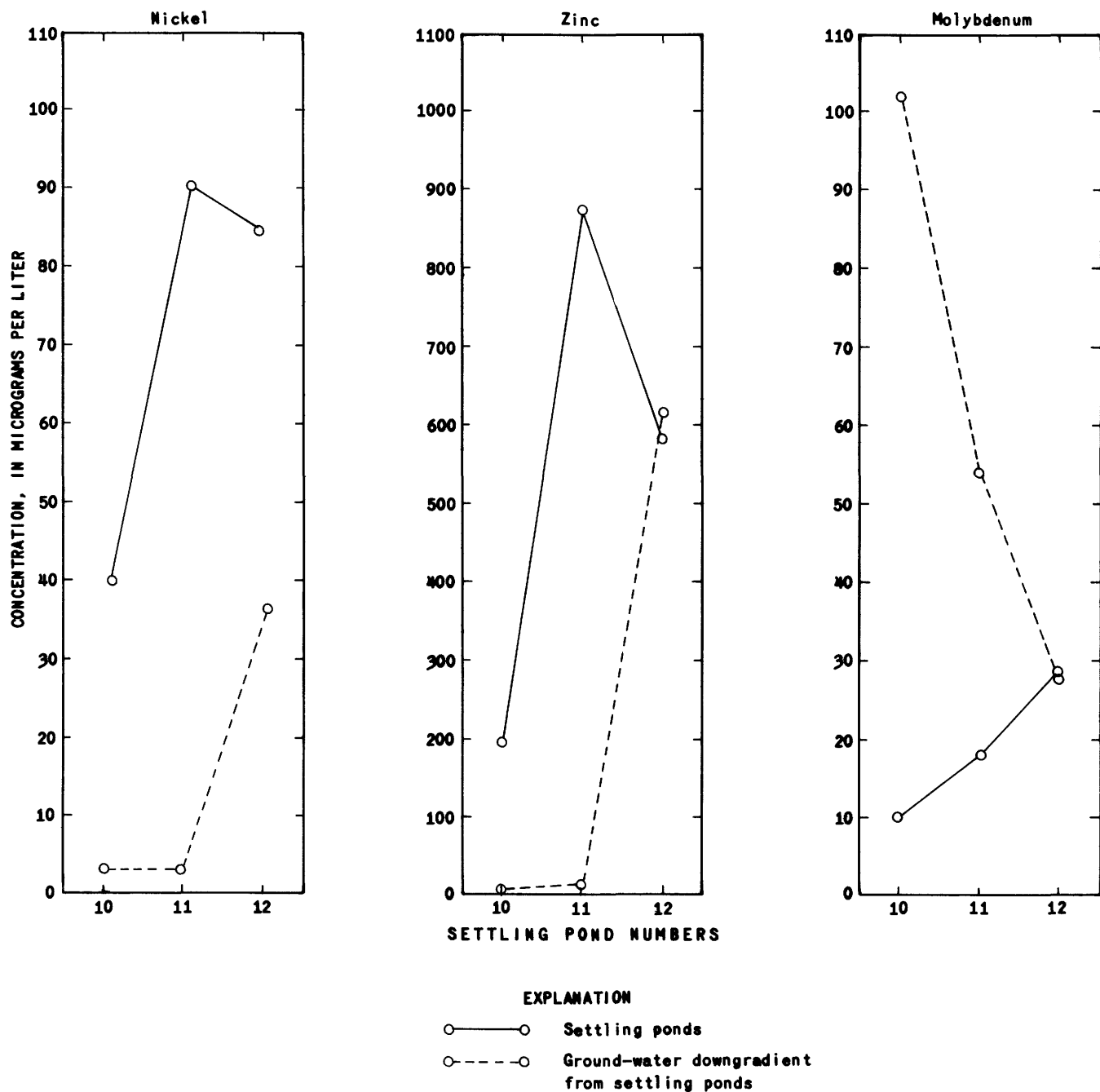


Figure 9.-- Mean concentrations of selected trace elements in settling ponds and in ground-water downgradient from settling ponds, September 1976 to May 1978.

The mean zinc concentrations of ground water downgradient from settling ponds 10 and 11 are lower than those of the ponds. However, the mean zinc concentration of ground water downgradient from pond 12 is similar to that of the upgradient settling pond. Mean concentrations of aluminum and lead display the same trend as that of zinc. Cation exchange, sorption, complexation with the organic materials downgradient from ponds 10 and 11, and precipitation as sulfides are probably the primary processes removing these elements from solution.

The mean molybdenum concentrations of ground water downgradient from settling ponds 10 and 11 are higher than those of the upgradient settling ponds, although the differences in the means for pond 11 and ground water downgradient are not significant at 95-percent confidence. Concentrations of arsenic and strontium display the same trends as that of molybdenum.

Molybdenum is accumulated by various biota (Chappel, 1976; Rankama and Sahama, 1950, p. 628) and arsenic is known to have many organic derivatives (Mesmer and Baes, 1974). Decomposition of the organic material downgradient from ash ponds 10 and 11 may be a source of these elements in ground water.

Strontium is an alkaline-earth element commonly in calcareous materials (Hem, 1970, p. 195). The accelerated dissolution of calcareous materials downgradient from ash ponds 10 and 11 may have also resulted in increased dissolution of associated strontium. (See pages 22-25.)

Beneath interdunal pond 2

If redox potentials in and beneath the interdunal ponds differ, then dissolved trace-element concentrations in and beneath the ponds may also differ. Concentrations of selected trace elements in water beneath interdunal pond 2 at three sites are compared with the concentration ranges in pond water at the same site at the 95-percent confidence interval (table 6).

Concentrations of aluminum beneath interdunal pond 2 at sites 20E and 20D exceeded the 95-percent confidence range for aluminum concentrations in overlying pond water. Arsenic concentrations beneath the pond at sites 20 and 20D also exceeded the 95-percent confidence range in overlying pond water. At site 20D, the pH beneath the pond was lower than the pH range of the pond.

These data suggest that concentrations of some trace elements beneath interdunal pond 2 may be higher than their concentrations in the pond. Uneven distribution of trace elements in and beneath the pond may be due to different general water chemistry, including pH, at these two sampling areas.

Table 6.--Concentrations of trace elements in water beneath interdunal pond 2 and ranges of concentrations of the trace elements in the pond, June 21, 1978

[All data except pH, are micrograms per liter;
ND, not detectable; samples collected and
analyzed by U.S. Geological Survey]

| Constituents and pH | Site 20 | | Site 20E | | Site 20D | |
|------------------------|-----------------|--|-----------------|--|-----------------|--|
| | Beneath pond | Concen- tration range in pond ¹ | Beneath pond | Concen- tration range in pond ¹ | Beneath pond | Concen- tration range in pond ¹ |
| Aluminum | 90 | 38-130 | 190 | 65-150 | 310 | 12-53 |
| Arsenic | 3 | 0-2 | 5 | 4-18 | 6 | 1-2 |
| Cadmium | ND | 1-7 | ND | 1-3 | ND | 0-1 |
| Chromium | 3 | 1-68 | ND | ND | 6 | 0-2 |
| Lead | ND | 0-2 | ND | 0-4 | ND | 0-2 |
| Molybdenum | 19 | 25-120 | 280 | 100-600 | 1 | 110-200 |
| Nickel | 8 | 17-31 | 2 | 8-29 | 4 | 5-18 |
| Selenium | ND | ND | ND | ----- | ND | ² ND |
| pH | 6.0 | 5.9-7.8 | 6.7 | 6.3-7.8 | 4.5 | 6.7-9.4 |

¹At 95-percent confidence interval.

²Only one observation was made.

Ash Fill

The ash fill is a source of boron and molybdenum for surface water bordering it. This conclusion is supported by mean concentrations of these elements at surface-water sites 24B and 25B bordering the fill, which exceed mean background concentrations. Similar results were observed in other studies (Plank and others, 1975; Martens and Beahm, 1976; and Helm and others, 1976).

In the Lakeshore, boron concentrations at surface-water sites 24A and 25A were approximately 4 to 7 times, respectively, background concentrations. The molybdenum concentration at surface-water site 25A was 4.5 times the background concentration. The maximum concentrations of boron and molybdenum in the Lakeshore surface water exceeded the maximum recommended limits, 750 µg/L (U.S. Environmental Protection Agency, 1976b) and 10 µg/L (National Academy of Sciences and the National Academy of Engineering, 1972, p. 314), respectively.

Atmospheric Deposition

Concentrations and loads of trace elements in bulk precipitation are presented in table 7. Loads varied temporally and spatially within the study area. No constituent was consistently greatest at any one site. Because loading at P2 did not exceed loading at P3, windblown material from the ash fill probably does not increase chemical loading on the Lakeshore property.

Very little information on atmospheric loads of trace elements in northwest Indiana has been published. Parker and others (1978) found atmospheric loading of cadmium, copper, lead, and zinc for 1 yr to be greater in Gary, Ind., than in a rural area of northwest Indiana. Cadmium, copper, lead, and zinc loads at site P1, the only site where data were collected for a complete year, more closely resembled Parker's determinations for the rural site than those for Gary, Ind. (See table 8.) However, the total zinc load at site P3 (72.3 $\mu\text{g}/\text{m}^2$), collected in less than 1 yr, exceeds the load collected at site P1 by more than 40 percent. The reason for greater zinc loading at site P3 is not known.

Concentrations of all trace elements in precipitation, except aluminum, copper, and lead, were within or lower than background surface-water and ground-water ranges. Consequently, precipitation did not seem to contribute significant amounts of most trace elements to the study area.

Combustion of leaded gasoline by automobiles is considered to be a major source of atmospheric lead (Greenberg and others, 1978; Andren and others, 1975, p. 1; Atkins, 1969; Lazarus and others, 1970). The sources of atmospheric copper and aluminum are not known, although industrial activity may be one source.

Radioactivity

Thatcher, Janzer, and Edwards (1977, p. 3) and Bedrosian, Easterly, and Cummings (1970) have documented the content of radioactive materials in fly ash. Therefore, there is a potential for the settling pond leachate to increase radioactivity in the Lakeshore water resources.

Suspended and dissolved gross alpha and gross beta radioactivity and estimates of dissolved potassium-40 radioactivity for a single sampling of two settling ponds and interdunal ponds 2 and 7 are plotted in figure 10. (Pond 7 was used as background.) For comparisons of samples with different concentrations of suspended materials, suspended radioactivity was expressed as the ratio of suspended radioactivity and suspended residue.

