WATER-QUALITY ASSESSMENT OF THE INDIANA DUNES NATIONAL LAKESHORE, 1973-74

Prepared for the National Park Service

U.S. GEOLOGICAL SURVEY
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1975

UNITED STATES DEPARTMENT OF THE INTERIOR

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WATER-QUALITY ASSESSMENT OF THE INDIANA DUNES NATIONAL LAKESHORE, 1973-74

By Leslie D. Arihood

ABSTRACT

The Indiana Dunes National Lakeshore is underlain by unconsolidated lake and glacial deposits which have been divided into three units. Unit 1 is comprised mostly of sand and, in the western part of the National Lakeshore, is capable of yielding more than 500 gallons per minute (32 litres per second) to properly constructed wells. Unit 2, a silt till below unit 1, has little potential as a source of water for public supplies within the National Lakeshore area. Unit 4, a clay till under unit 2, is capable of yielding from 10 to 65 gallons per minute (0.6 to 4 litres per second) throughout the National Lakeshore.

Precipitation samples collected at the National Lakeshore had average inorganic ion concentrations ranging from 0 to 7.0 milligrams per litre. Streams in the National Lakeshore generally had a specific conductance ranging from 300 to 600 micromhos, a pH ranging from 6.5 to 8.1, and a dissolved oxygen concentration near saturation (7.7 to 12.9 milligrams per litre). The bogs and marshlands generally contained water with a specific conductance ranging from 40 to 150 micromhos, a pH ranging from 5.0 to 6.5, and dissolved oxygen ranging from 0.2 to 4.0 milligrams per litre. Most surface waters tended to have calcium and bicarbonate as the dominant ion pair. Exceptions include some inter-dunal ponds and certain watercourses and areas of Pinhook Bog. Ground-water chemical quality varied with depth and location but not with time during a 6-month interval. Ground water was usually a calcium magnesium bicarbonate type and moderately to very hard (71 to 390 milligrams per litre).

INTRODUCTION

Purpose and Scope

The area between the Indiana cities of Gary and Michigan City (fig. 1) is being rapidly developed into urban and suburban communities supported by nearby industrial complexes. Part of this area is being preserved by the National Park Service, which has begun acquiring land for the Indiana Dunes National Lakeshore. As part of developing the National Lakeshore, the Park Service requested the U.S. Geological Survey to make a water-quality assessment of the area. Sampling for this assessment began July 1973 and ended April 1974. The Park Service also requested a discussion of the area's geohydrology and potential ground-water supplies.

The water-quality assessment includes an analysis of the chemical, organic, and bacteriological quality of ground and surface water and the chemical quality of precipitation. Water-quality sampling was done quarterly and included approximately 78 sampling points (fig. 2).