Concentrations of dissolved and suspended gross alpha and gross beta radioactivity were greater for the settling ponds than for interdunal pond 7, the background site. The radioactivity in the settling ponds agreed with

Table 7.--Concentrations and loads of trace elements in bulk deposition

[Precipitation, in inches; upper number is concentration, in micrograms per liter; lower number is load, in milligrams per square meter per month; samples collected and analyzed by U.S. Geological Survey; ND, not detectable]

| | Site P1 | | | | | | Site P2 | | | | Site P3 | | | | | |
|------------------------|--------------------------|--------------------------|---------------------------|----------------------------|--------------------------|--------------------------|---------------------------|--------------------------|--------------------------|--------------------------|-------------------------|-------------------------|---------------------------|----------------------------|----------------------------|--------------------------|
| | Collection period | | | | | | Collection period | | | | Collection period | | | | | |
| | 4-20-77 to 6-28-77 | 6-28-77 to 8-19-77 | 8-19-77 to 10-12-77 | 10-12-77 to 11-23-77 | 11-23-77 to 4-3-78 | 4-3-78 to 11-23-77 | 9-22-77 to 11-23-77 | 11-23-77 to 4-3-78 | 4-3-78 to 11-23-77 | 11-23-77 to 4-3-78 | 4-20-77 to 7-1-77 | 7-1-77 to 8-19-77 | 8-19-77 to 10-13-77 | 10-13-77 to 11-23-77 | 11-23-77 to 12-21-77 | 12-21-77 to 4-3-78 |
| Precipitation (in.) | 5.0 | 6.5 | ¹ 11.7 | 3.0 | 2.2 | 3.8 | 3.8 | 1.75 | 7.5 | 5.3 | ¹ 11.7 | 3.5 | 2.7 | 3.5 | 2.7 | 3.5 |
| Aluminum | 220 9.7 | 240 23 | 340 56 | 260 14 | 500 63 | 190 18 | 5,500 56 | 150 9.7 | 170 14 | ND 0 | ND 0 | 190 12 | 600 44 | 11-23-77 to 12-21-77 | 600 44 | 12-21-77 to 4-3-78 |
| Arsenic | 2 .1 | 1 .1 | 1 .2 | 1 .1 | 20 .3 | 1 .1 | 36 .4 | 2 .1 | 1 .1 | ND 0 | ND 0 | 1 .1 | 2 .2 | 1 .1 | 2 .2 | 2 .2 |
| Barium | ND 0 | ND 0 | ND 0 | ND 0 | 100 1.3 | ND 0 | ND 0 | 100 6.4 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 |
| Boron | 9 .4 | 30 2.8 | 5 .8 | 10 .5 | 20 .3 | ND 0 | 20 .2 | ND 0 | 20 1.6 | ND 0 | 3 .2 | ND 0 | 90 6.6 | ND 0 | 90 6.6 | ND 0 |
| Cadmium | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | 2 4.1 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 |
| Chromium | 10 .4 | 10 .9 | 10 1.7 | 10 .5 | 70 .9 | 10 .9 | 70 .7 | 10 .6 | 20 1.6 | 10 .8 | 10 .8 | 10 .6 | 20 1.5 | 10 .6 | 20 1.5 | 20 1.5 |
| Cobalt | ND 0 | ND 0 | ND 0 | 3 .5 | ND 0 | 2 .2 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 | ND 0 |
| Copper | 8 .4 | 6 .6 | 5 .8 | 7 .4 | 42 .5 | 4 .4 | 43 .4 | 4 .3 | 6 .5 | 4 .3 | 4 .3 | 4 .3 | 17 1.3 | 4 .3 | 17 1.3 | 4 .3 |
| Iron | 1,900 84 | 560 53 | 1,000 170 | 2,600 140 | 25,000 320 | 490 46 | 12,000 120 | 250 16 | 800 65 | 420 33 | 490 32 | 490 32 | 2,900 210 | 490 32 | 2,900 210 | 490 32 |
| Lead | 21 .9 | 16 1.5 | 13 2.2 | 44 2.4 | 270 3.4 | 11 1.0 | 240 2.4 | 12 .8 | 27 2.2 | 5 .4 | 18 1.2 | 49 3.6 | 49 3.6 | 18 1.2 | 49 3.6 | 49 3.6 |
| Manganese | 120 5.2 | 90 8.6 | 80 13 | 310 17 | 3,500 44 | 70 6.6 | 1,200 12 | 70 4.5 | 50 4.0 | 80 6.2 | 100 6.5 | 280 21 | 280 21 | 100 6.5 | 280 21 | 280 21 |
| Molybdenum | 3 .1 | 2 .2 | 4 .7 | 3 .2 | 24 .3 | 4 .4 | 30 .3 | 2 .1 | 1 .1 | 2 .2 | 3 .2 | 5 .4 | 5 .4 | 3 .2 | 5 .4 | 5 .4 |
| Nickel | 11 .5 | 7 .6 | 4 .7 | 3 .2 | 29 .4 | 2 .2 | 24 .2 | 5 .3 | 5 .4 | 3 .2 | 2 .1 | 15 1.1 | 15 1.1 | 2 .1 | 15 1.1 | 2 .1 |
| Strontium | 70 3.1 | 10 .9 | 40 6.6 | 50 2.7 | 90 1.1 | 50 4.7 | 90 .9 | 60 3.9 | 10 .8 | 40 3.1 | 50 3.3 | 60 4.4 | 60 4.4 | 50 3.3 | 60 4.4 | 60 4.4 |
| Zinc | 40 1.8 | 40 3.9 | 60 9.9 | 80 4.4 | 270 3.4 | 100 9.4 | 200 2.0 | 10 .6 | 200 16 | 80 6.2 | 180 12 | 50 3.7 | 50 3.7 | 180 12 | 50 3.7 | 50 3.7 |

¹Precipitation measured at Ogden Dunes station.

Table 8.--Atmospheric loads of selected trace elements in Gary, Ind., rural northwest Indiana, and the study area

| Element | Loads [(mg/m ²)/yr] | | |
|---------|---|--|------------------------------------|
| | Gary, Ind., ¹ May 1975- April 1976 | Rural north- west Indiana ¹ May 1975- April 1976 | Site P1 April 1977- May 1978 |
| Cadmium | 0.82 | 0.67 | 0 |
| Copper | 16.5 | 4.3 | 6.3 |
| Lead | 81.5 | 22.1 | 27 |
| Zinc | 98.4 | 47.2 | 50 |

¹Data obtained from Parker and others (1978).

those found in fly-ash sluice water by Rohrman (1971). Higher than background dissolved gross alpha and gross beta radioactivity in interdunal pond 2 indicate that the settling-pond seepage has contributed radioactivity to the Lake-shore surface-water resources.

Additional analyses for specific alpha- and beta-emitting elements were not made. Further analysis for specific alpha-emitting elements in drinking water is recommended by the U.S. Environmental Protection Agency (1976a) where gross alpha radioactivity is greater than 15 pCi/L (picocuries per liter), excluding contributions by radon and uranium. The dissolved gross alpha radioactivity did not exceed this limit. Further analysis for beta-emitting elements in drinking water is recommended by the National Academy of Sciences and the National Academy of Engineering (1972) where gross beta radioactivity, excluding contributions by potassium-40, exceeds 5 pCi/L. Estimates of radioactivity contributed by potassium-40 suggest that this limit was not exceeded.

Polychlorinated Biphenyls

PCB's (polychlorinated biphenyls) are a class of organic compounds that can be hazardous to human health and other biota chronically exposed to them. PCB's and other polycyclic organic matter in stack discharges possibly form during coal combustion (Cowherd and others, 1975, p. 14). However, PCB's were not detected in interdunal pond 2 bottom materials at site 20.

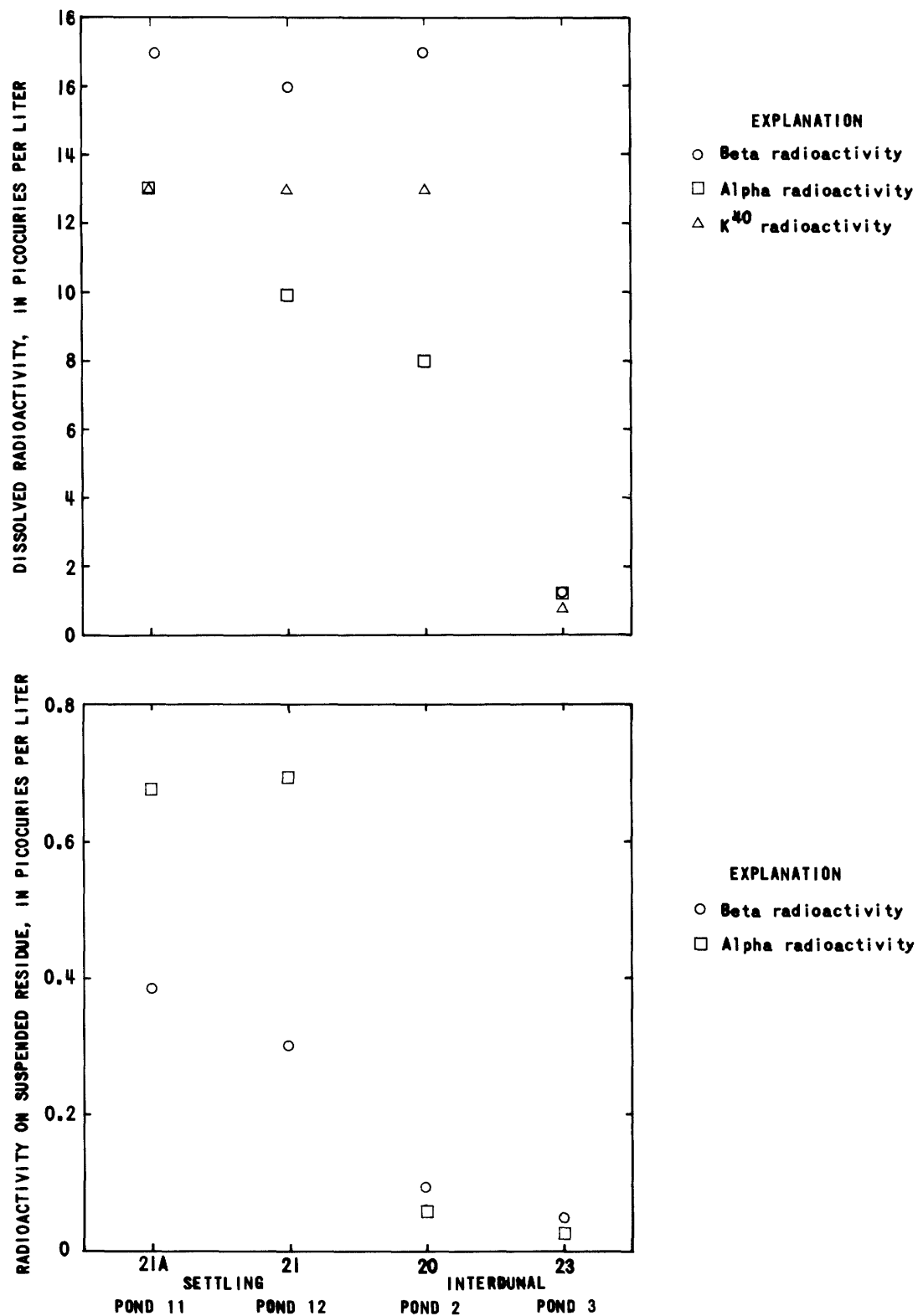


Figure 10.-- Gross alpha and gross beta radioactivity and estimates of dissolved potassium-40 radioactivity in settling ponds and interdunal ponds, February 11, 1977.

Unit 3

Statistical summaries of concentrations for general water-quality and trace-element data in unit 3, the confined aquifer beneath the study area, are presented in tables 9 and 10, respectively. Mean concentrations of constituents in unit 3 that exceeded those of background unit 1 (site 106) were iron (by 12 times), manganese (by 12.7 times), and strontium (by 6.4 times).

Although seepage from the settling ponds causes water beneath them to move downward from unit 1 into unit 3, mean concentrations of major or trace elements significantly enriched in the settling ponds were not significantly higher downgradient from the settling ponds in unit 3 (site 101) than at both sites upgradient (sites 102 and 105). The only constituent that was significantly enriched at sites downgradient from the settling-pond seepage was silica. Settling-pond seepage is probably not a source of silica to unit 3 because the mean silica concentration of the settling ponds (3.5 mg/L) is less than the mean at site 101 (12 mg/L). The reason for the greater mean silica concentration downgradient from the settling ponds is not known.

The strontium concentration at site 105 generally increased during the period of study upgradient from the settling ponds (fig. 11). The source of the strontium might be calcareous material in the aquifer (Hem, 1970, p. 195), but the reason for the continual increase is not known.

Table 9.--Statistical summary of general water-quality data in unit 3,
September 1976-May 1978

[All data except pH are in milligrams per liter; samples
collected and analyzed by U.S. Geological Survey]

| Constituents and properties | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
|-----------------------------------|------|-----------------------|------------------|------------------|---------------------------|
| Dissolved solids | | | | | |
| (calculated sum) | 326 | 0.3 | 194 | 469 | 28 |
| pH | 7.7 | .1 | 6.4 | 8.8 | 28 |
| Alkalinity, as CaCO ₃ | 200 | <1 | 120 | 250 | 28 |
| Silica ¹ | 7.9 | 3.8 | .6 | 13 | 28 |
| Calcium | 40 | .7 | 8.1 | 72 | 28 |
| Magnesium ¹ | 26 | 4.2 | 19 | 34 | 28 |
| Sodium | 40 | .4 | 20 | 75 | 28 |
| Potassium | 3.3 | 1.6 | 2.0 | 5.6 | 28 |
| Sulfate ¹ | 26 | 19 | .4 | 70 | 28 |
| Chloride | 39 | 1.7 | 7.9 | 160 | 28 |
| Fluoride | .3 | .1 | .1 | .5 | 28 |
| Dissolved organic | | | | | |
| carbon | 9.4 | .8 | 2.0 | 28 | 19 |

¹Statistical information calculated from nontransformed data.

Table 10.--Statistical summary of trace-element data in
unit 3, September 1976-May 1978

[All data are in micrograms per liter; samples
collected and analyzed by U.S. Geological
Survey; ND, not detectable]

| Constituent | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
|----------------------|------|-----------------------|------------------|------------------|---------------------------|
| Aluminum | 20 | 6 | ND | 1,000 | 21 |
| Arsenic | 1 | <1 | ND | 8 | 21 |
| Barium ¹ | 100 | 100 | ND | 300 | 13 |
| Beryllium | 0 | 0 | ND | ND | 6 |
| Boron | 330 | <1 | 30 | 830 | 24 |
| Cadmium ¹ | 0 | 0 | ND | ND | 21 |
| Chromium | <1 | <1 | ND | 1 | 6 |
| Cobalt ¹ | 0 | 0 | ND | ND | 3 |
| Copper | <1 | 2 | ND | 17 | 14 |
| Iron | 120 | 3 | 10 | 2,000 | 28 |
| Lead | 1 | 2 | ND | 12 | 21 |
| Manganese | 89 | 1 | 10 | 460 | 28 |
| Mercury | 0 | 0 | ND | ND | 6 |
| Molybdenum | 8 | 2 | ND | 44 | 21 |
| Nickel | 3 | 1 | ND | 14 | 21 |
| Selenium | 0 | 0 | ND | ND | 3 |
| Strontium | 700 | 1 | 130 | 1,400 | 22 |
| Zinc | 4 | 3 | ND | 60 | 21 |

¹Statistical information calculated from nontransformed data.

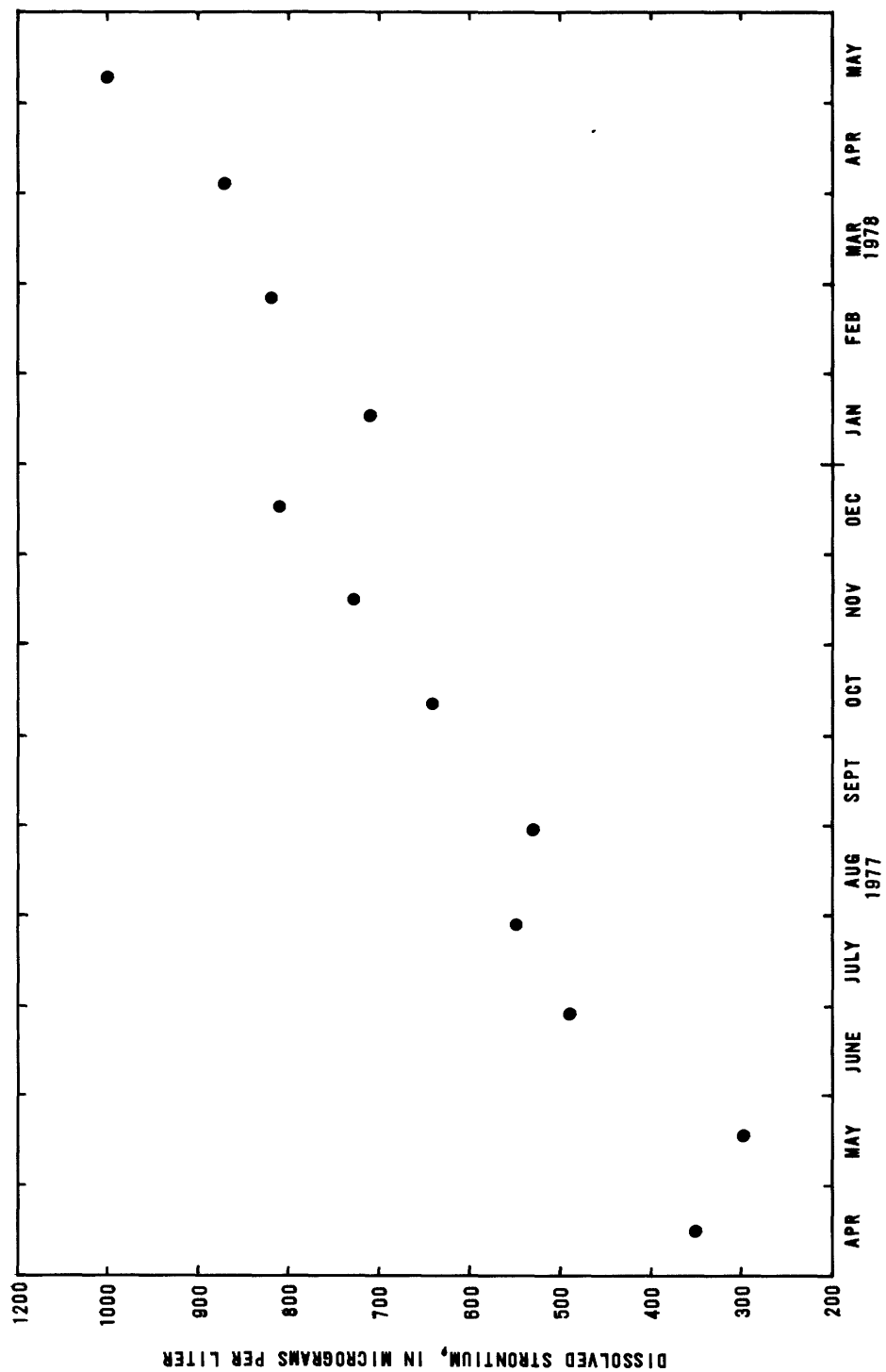


Figure 11.-- Relation between strontium concentration and time in unit 3 at site 105.

SUMMARY AND CONCLUSIONS

The Bailly Generating Station, a coal-fired electrical generating facility owned by NIPSCO, borders a part of the Indiana Dunes National Lakeshore near Dune Acres, Ind. Fly ash produced by coal combustion at the generating station is transported through a pipeline to two settling-pond systems that lose water at a rate of at least 2 Mgal/d through ground-water seepage. The settling ponds are separated from the Lakeshore land by a dike constructed primarily of sand and fragments of limestone and slag. An organic layer is about 20 ft below the surface near the west end of the dike. The settling ponds are periodically drained, and the settled ash is hauled to a fill area in the east part of the study area. Dikes, constructed primarily of sand, also separate the ash-fill area from the Lakeshore.

Compared with background concentrations, the settling ponds are enriched with dissolved calcium, fluoride, sulfate, sodium, potassium, boron, aluminum, arsenic, barium, cadmium, cobalt, copper, iron, lead, molybdenum, manganese, nickel, strontium, zinc, and alpha and beta radioactivity. All these constituents except barium, cadmium, cobalt, copper, and lead are enriched downgradient from the settling ponds.

Generally concentrations of most constituents in the Lakeshore water did not exceed maximum concentration limits recommended by the U.S. Environmental Protection Agency (1976b) and the National Academy of Sciences and the National Academy of Engineering (1972). However, limits for boron (based on potential plant toxicity), molybdenum (based on ability of some plants to accumulate concentrations toxic to sheep and cattle), and cadmium and zinc (based on potential toxicity to aquatic organisms) were exceeded at times. Because most of the alpha and beta radioactivity is probably caused by uranium and potassium-40, respectively, the limits for gross alpha and gross beta radioactivity are probably not exceeded. Concentrations of trace elements beneath the sediment interface of pond 2 suggest that differences in the geochemical environment may result in higher concentrations of some dissolved trace elements beneath interdunal pond 2 than in the pond.

In ground water downgradient from the settling ponds, concentrations of boron, iron, manganese, and sodium were not significantly different from concentrations of these metals in the settling ponds. Concentrations of arsenic, fluoride, molybdenum, potassium, sulfate, and strontium in ground water downgradient from the settling ponds were greater where ground water was associated with organic material than where it wasn't. Compared with calcium concentrations in the settling ponds, calcium concentrations were enriched in settling pond leachate downgradient from all the settling ponds, and especially where organic matter was present.

Concentrations of aluminum, cadmium, cobalt, copper, lead, nickel, and zinc were generally lower in settling-pond leachate downgradient from the settling ponds than concentrations of these metals in the settling ponds. Concentrations of aluminum, cobalt, lead, and zinc in the leachate were lower than those in the settling ponds only where organic matter was present

downgradient from the ponds. Concentrations of cadmium, copper, and nickel in leachate downgradient from all settling ponds were lower than those of the same metals in the settling ponds, although concentrations of cadmium and nickel were lowest where organic material was present downgradient from the ponds.

Continuous leaching of the ash-fill area increased boron, molybdenum, and potassium concentrations of surface water bordering the Lakeshore. Although sulfate concentrations were more variable in surface water adjacent to active filling operations, no significant leaching of sulfate from the fill itself was observed. At times, boron and molybdenum concentrations in the Lakeshore surface water bordering the fill exceeded the maximum concentration limits recommended by the U.S. Environmental Protection Agency (1976b) and the National Academy of Sciences and National Academy of Engineering (1972).

Atmospheric-deposition loads varied temporally and spatially. Traffic on the NIPSCO access road seems to increase total chemical loading along the road by suspending particulates in the atmosphere, but windblown material from the ash fill does not seem to increase atmospheric chemical loading to adjacent Lakeshore wetlands. Compared to continuous seepage of leachate from the settling ponds, atmospheric precipitation is probably not a major source of any element in the Lakeshore water.

PCB's, which possibly form during coal combustion, were not detected in bottom materials of interdunal pond 2.

Settling-pond seepage did not significantly affect water chemistry in the confined aquifer beneath the study area. Mean silica concentration was significantly higher at one site in this unit (site 101) than at the others. The strontium concentration generally increased with time at one site in the confined aquifer (site 105). The reason for these anomalies is not known.

Although concentrations of some elements have been demonstrated to exceed maximum recommended limits, available data do not indicate whether the elements may be accumulated by biota or whether they may be harmful to resident plant and animal species. Such information could be obtained by tissue and bioassay analyses of various resident organisms. Effects of chronic, low-level concentrations of various elements on biota, which could not be detected by this study, might also be indicated by such analyses.

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Table 11.--Statistical summary of general water-quality data for individual sites, September 1976-May 1978

[All data except pH are in milligrams per liter; samples collected and analyzed by U.S. Geological Survey; ND, not detectable]

| Site type | Site number | Dissolved solids | | | | | pH | | | |
|---------------------------------------|-------------|------------------|--------------------|---------------|---------------|------------------------|--------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Median | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | 585 | 0.3 | 392 | 921 | 16 | 5.8 | 3.2 | 7.7 | 15 |
| | 21A | 536 | .4 | 338 | 1,040 | 13 | 5.4 | 3.3 | 7.9 | 12 |
| | 21B | 280 | .3 | 201 | 584 | 19 | 6.5 | 4.1 | 7.8 | 12 |
| | 22 | 373 | .3 | 233 | 501 | 10 | 6.3 | 4.2 | 7.9 | 11 |
| | 22A | 306 | .2 | 249 | 374 | 7 | 7.3 | 6.2 | 8.1 | 7 |
| Dike downgradient from settling ponds | G1 | 680 | .4 | 461 | 1,030 | 9 | 7.8 | 7.4 | 8.5 | 10 |
| | G2 | 1,200 | .3 | 661 | 1,760 | 12 | 6.3 | 5.7 | 7.1 | 12 |
| | G4 | 685 | .3 | 500 | 1,050 | 15 | 5.9 | 4.7 | 7.7 | 16 |
| | G6 | 455 | .1 | 380 | 617 | 14 | 7.3 | 6.2 | 8.3 | 14 |
| Downgradient from settling ponds | 19 | 546 | .2 | 441 | 691 | 12 | 7.4 | 6.6 | 8.6 | 12 |
| | 20 | 545 | .2 | 379 | 742 | 16 | 6.8 | 5.9 | 7.8 | 17 |
| | 20D | 556 | .2 | 433 | 707 | 14 | 7.5 | 6.7 | 9.4 | 15 |
| | 20E | 792 | .5 | 459 | 1,480 | 10 | 6.9 | 6.3 | 7.8 | 10 |
| | D1 | 626 | .1 | 604 | 668 | 3 | 7.0 | 7.0 | 7.0 | 1 |
| | D2 | 503 | .1 | 471 | 559 | 3 | 6.8 | 6.8 | 6.8 | 1 |
| | D4 | 125 | .2 | 99 | 140 | 3 | 7.0 | 7.0 | 7.0 | 1 |
| Ash fill | 24A | 175 | .4 | 98 | 314 | 13 | 6.6 | 6.1 | 7.0 | 14 |
| | 24B | 288 | .5 | 174 | 621 | 15 | 7.2 | 6.5 | 8.3 | 16 |
| | 25A | 389 | .3 | 235 | 530 | 10 | 7.2 | 6.6 | 8.0 | 11 |
| | 25B | 352 | .2 | 275 | 473 | 16 | 7.5 | 6.2 | 8.1 | 16 |
| Background | 23 | 157 | .4 | 98 | 232 | 11 | 6.6 | 6.2 | 7.6 | 12 |
| | 23A | 151 | .5 | 79 | 315 | 12 | 7.0 | 6.1 | 8.3 | 12 |
| | 106 | 399 | .1 | 348 | 442 | 12 | 7.5 | 6.6 | 8.2 | 12 |
| Unit 3 | 101 | 335 | .1 | 309 | 354 | 8 | 7.5 | 6.6 | 8.0 | 8 |
| | 102 | 233 | .1 | 194 | 271 | 9 | 7.8 | 6.4 | 8.8 | 9 |
| | 105 | 421 | .1 | 364 | 470 | 11 | 7.7 | 6.7 | 8.2 | 11 |

Table 11.--Statistical summary of general water-quality data for individual sites,
September 1976-May 1978--Continued

| Site type | Site number | Alkalinity (as CaCO ₃) | | | | | Calcium | | | | |
|---------------------------------------|-------------|------------------------------------|--------------------|---------------|---------------|------------------------|---------|--------------------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | 2 | 2.7 | ND | 38 | 16 | 94 | 0.3 | 62 | 170 | 16 |
| | 21A | 2 | 2.1 | ND | 29 | 13 | 87 | .3 | 59 | 150 | 13 |
| | 21B | 23 | 2.7 | ND | 60 | 19 | 49 | .1 | 41 | 62 | 19 |
| | 22 | 12 | 3.0 | ND | 41 | 10 | 59 | .2 | 46 | 80 | 10 |
| | 22A | 22 | 3.3 | ND | 64 | 7 | 55 | .2 | 46 | 75 | 7 |
| Dike downgradient from settling ponds | G1 | 61 | .7 | 25 | 120 | 9 | 170 | .4 | 110 | 260 | 9 |
| | G2 | 27 | .7 | 8 | 55 | 12 | 270 | .5 | 110 | 500 | 12 |
| | G4 | 4 | 2.3 | ND | 45 | 15 | 120 | .4 | 78 | 210 | 15 |
| | G6 | 79 | .3 | 39 | 110 | 14 | 87 | .2 | 67 | 130 | 14 |
| Downgradient from settling ponds | 19 | 34 | .2 | 25 | 41 | 12 | 110 | .2 | 85 | 130 | 12 |
| | 20 | 20 | .6 | 7 | 34 | 16 | 100 | .3 | 67 | 150 | 16 |
| | 20D | 36 | .2 | 25 | 49 | 15 | 110 | .2 | 91 | 150 | 15 |
| | 20E | 10 | 2.6 | ND | 55 | 10 | 170 | .6 | 98 | 370 | 10 |
| | D1 | 64 | .7 | 45 | 120 | 3 | 110 | .2 | 95 | 130 | 3 |
| | D2 | 74 | .1 | 64 | 81 | 3 | 92 | .2 | 81 | 110 | 3 |
| | D4 | 40 | .2 | 33 | 49 | 3 | 19 | .2 | 15 | 22 | 3 |
| Ash fill | 24A | 69 | .5 | 25 | 110 | 13 | 31 | .5 | 13 | 58 | 13 |
| | 24B | 120 | .4 | 60 | 220 | 15 | 61 | .5 | 38 | 130 | 15 |
| | 25A | 220 | 1.7 | 12 | 350 | 10 | 92 | .2 | 67 | 120 | 10 |
| | 25B | 260 | .2 | 170 | 360 | 16 | 72 | .2 | 45 | 100 | 15 |
| Background | 23 | 45 | .3 | 33 | 63 | 11 | 29 | .5 | 17 | 46 | 11 |
| | 23A | 58 | .6 | 24 | 110 | 12 | 28 | .5 | 15 | 61 | 12 |
| | 106 | 200 | .1 | 160 | 220 | 12 | 78 | <.1 | 74 | 85 | 12 |
| Unit 3 | 101 | 240 | .1 | 210 | 250 | 8 | 46 | <.1 | 42 | 50 | 8 |
| | 102 | 190 | .2 | 120 | 250 | 9 | 20 | <.1 | 8.1 | 35 | 9 |
| | 105 | 190 | .2 | 140 | 220 | 11 | 64 | <.1 | 57 | 72 | 11 |

Table 11.--Statistical summary of general water-quality data for individual sites,
September 1976-May 1978--Continued

| Site type | Site number | Chloride | | | | | Fluoride | | | | |
|---------------------------------------|-------------|----------|--------------------|---------------|---------------|------------------------|----------|--------------------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | 10 | 0.1 | 8.6 | 12 | 16 | 0.3 | 0.1 | 0.2 | 0.8 | 16 |
| | 21A | 9.9 | .1 | 8.2 | 11 | 13 | .3 | .1 | .2 | .5 | 13 |
| | 21B | 9.6 | .1 | 7.8 | 12 | 10 | .2 | .1 | .1 | .2 | 13 |
| | 22 | 11 | .1 | 9.2 | 12 | 10 | .2 | <.1 | .1 | .3 | 10 |
| | 22A | 10 | .1 | 8.9 | 13 | 7 | .2 | <.1 | .1 | .2 | 7 |
| Dike downgradient from settling ponds | G1 | 18 | .9 | 9.8 | 90 | 9 | 2.2 | .4 | .7 | 3.8 | 9 |
| | G2 | 19 | .6 | 12 | 57 | 12 | <.1 | .1 | ND | .1 | 12 |
| | G4 | 9.7 | .4 | 2.4 | 15 | 15 | .4 | .3 | ND | 1.6 | 15 |
| | G6 | 9.6 | .1 | 8.6 | 11 | 14 | .2 | .1 | .1 | .2 | 14 |
| Downgradient from settling ponds | 19 | 10 | .1 | 8.6 | 11 | 12 | .3 | .1 | .2 | .4 | 12 |
| | 20 | 10 | .1 | 7.0 | 13 | 16 | .3 | .1 | .2 | .5 | 16 |
| | 20D | 11 | .1 | 8.8 | 13 | 14 | .2 | .1 | .2 | .4 | 14 |
| | 20E | 12 | .1 | 10 | 13 | 10 | .5 | .1 | .3 | .7 | 10 |
| | D1 | 11 | .1 | 9.7 | 12 | 3 | .1 | 0 | .1 | .1 | 3 |
| | D2 | 11 | .2 | 10 | 13 | 3 | .1 | <.1 | ND | .1 | 3 |
| Ash fill | D4 | 6 | .2 | 4.9 | 6.7 | 3 | .1 | <.1 | ND | .1 | 3 |
| | 24A | 11 | .1 | 8.1 | 13 | 13 | .2 | .1 | .1 | .2 | 13 |
| | 24B | 10 | .3 | 7.0 | 15 | 15 | .2 | <.1 | .1 | .3 | 15 |
| | 25A | 14 | .3 | 8.7 | 19 | 10 | .5 | .2 | .1 | 1.1 | 10 |
| Background | 25B | 13 | .4 | 6.1 | 22 | 15 | .4 | .1 | .3 | .7 | 15 |
| | 23 | 6.6 | .2 | 4.3 | 9.7 | 11 | .1 | 0 | .1 | .1 | 11 |
| | 23A | 7.7 | .4 | 3.5 | 14 | 12 | .2 | .1 | .1 | .2 | 12 |
| Unit 3 | 106 | 59 | .2 | 44 | 83 | 12 | .1 | .1 | ND | .1 | 12 |
| | 101 | 29 | .2 | 23 | 36 | 8 | .4 | <.1 | .4 | .5 | 8 |
| | 102 | 12 | .4 | 7.9 | 20 | 9 | .2 | .1 | .1 | .4 | 9 |
| | 105 | 120 | .4 | 51 | 160 | 11 | .3 | .1 | .2 | .5 | 11 |

Table 11.--Statistical summary of general water-quality data for individual sites,
September 1976-May 1978--Continued

| Site type | Site number | Magnesium ¹ | | | | | Potassium | | | | |
|---------------------------------------|-------------|------------------------|--------------------|---------------|---------------|------------------------|-----------|--------------------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | 27 | 12 | 12 | 52 | 16 | 18 | 0.4 | 9.4 | 36 | 16 |
| | 21A | 26 | 13 | 13 | 54 | 13 | 16 | .5 | 8.0 | 43 | 13 |
| | 21B | 14 | 2.3 | 11 | 18 | 19 | 5.1 | .3 | 2.4 | 9.5 | 19 |
| | 22 | 19 | 6.6 | 12 | 31 | 10 | 8.2 | .7 | 3.4 | 23 | 10 |
| | 22A | 15 | 1.6 | 12 | 17 | 7 | 5.8 | .2 | 3.4 | 7.2 | 7 |
| Dike downgradient from settling ponds | G1 | 6.7 | 6.1 | 1.3 | 21 | 9 | 23 | .3 | 17 | 36 | 9 |
| | G2 | 14 | 17 | .7 | 49 | 12 | 46 | .4 | 19 | 68 | 12 |
| | G4 | 28 | 6.8 | 18 | 44 | 15 | 22 | .2 | 16 | 29 | 15 |
| | G6 | 25 | 33 | 22 | 34 | 14 | 7.6 | .4 | 4.4 | 16 | 14 |
| Downgradient from settling ponds | 19 | 23 | 4.8 | 15 | 29 | 12 | 16 | .2 | 9.1 | 22 | 12 |
| | 20 | 23 | 6.0 | 15 | 35 | 16 | 17 | .3 | 10 | 25 | 16 |
| | 20D | 24 | 5.4 | 16 | 34 | 14 | 17 | .2 | 13 | 22 | 14 |
| | 20E | 17 | 4.5 | 9.6 | 23 | 10 | 25 | .6 | 11 | 48 | 10 |
| | D1 | 27 | 5.1 | 23 | 33 | 3 | 15 | .5 | 9.8 | 22 | 3 |
| | D2 | 27 | 2.0 | 25 | 29 | 3 | 8.9 | .4 | 6.6 | 14 | 3 |
| | D4 | 8.1 | 2.4 | 5.4 | 10 | 3 | .9 | .2 | .5 | 1.2 | 3 |
| Ash fill | 24A | 12 | 4.3 | 5.0 | 20 | 13 | 5.0 | .3 | 2.4 | 7.6 | 13 |
| | 24B | 19 | 6.4 | 12 | 35 | 15 | 8.1 | .5 | 4.3 | 19 | 15 |
| | 25A | 31 | 3.7 | 25 | 36 | 10 | 5.8 | .2 | 3.4 | 7.5 | 10 |
| | 25B | 32 | 7.1 | 20 | 45 | 15 | 4.2 | .3 | 2.4 | 7.5 | 15 |
| Background | 23 | 11 | 3.6 | 6.5 | 16 | 11 | 1.9 | .2 | 1.2 | 2.5 | 11 |
| | 23A | 13 | 5.0 | 6.1 | 21 | 12 | 2.2 | .4 | .7 | 4.1 | 12 |
| | 106 | 30 | 1.3 | 28 | 32 | 12 | 2.0 | <.1 | 1.7 | 2.4 | 12 |
| Unit 3 | 101 | 27 | .9 | 25 | 28 | 8 | 3.9 | .1 | 3.3 | 4.4 | 8 |
| | 102 | 29 | 6.7 | 19 | 34 | 9 | 3.4 | .3 | 2.4 | 5.6 | 9 |
| | 105 | 24 | .5 | 23 | 25 | 11 | 2.9 | .2 | 2.0 | 3.5 | 11 |

Table 11.--Statistical summary of general water-quality data for individual sites,
September 1976-May 1978--Continued

| Site type | Site number | Silica ¹ | | | | | Sodium | | | | |
|---------------------------------------|-------------|---------------------|--------------------|---------------|---------------|------------------------|--------|--------------------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | 5.9 | 2.8 | 2.5 | 11 | 16 | 18 | 0.3 | 11 | 27 | 16 |
| | 21A | 4.8 | 2.8 | 1.8 | 12 | 13 | 18 | .3 | 11 | 28 | 13 |
| | 21B | 1.8 | .6 | 1.0 | 2.9 | 19 | 14 | .4 | 7.8 | 22 | 19 |
| | 22 | 2.7 | .9 | 1.5 | 3.9 | 10 | 16 | .2 | 9.3 | 20 | 10 |
| | 22A | 2.0 | 1.2 | .7 | 3.6 | 7 | 13 | .3 | 9.8 | 18 | 7 |
| Dike downgradient from settling ponds | G1 | 10 | 2.8 | 7.4 | 14 | 9 | 16 | .1 | 13 | 20 | 9 |
| | G2 | 3.9 | 2.2 | .8 | 8.1 | 12 | 20 | .2 | 12 | 25 | 12 |
| | G4 | 8.4 | 3.1 | 4.9 | 16 | 15 | 18 | .1 | 14 | 21 | 15 |
| | G6 | 11 | 2.9 | 6.4 | 17 | 14 | 11 | .1 | 8.3 | 13 | 14 |
| Downgradient from settling ponds | 19 | 2.7 | 2.2 | .2 | 7.5 | 12 | 15 | .2 | 11 | 19 | 12 |
| | 20 | 5.7 | 3.3 | 1.0 | 13 | 16 | 15 | .2 | 12 | 20 | 16 |
| | 20D | 3.1 | 2.2 | .1 | 7.4 | 14 | 15 | .1 | 12 | 19 | 14 |
| | 20E | 7.9 | 4.0 | 3.8 | 15 | 10 | 18 | .1 | 14 | 22 | 10 |
| | D1 | 2.2 | 1.0 | 1.5 | 3.3 | 3 | 23 | .8 | 14 | 46 | 3 |
| | D2 | 3.8 | 1.2 | 2.6 | 4.9 | 3 | 16 | .3 | 13 | 21 | 3 |
| | D4 | 9.2 | 2.0 | 7.0 | 11 | 3 | 3.1 | <.1 | 3 | 3.2 | 3 |
| Ash fill | 24A | 9.1 | 2.4 | 3.1 | 12 | 13 | 8.1 | .2 | 6.5 | 11 | 13 |
| | 24B | 4.9 | 3.6 | .1 | 12 | 15 | 8.5 | .3 | 4.6 | 16 | 15 |
| | 25A | 14 | 5.3 | 3.4 | 22 | 10 | 14 | .2 | 10 | 18 | 10 |
| | 25B | 6.6 | 3.8 | .2 | 13 | 15 | 11 | .3 | 7 | 16 | 15 |
| Background | 23 | 9.4 | 3.6 | 2.1 | 14 | 11 | 4.8 | .5 | 2.0 | 8.7 | 11 |
| | 23A | 1.0 | 2.1 | ND | 7.7 | 12 | 6.8 | .4 | 3.4 | 12 | 12 |
| | 106 | 12 | .7 | 11 | 14 | 16 | 26 | .2 | 20 | 34 | 12 |
| Unit 3 | 101 | 12 | .8 | 11 | 13 | 8 | 38 | .2 | 30 | 46 | 8 |
| | 102 | 4.4 | 3.2 | .6 | 9.5 | 9 | 28 | .3 | 20 | 41 | 9 |
| | 105 | 7.4 | 1.2 | 5.8 | 9.2 | 11 | 56 | .3 | 28 | 75 | 11 |

Table 11.--Statistical summary of general water-quality data for individual sites,
September 1976-May 1978--Continued

| Site type | Site number | Sulfate ¹ | | | | | Dissolved organic carbon | | | | |
|---------------------------------------|-------------|----------------------|--------------------|---------------|---------------|------------------------|--------------------------|--------------------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | 410 | 122 | 260 | 650 | 16 | 4.8 | 0.8 | 1.0 | 16 | 11 |
| | 21A | 380 | 148 | 210 | 730 | 13 | 3.9 | .6 | 1.8 | 10 | 7 |
| | 21B | 170 | 80 | 88 | 410 | 19 | 4.7 | 1.8 | 1.1 | 65 | 9 |
| | 22 | 250 | 74 | 130 | 340 | 10 | 10 | --- | 10 | 10 | 1 |
| | 22A | 180 | 46 | 120 | 250 | 7 | ---- | --- | ---- | ---- | 0 |
| Dike downgradient from settling ponds | G1 | 410 | 135 | 270 | 600 | 9 | 8.4 | .6 | 3.9 | 16 | 7 |
| | G2 | 820 | 239 | 430 | 1,200 | 12 | 18 | 1.1 | 2.6 | 72 | 10 |
| | G4 | 480 | 135 | 330 | 740 | 15 | 6.0 | 1.2 | 1.5 | 38 | 13 |
| | G6 | 250 | 40 | 200 | 360 | 14 | 4.4 | 1.1 | 1.1 | 22 | 11 |
| Downgradient from settling ponds | 19 | 350 | 58 | 270 | 460 | 12 | 9.1 | --- | 9.1 | 9.1 | 1 |
| | 20 | 360 | 84 | 230 | 500 | 16 | 5.2 | .6 | 3.0 | 19 | 12 |
| | 20D | 670 | 74 | 220 | 480 | 15 | 5.8 | .4 | 3.6 | 10 | 10 |
| | 20E | 560 | 230 | 290 | 970 | 10 | 6.6 | .5 | 2.9 | 11 | 8 |
| | D1 | 390 | 42 | 340 | 420 | 3 | ---- | --- | ---- | ---- | 0 |
| | D2 | 300 | 31 | 270 | 330 | 3 | ---- | --- | ---- | ---- | 0 |
| Ash fill | D4 | 53 | 11 | 41 | 62 | 3 | ---- | --- | ---- | ---- | 0 |
| | 24A | 58 | 55 | 11 | 150 | 13 | 18 | 1.3 | 5.6 | 43 | 7 |
| | 24B | 120 | 95 | 11 | 300 | 15 | 15 | .6 | 5.3 | 31 | 11 |
| | 25A | 59 | 34 | 9.6 | 120 | 10 | 16 | .7 | 5.7 | 33 | 8 |
| Background | 25B | 53 | 26 | 26 | 120 | 15 | 10 | .6 | 3.7 | 19 | 12 |
| | 23 | 72 | 38 | 20 | 120 | 11 | 8.4 | .4 | 6.3 | 13 | 3 |
| | 23A | 62 | 33 | 13 | 130 | 12 | 9.5 | .7 | 4.1 | 22 | 10 |
| Unit 3 | 106 | 66 | 6.1 | 59 | 77 | 12 | 2.8 | .9 | ND | 11 | 11 |
| | 101 | 34 | 6.7 | 26 | 45 | 8 | 11 | 1.1 | 3.2 | 24 | 6 |
| | 102 | 13 | 18 | .4 | 48 | 9 | 9.1 | 2.1 | 2.0 | 28 | 3 |
| | 105 | 31 | 21 | 8.3 | 70 | 11 | 8.7 | .4 | 4.1 | 14 | 10 |

¹Indicates statistical information calculated using nontransformed data.

Table 12.--Statistical summary of trace-element data for individual sites,
September 1976-May 1978

[All data are in micrograms per liter; samples collected and analyzed
by U.S. Geological Survey; ND, not detectable]

| Site type | Site num- ber | Aluminum | | | | | Arsenic | | | | |
|---|---------------------|----------|---------------------------------|-----------------------|-----------------------|--------------------------------|---------|---------------------------------|-----------------------|-----------------------|--------------------------------|
| | | Mean | Stand- ard devia- tion | Mini- mum value | Maxi- mum value | Number of observa- tions | Mean | Stand- ard devia- tion | Mini- mum value | Maxi- mum value | Number of observa- tions |
| Settling ponds | 21 | 500 | 4 | 20 | 3,500 | 13 | 3 | 1 | ND | 10 | 13 |
| | 21A | 1,200 | 5 | 140 | 32,000 | 10 | 4 | 1 | ND | 15 | 10 |
| | 21B | 40 | 9 | ND | 670 | 11 | 1 | 1 | ND | 9 | 11 |
| | 22 | 70 | -- | 70 | 70 | 1 | 1 | --- | 1 | 1 | 1 |
| | 22A | ----- | -- | --- | ----- | 0 | -- | --- | -- | --- | 0 |
| Dike downgradient from settling ponds | G1 | 60 | 1 | 10 | 150 | 8 | 12 | 3 | 1 | 200 | 8 |
| | G2 | 100 | <1 | 70 | 230 | 11 | 74 | 4 | 1 | 230 | 11 |
| | G4 | 400 | 1 | 100 | 2,200 | 14 | 2 | <1 | ND | 10 | 14 |
| | G6 | 20 | 4 | ND | 120 | 12 | <1 | 1 | ND | 10 | 12 |
| Downgradient from settling ponds | 19 | 30 | 2 | 10 | 60 | 2 | 1 | <1 | 1 | 2 | 2 |
| | 20 | 70 | 2 | 10 | 300 | 15 | 1 | <1 | ND | 3 | 15 |
| | 20D | 30 | 2 | ND | 110 | 12 | 1 | <1 | ND | 3 | 12 |
| | 20E | 100 | <1 | 40 | 180 | 8 | 9 | 1 | 2 | 48 | 8 |
| | D1 | ----- | -- | --- | ----- | 0 | -- | -- | -- | --- | 0 |
| | D2 | ----- | -- | --- | ----- | 0 | -- | -- | -- | --- | 0 |
| Ash fill | 24A | 220 | <1 | 160 | 340 | 8 | 2 | <1 | 1 | 3 | 8 |
| | 24B | 50 | 2 | 10 | 150 | 13 | 2 | <1 | ND | 4 | 13 |
| | 25A | 40 | <1 | 20 | 110 | 10 | 6 | <1 | 1 | 13 | 10 |
| | 25B | 30 | 2 | ND | 120 | 16 | 7 | 1 | 2 | 32 | 15 |
| Background | 23 | 30 | <1 | 20 | 90 | 5 | <1 | <1 | ND | 2 | 5 |
| | 23A | 30 | 3 | ND | 110 | 12 | 1 | <1 | ND | 2 | 12 |
| | 106 | 10 | 3 | ND | 70 | 11 | <1 | <1 | ND | 5 | 11 |
| Unit 3 | 101 | 10 | 5 | ND | 70 | 7 | 1 | <1 | ND | 3 | 7 |
| | 102 | <10 | 9 | ND | 50 | 3 | <1 | <1 | ND | 1 | 3 |
| | 105 | 40 | 5 | ND | 1,000 | 11 | 2 | 1 | ND | 8 | 11 |

Table 12.--Statistical summary of trace-element data for individual sites,
September 1976-May 1978 --Continued

| Site type | Site number | Barium ¹ | | | | | Beryllium | | | | |
|---------------------------------------|-------------|---------------------|--------------------|---------------|---------------|------------------------|-----------|--------------------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | 200 | 107 | ND | 300 | 7 | 0 | 0 | ND | ND | 3 |
| | 21A | 200 | 82 | 100 | 300 | 4 | 0 | - | ND | ND | 1 |
| | 21B | 100 | 114 | ND | 300 | 5 | 0 | 0 | ND | ND | 2 |
| | 22 | ---- | --- | --- | --- | 0 | --- | - | -- | -- | 0 |
| | 22A | ---- | --- | --- | --- | 0 | --- | - | -- | -- | 0 |
| Dike downgradient from settling ponds | G1 | 100 | 0 | 100 | 100 | 2 | --- | - | -- | -- | 0 |
| | G2 | 300 | 192 | ND | 500 | 5 | 0 | 0 | ND | ND | 3 |
| | G4 | 100 | 113 | ND | 300 | 8 | 10 | 5 | ND | 30 | 3 |
| | G6 | 100 | 110 | ND | 300 | 6 | 0 | 0 | ND | ND | 3 |
| Downgradient from settling ponds | 19 | 100 | 71 | ND | 100 | 2 | 0 | - | ND | ND | 1 |
| | 20 | 100 | 100 | ND | 300 | 9 | 0 | 0 | ND | ND | 3 |
| | 20D | 100 | 121 | ND | 300 | 6 | 0 | 0 | ND | ND | 2 |
| | 20E | 300 | 354 | ND | 500 | 2 | 0 | - | ND | ND | 1 |
| | D1 | ---- | --- | --- | --- | 0 | --- | - | -- | -- | 0 |
| | D2 | ---- | --- | --- | --- | 0 | --- | - | -- | -- | 0 |
| Ash fill | D4 | ---- | --- | --- | --- | 0 | --- | - | -- | -- | 0 |
| | 24A | <100 | 52 | ND | 100 | 6 | 0 | 0 | ND | ND | 2 |
| | 24B | 100 | 98 | ND | 200 | 7 | 0 | 0 | ND | ND | 2 |
| | 25A | 100 | 82 | ND | 200 | 6 | 0 | - | ND | ND | 1 |
| Background | 25B | 100 | 71 | ND | 200 | 9 | 0 | 0 | ND | ND | 2 |
| | 23 | <100 | 55 | ND | 100 | 5 | <10 | 4 | ND | 10 | 2 |
| | 23A | 100 | 52 | ND | 100 | 6 | 0 | 0 | ND | ND | 2 |
| | 106 | 100 | 130 | ND | 300 | 5 | 0 | 0 | ND | ND | 2 |
| Unit 3 | 101 | 100 | 117 | ND | 300 | 6 | 0 | 0 | ND | ND | 2 |
| | 102 | 100 | 70 | ND | 100 | 2 | 0 | 0 | ND | ND | 2 |
| | 105 | 100 | 134 | ND | 300 | 5 | 0 | 0 | ND | ND | 2 |

Table 12.--Statistical summary of trace-element data for individual sites,
September 1976-May 1978 --Continued

| Site type | Site number | Boron | | | | | Cadmium ¹ | | | | |
|---------------------------------------|-------------|-------|--------------------|---------------|---------------|------------------------|----------------------|--------------------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | 2,700 | 1 | 710 | 7,700 | 12 | 120 | 216 | ND | 800 | 13 |
| | 21A | 1,400 | 3 | 90 | 8,300 | 10 | 120 | 207 | 1 | 700 | 10 |
| | 21B | 790 | <1 | 330 | 2,800 | 11 | 12 | 6 | 2 | 22 | 11 |
| | 22 | 1,000 | <1 | 680 | 2,300 | 6 | 20 | --- | 20 | 20 | 1 |
| | 22A | 680 | <1 | 290 | 1,100 | 4 | --- | --- | -- | --- | 0 |
| Dike downgradient from settling ponds | G1 | 2,800 | <1 | 1,300 | 4,400 | 8 | 0 | 0 | ND | ND | 8 |
| | G2 | 2,900 | 1 | 770 | 8,500 | 10 | <1 | <1 | ND | 1 | 11 |
| | G4 | 3,400 | <1 | 870 | 8,800 | 13 | 52 | 76 | 1 | 250 | 14 |
| | G6 | 1,000 | 1 | 260 | 4,800 | 11 | 0 | 0 | ND | ND | 12 |
| Downgradient from settling ponds | 19 | 2,200 | 1 | 330 | 4,700 | 8 | 0 | 0 | ND | ND | 2 |
| | 20 | 2,600 | <1 | 1,000 | 5,100 | 14 | 4 | 5 | ND | 15 | 15 |
| | 20D | 2,900 | <1 | 780 | 4,800 | 12 | <1 | <1 | ND | 1 | 12 |
| | 20E | 2,300 | 3 | 210 | 12,000 | 8 | 1 | 2 | ND | 4 | 8 |
| | D1 | 2,900 | -- | 2,900 | 2,900 | 1 | --- | --- | -- | --- | 0 |
| | D2 | 2,700 | -- | 2,700 | 2,700 | 1 | --- | --- | -- | --- | 0 |
| | D4 | 150 | -- | 150 | 150 | 1 | --- | --- | -- | --- | 0 |
| Ash fill | 24A | 840 | 2 | 80 | 2,800 | 11 | <1 | <1 | ND | 1 | 8 |
| | 24B | 940 | <1 | 360 | 2,300 | 13 | <1 | 2 | ND | 7 | 13 |
| | 25A | 1,600 | <1 | 830 | 2,900 | 9 | <1 | <1 | ND | 2 | 10 |
| | 25B | 1,400 | <1 | 420 | 2,300 | 15 | 0 | 0 | ND | ND | 15 |
| Background | 23 | 260 | 1 | 90 | 760 | 6 | <1 | <1 | ND | 1 | 5 |
| | 23A | 430 | 1 | 70 | 750 | 11 | 0 | 0 | ND | ND | 12 |
| | 106 | 100 | 2 | 30 | 840 | 11 | 21 | 67 | ND | 220 | 11 |
| Unit 3 | 101 | 310 | 2 | 30 | 490 | 8 | 0 | 0 | ND | ND | 7 |
| | 102 | 260 | <1 | 150 | 440 | 5 | 0 | 0 | ND | ND | 3 |
| | 105 | 370 | <1 | 160 | 830 | 11 | 0 | 0 | ND | ND | 11 |

Table 12.--Statistical summary of trace-element data for individual sites,
September 1976-May 1978 --Continued

| Site type | Site number | Chromium | | | | | Cobalt ¹ | | | | |
|---------------------------------------|-------------|----------|--------------------|---------------|---------------|------------------------|---------------------|--------------------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | 4 | 3 | ND | 10 | 3 | 14 | 10 | 7 | 21 | 2 |
| | 21A | 20 | -- | 18 | 18 | 1 | 18 | -- | 18 | 18 | 1 |
| | 21B | 0 | 0 | ND | ND | 2 | 5 | -- | 5 | 5 | 1 |
| | 22 | -- | -- | -- | -- | 0 | -- | -- | -- | -- | 0 |
| | 22A | -- | -- | -- | -- | 0 | -- | -- | -- | -- | 0 |
| Dike downgradient from settling ponds | G1 | -- | -- | -- | -- | 0 | -- | -- | -- | -- | 0 |
| | G2 | 2 | 2 | ND | 10 | 3 | 0 | 0 | ND | ND | 2 |
| | G4 | 1 | 3 | ND | 10 | 3 | 9 | 5 | 5 | 12 | 2 |
| | G6 | 2 | 2 | ND | 10 | 3 | <1 | <1 | ND | 1 | 2 |
| Downgradient from settling ponds | 19 | 2 | -- | 2 | 2 | 1 | -- | -- | -- | -- | 0 |
| | 20 | 1 | 3 | ND | 10 | 3 | 9 | 1 | 8 | 10 | 2 |
| | 20D | 0 | 0 | ND | ND | 2 | 0 | -- | ND | ND | 1 |
| | 20E | 0 | -- | ND | ND | 1 | -- | -- | -- | -- | 0 |
| | D1 | -- | -- | -- | -- | 0 | -- | -- | -- | -- | 0 |
| | D2 | -- | -- | -- | -- | 0 | -- | -- | -- | -- | 0 |
| Ash fill | D4 | -- | -- | -- | -- | 0 | -- | -- | -- | -- | 0 |
| | 24A | <1 | 1 | ND | 2 | 2 | 0 | -- | ND | ND | 1 |
| | 24B | <1 | <1 | ND | 1 | 2 | 0 | -- | ND | ND | 1 |
| | 25A | 10 | -- | 10 | 10 | 1 | 0 | -- | ND | ND | 1 |
| Background | 25B | 0 | 0 | ND | ND | 2 | 0 | -- | ND | ND | 1 |
| | 23 | 2 | 5 | ND | 10 | 2 | 1 | -- | 1 | 1 | 1 |
| | 23A | 0 | 0 | ND | ND | 2 | 0 | -- | ND | ND | 1 |
| Unit 3 | 106 | 0 | 0 | ND | ND | 2 | 0 | -- | ND | ND | 1 |
| | 101 | <1 | <1 | ND | 1 | 2 | 0 | -- | ND | ND | 1 |
| | 102 | 0 | 0 | ND | ND | 2 | 0 | -- | ND | ND | 1 |
| | 105 | <1 | <1 | ND | 1 | 2 | 0 | -- | ND | ND | 1 |

Table 12.--Statistical summary of trace-element data for individual sites,
September 1976-May 1978 --Continued

| Site type | Site number | Copper | | | | | Iron | | | | |
|---------------------------------------|-------------|--------|--------------------|---------------|---------------|------------------------|-------|--------------------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | 53 | 9 | ND | 310 | 9 | 340 | 10 | ND | 11,000 | 16 |
| | 21A | 100 | 7 | ND | 310 | 7 | 430 | 8 | 10 | 14,000 | 13 |
| | 21B | 21 | 3 | 2 | 120 | 8 | 210 | 20 | 10 | 47,000 | 13 |
| | 22 | 16 | -- | 16 | 16 | 1 | 220 | 10 | 20 | 27,000 | 10 |
| | 22A | --- | -- | -- | --- | 0 | 70 | 11 | 10 | 11,000 | 7 |
| Dike downgradient from settling ponds | G1 | <1 | <1 | ND | 1 | 6 | 560 | 2 | 200 | 2,800 | 9 |
| | G2 | 1 | 1 | ND | 8 | 9 | 840 | <1 | 360 | 1,600 | 12 |
| | G4 | <1 | 2 | ND | 21 | 9 | 1,400 | 5 | 70 | 14,000 | 15 |
| | G6 | <1 | <1 | ND | 1 | 9 | 180 | 2 | 30 | 680 | 14 |
| Downgradient from settling ponds | 19 | 0 | -- | ND | 0 | 1 | 120 | 2 | 20 | 2,200 | 12 |
| | 20 | 1 | 1 | ND | 5 | 9 | 340 | 2 | 70 | 1,500 | 16 |
| | 20D | <1 | <1 | ND | 1 | 8 | 110 | 3 | 10 | 2,900 | 14 |
| | 20E | <1 | <1 | ND | 3 | 7 | 900 | 2 | 130 | 4,600 | 10 |
| | D1 | --- | -- | -- | --- | 0 | 20 | 1 | 10 | 50 | 3 |
| | D2 | --- | -- | -- | --- | 0 | 180 | 3 | 40 | 430 | 3 |
| | D4 | --- | -- | -- | --- | 0 | 2,000 | <1 | 1,800 | 2,500 | 3 |
| Ash fill | 24A | 4 | <1 | 3 | 8 | 3 | 2,500 | <1 | 740 | 5,700 | 13 |
| | 24B | 2 | 2 | ND | 18 | 8 | 610 | 1 | 140 | 3,800 | 15 |
| | 25A | 1 | 1 | ND | 4 | 5 | 960 | 2 | 100 | 4,100 | 10 |
| | 25B | <1 | <1 | ND | 3 | 8 | 180 | 3 | 40 | 2,600 | 15 |
| Background | 23 | 0 | 0 | ND | ND | 2 | 320 | 2 | 40 | 1,300 | 11 |
| | 23A | <1 | <1 | ND | 2 | 8 | 190 | 3 | 40 | 2,700 | 12 |
| | 106 | 1 | <1 | ND | 2 | 8 | 10 | 4 | ND | 150 | 12 |
| Unit 3 | 101 | <1 | <1 | ND | 1 | 3 | 350 | 4 | 20 | 2,000 | 8 |
| | 102 | <1 | <1 | ND | 1 | 3 | 70 | 2 | 10 | 450 | 9 |
| | 105 | 2 | 2 | ND | 17 | 8 | 100 | 3 | 10 | 610 | 11 |

Table 12.--Statistical summary of trace-element data for individual sites,
September 1976-May 1978 --Continued

| Site type | Site number | Lead | | | | | Manganese | | | | |
|---------------------------------------|-------------|------|--------------------|---------------|---------------|------------------------|-----------|--------------------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | 7 | 4 | ND | 74 | 7 | 170 | 1 | 30 | 370 | 16 |
| | 21A | 15 | 4 | ND | 200 | 10 | 180 | <1 | 40 | 410 | 13 |
| | 21B | 2 | 3 | ND | 28 | 11 | 110 | <1 | 40 | 290 | 13 |
| | 22 | 8 | -- | 8 | 8 | 1 | 170 | <1 | 90 | 220 | 10 |
| | 22A | -- | -- | -- | --- | 0 | 78 | 2 | 10 | 250 | 7 |
| Dike downgradient from settling ponds | G1 | <1 | <1 | ND | 5 | 8 | 110 | 1 | 40 | 380 | 9 |
| | G2 | <1 | 1 | ND | 5 | 11 | 130 | 1 | 40 | 410 | 12 |
| | G4 | 2 | 3 | ND | 63 | 14 | 290 | <1 | 180 | 560 | 15 |
| | G6 | 1 | 1 | ND | 6 | 12 | 170 | 2 | 20 | 770 | 14 |
| Downgradient from settling ponds | 19 | 1 | 3 | ND | 5 | 2 | 140 | 5 | 10 | 1,900 | 12 |
| | 20 | 1 | 1 | ND | 10 | 15 | 440 | <1 | 200 | 2,000 | 16 |
| | 20D | 1 | 1 | ND | 8 | 12 | 210 | 8 | 10 | 2,900 | 14 |
| | 20E | 1 | 1 | ND | 8 | 7 | 280 | <1 | 90 | 570 | 10 |
| | D1 | -- | -- | -- | --- | 0 | 1,800 | 1 | 1,100 | 3,900 | 3 |
| | D2 | -- | -- | -- | --- | 0 | 260 | 4 | 90 | 1,500 | 3 |
| | D4 | -- | -- | -- | --- | 0 | 82 | <1 | 70 | 100 | 3 |
| Ash fill | 24A | 2 | 1 | ND | 8 | 8 | 400 | <1 | 200 | 1,200 | 13 |
| | 24B | <1 | 1 | ND | 6 | 13 | 150 | 3 | 20 | 2,100 | 15 |
| | 25A | 1 | 2 | ND | 8 | 10 | 640 | <1 | 310 | 1,400 | 10 |
| | 25B | <1 | 1 | ND | 7 | 15 | 110 | 4 | 10 | 1,200 | 15 |
| Background | 23 | 1 | 1 | ND | 7 | 5 | 130 | 1 | 20 | 630 | 12 |
| | 23A | 1 | 1 | ND | 5 | 12 | 74 | 4 | 10 | 1,500 | 12 |
| | 106 | 1 | 1 | ND | 7 | 17 | 7 | 2 | ND | 20 | 12 |
| Unit 3 | 101 | <1 | 1 | ND | 6 | 7 | 52 | 1 | 10 | 90 | 8 |
| | 102 | 0 | 0 | ND | ND | 3 | 49 | <1 | 20 | 100 | 9 |
| | 105 | 2 | 2 | ND | 12 | 11 | 220 | <1 | 100 | 460 | 11 |

Table 12.--Statistical summary of trace-element data for individual sites,
September 1976-May 1978 --Continued

| Site type | Site number | Mercury | | | | | Molybdenum | | | | |
|---------------------------------------|-------------|---------|--------------------|---------------|---------------|------------------------|------------|--------------------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | <0.5 | 0.3 | ND | 0.5 | 3 | 29 | 6 | 1 | 1,600 | 13 |
| | 21A | 0 | --- | ND | ND | 1 | 18 | 3 | 2 | 87 | 10 |
| | 21B | 0 | 0 | ND | ND | 2 | 10 | 2 | ND | 75 | 11 |
| | 22 | ---- | --- | --- | --- | 0 | 17 | -- | 17 | 17 | 1 |
| | 22A | ---- | --- | --- | --- | 0 | --- | -- | -- | ----- | 0 |
| Dike downgradient from settling ponds | G1 | ---- | --- | --- | --- | 0 | 100 | 5 | 2 | 1,000 | 8 |
| | G2 | .5 | .2 | .2 | .6 | 3 | 54 | 5 | 4 | 1,700 | 11 |
| | G4 | <.5 | .3 | ND | .5 | 3 | 28 | 6 | 2 | 1,200 | 14 |
| | G6 | <.5 | .3 | ND | .5 | 3 | 3 | <1 | 1 | 16 | 12 |
| | | | | | | | | | | | |
| Downgradient from settling ponds | 19 | 0 | --- | ND | ND | 1 | 120 | <1 | 10 | 120 | 2 |
| | 20 | <.5 | .3 | ND | .5 | 3 | 55 | 3 | 4 | 390 | 15 |
| | 20D | 0 | 0 | ND | ND | 2 | 150 | <1 | 70 | 400 | 12 |
| | 20E | <.5 | --- | <.5 | <.5 | 1 | 250 | 2 | 40 | 1,100 | 8 |
| | D1 | 0 | 0 | ND | ND | - | --- | -- | -- | ----- | 0 |
| | D2 | 0 | 0 | ND | ND | - | --- | -- | -- | ----- | 0 |
| | D4 | 0 | 0 | ND | ND | - | --- | -- | -- | ----- | 0 |
| Ash fill | 24A | <.5 | .1 | ND | <.5 | 2 | 2 | 2 | ND | 20 | 8 |
| | 24B | 0 | 0 | ND | ND | 2 | 12 | 2 | ND | 70 | 13 |
| | 25A | .5 | --- | .5 | .5 | 1 | 9 | 2 | ND | 29 | 10 |
| | 25B | 0 | 0 | ND | ND | 2 | 110 | 2 | 10 | 800 | 15 |
| Background | 23 | <.5 | .3 | ND | .5 | 2 | <1 | <1 | ND | 2 | 5 |
| | 23A | <.5 | .1 | ND | <.5 | 2 | 2 | 2 | ND | 19 | 12 |
| | 106 | 0 | 0 | ND | ND | 2 | 2 | 2 | ND | 23 | 11 |
| Unit 3 | 101 | 0 | 0 | ND | ND | 2 | 5 | 2 | ND | 24 | 7 |
| | 102 | 0 | 0 | ND | ND | 2 | 6 | 2 | 2 | 22 | 3 |
| | 105 | 0 | 0 | ND | ND | 2 | 12 | 1 | 2 | 44 | 11 |

Table 12.--Statistical summary of trace-element data for individual sites,
September 1976-May 1978 --Continued

| Site type | Site number | Nickel | | | | | Selenium | | | | |
|---------------------------------------|-------------|--------|--------------------|---------------|---------------|------------------------|----------|--------------------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | 85 | <1 | 29 | 170 | 13 | 0 | 0 | ND | ND | 2 |
| | 21A | 90 | <1 | 21 | 200 | 10 | 0 | - | ND | ND | 1 |
| | 21B | 40 | 1 | 13 | 250 | 11 | 0 | - | ND | ND | 1 |
| | 22 | 44 | -- | 44 | 44 | 1 | - | - | -- | -- | 0 |
| | 22A | -- | -- | -- | --- | 0 | - | - | -- | -- | 0 |
| Dike downgradient from settling ponds | G1 | 3 | 2 | ND | 10 | 8 | - | - | -- | -- | 0 |
| | G2 | 3 | 1 | ND | 8 | 11 | 0 | 0 | ND | ND | 2 |
| | G4 | 37 | 2 | 4 | 250 | 14 | 0 | 0 | ND | ND | 2 |
| | G6 | 3 | 2 | ND | 19 | 12 | 0 | 0 | ND | ND | 2 |
| Downgradient from settling ponds | 19 | 4 | <1 | 2 | 6 | 2 | - | - | -- | -- | 0 |
| | 20 | 23 | <1 | 7 | 55 | 15 | 0 | 0 | ND | ND | 2 |
| | 20D | 10 | 2 | 2 | 40 | 12 | 0 | - | ND | ND | 1 |
| | 20E | 16 | 1 | 3 | 36 | 8 | - | - | -- | -- | 0 |
| | D1 | -- | -- | -- | --- | 0 | - | - | -- | -- | 0 |
| | D2 | -- | -- | -- | --- | 0 | - | - | -- | -- | 0 |
| | D4 | -- | -- | -- | --- | 0 | - | - | -- | -- | 0 |
| Ash fill | 24A | 3 | 2 | ND | 14 | 8 | 0 | - | ND | ND | 1 |
| | 24B | 6 | 1 | ND | 16 | 13 | 0 | - | ND | ND | 1 |
| | 25A | 2 | 2 | ND | 12 | 10 | 0 | - | ND | ND | 1 |
| | 25B | 2 | 1 | ND | 12 | 15 | 0 | - | ND | ND | 1 |
| Background | 23 | 3 | 2 | ND | 10 | 5 | 5 | - | 5 | 5 | 1 |
| | 23A | 2 | 1 | ND | 7 | 12 | 0 | - | ND | ND | 1 |
| | 106 | 2 | 1 | ND | 10 | 11 | 0 | - | ND | ND | 1 |
| Unit 3 | 101 | 3 | 1 | ND | 10 | 7 | 0 | - | ND | ND | 1 |
| | 102 | 4 | <1 | 3 | 6 | 3 | 0 | - | ND | ND | 1 |
| | 105 | 2 | 2 | ND | 14 | 11 | 0 | - | ND | ND | 1 |

Table 12.--Statistical summary of trace-element data for individual sites,
September 1976-May 1978 --Continued

| Site type | Site number | Strontium | | | | | Zinc | | | | |
|---------------------------------------|-------------|-----------|--------------------|---------------|---------------|------------------------|------|--------------------|---------------|---------------|------------------------|
| | | Mean | Standard deviation | Minimum value | Maximum value | Number of observations | Mean | Standard deviation | Minimum value | Maximum value | Number of observations |
| Settling ponds | 21 | 420 | <1 | 260 | 740 | 13 | 580 | 2 | 60 | 1,600 | 13 |
| | 21A | 390 | <1 | 220 | 730 | 10 | 870 | <1 | 490 | 1,800 | 10 |
| | 21B | 220 | <1 | 130 | 310 | 11 | 190 | 2 | 30 | 710 | 11 |
| | 22 | 380 | -- | 380 | 380 | 1 | 410 | --- | 410 | 410 | 1 |
| | 22A | ----- | -- | ---- | ----- | 0 | --- | --- | --- | ----- | 0 |
| Dike downgradient from settling ponds | G1 | 240 | <1 | 150 | 590 | 8 | <10 | 4 | ND | 30 | 8 |
| | G2 | 740 | <1 | 450 | 1,200 | 11 | 20 | 2 | ND | 70 | 11 |
| | G4 | 450 | <1 | 280 | 780 | 14 | 620 | 3 | 10 | 2,300 | 14 |
| | G6 | 240 | <1 | 190 | 330 | 12 | 20 | 3 | ND | 190 | 12 |
| | | | | | | | | | | | |
| Downgradient from settling ponds | 19 | 440 | <1 | 390 | 500 | 2 | <10 | 5 | ND | 10 | 2 |
| | 20 | 360 | <1 | 190 | 530 | 15 | 70 | 2 | 20 | 570 | 15 |
| | 20D | 400 | <1 | 330 | 530 | 12 | 20 | 2 | ND | 120 | 12 |
| | 20E | 530 | <1 | 280 | 880 | 8 | 40 | 2 | 10 | 220 | 8 |
| | D1 | ----- | -- | ---- | ----- | 0 | --- | --- | --- | ----- | 0 |
| | D2 | ----- | -- | ---- | ----- | 0 | --- | --- | --- | ----- | 0 |
| | D4 | ----- | -- | ---- | ----- | 0 | --- | --- | --- | ----- | 0 |
| Ash fill | 24A | 89 | 2 | 10 | 200 | 8 | 20 | 8 | ND | 280 | 8 |
| | 24B | 180 | <1 | 100 | 310 | 13 | 10 | 3 | ND | 70 | 13 |
| | 25A | 430 | <1 | 320 | 530 | 10 | 10 | 2 | ND | 30 | 10 |
| | 25B | 400 | <1 | 290 | 510 | 15 | <10 | 3 | ND | 40 | 15 |
| Background | 23 | 130 | <1 | 90 | 170 | 5 | 10 | 4 | ND | 40 | 5 |
| | 23A | 130 | <1 | 80 | 220 | 12 | <10 | 3 | ND | 20 | 12 |
| | 106 | 110 | <1 | 80 | 190 | 11 | 30 | 3 | ND | 170 | 11 |
| Unit 3 | 101 | 1,300 | <1 | 200 | 1,400 | 8 | <10 | 2 | ND | 20 | 7 |
| | 102 | 180 | <1 | 130 | 220 | 3 | <10 | 3 | ND | 10 | 3 |
| | 105 | 660 | <1 | 350 | 1,000 | 11 | 10 | 3 | ND | 60 | 11 |

¹Indicates statistical information calculated using nontransformed data.