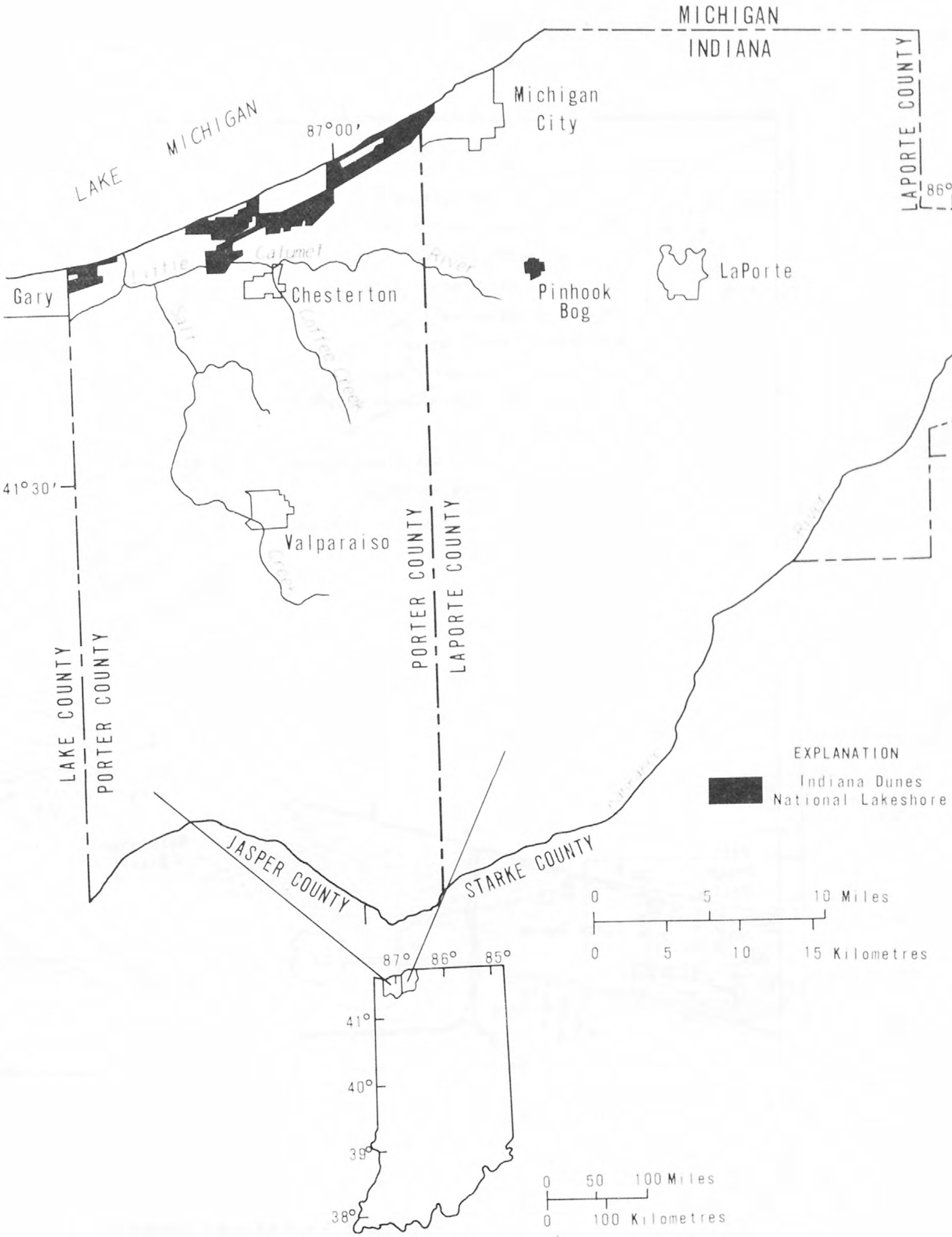


Figure 1.-- Location of study area

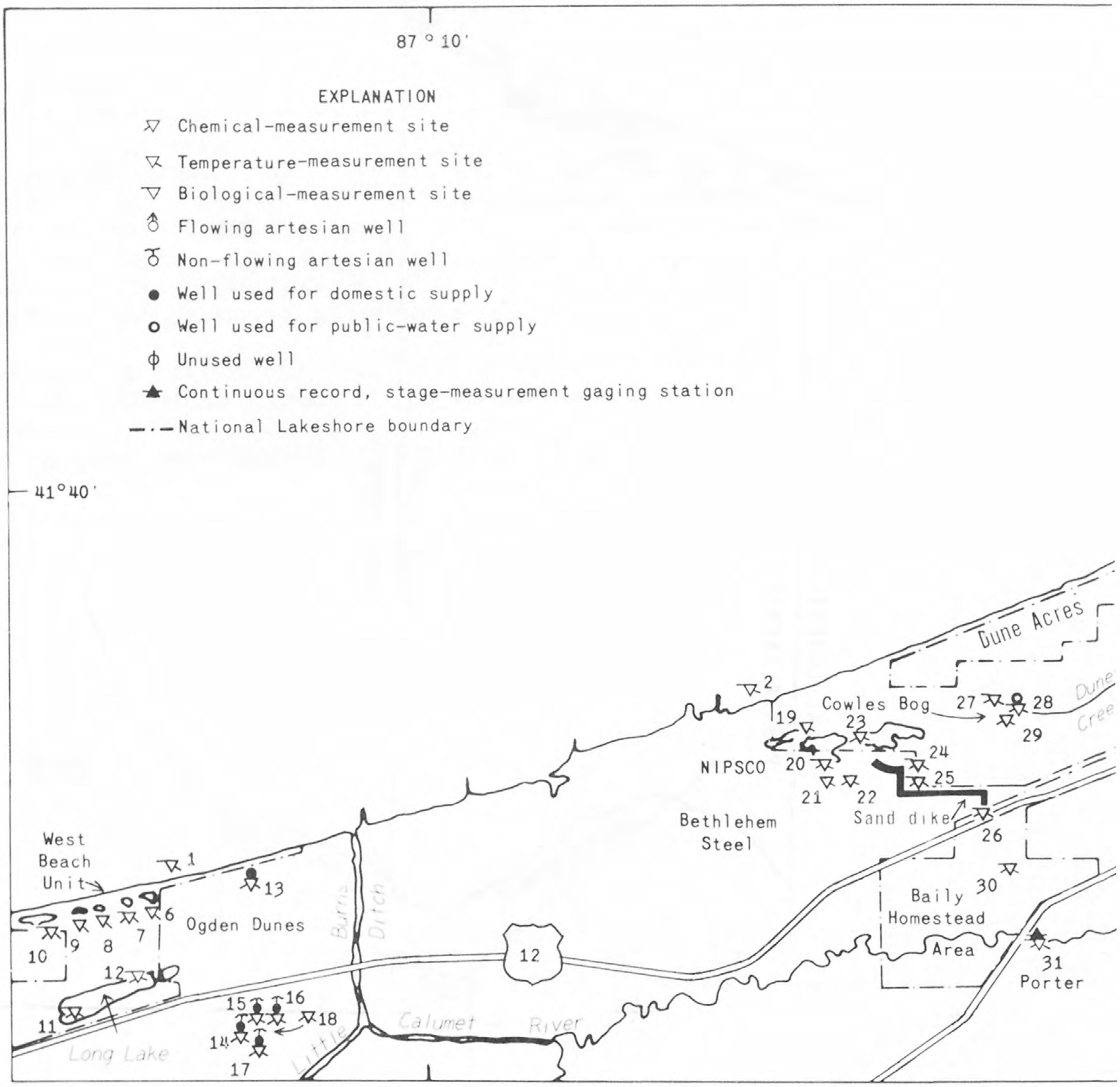
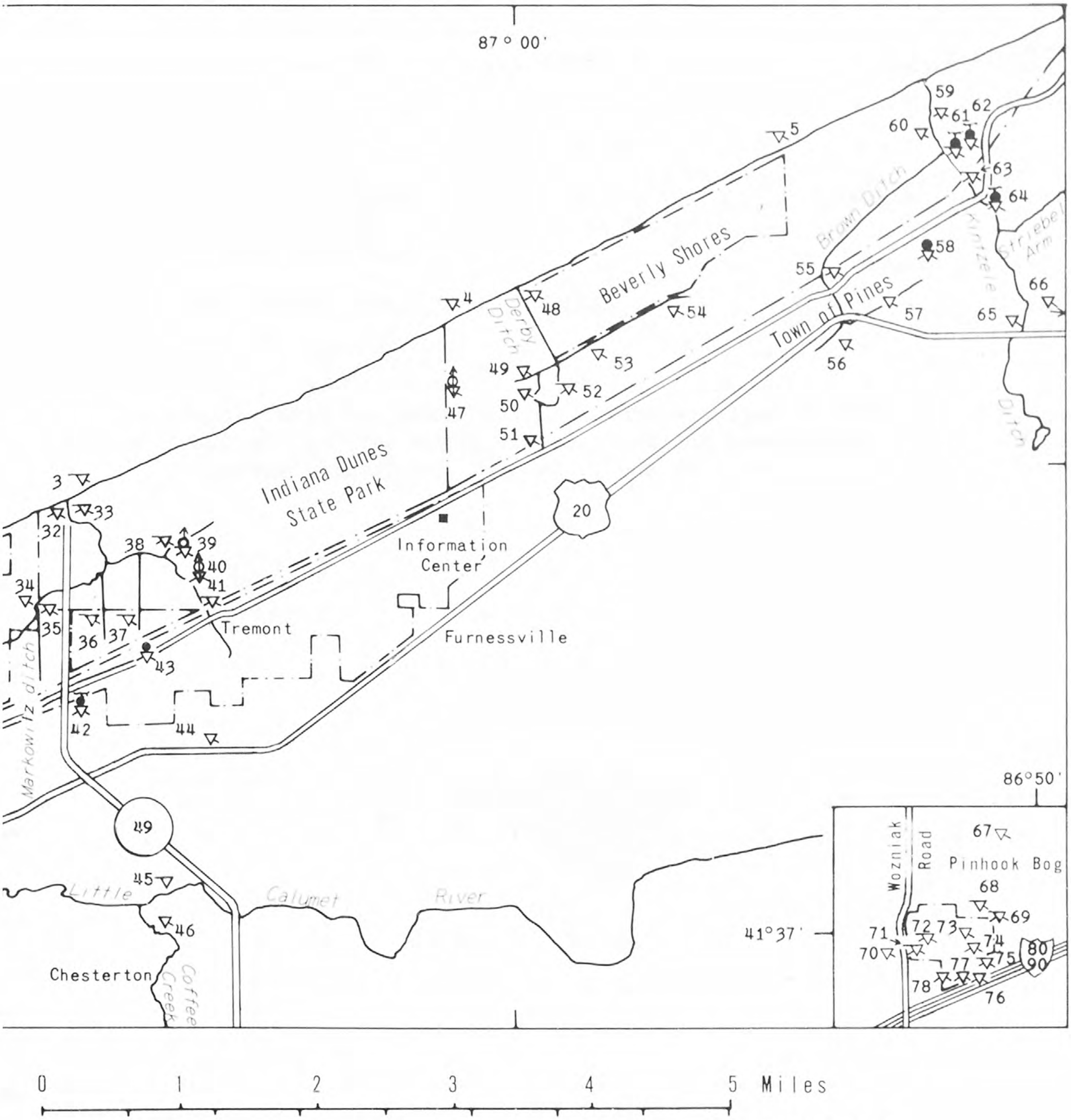


Figure 2.-- Indiana Dunes



National Lakeshore sampling sites

The following table can be used to convert report data from English to metric units:

English unit	Multiplied by	To obtain metric unit
inches	25.4	millimetres (mm)
feet	.3048	metres
gallons per minute (gal/min)	.06308	litres per second (l/s)
cubic feet per second (ft^3/s)	.02832	cubic metres per second (m^3/s)

Although the conversion factors are shown to as many as five significant figures, the metric equivalents in the text are shown only to the number of significant figures consistent with the values for the English units.

Acknowledgments

The author is especially grateful to the personnel of the Indiana Dunes National Lakeshore for their assistance in the project field work. The information from J. R. Hill and E. J. Hartke, of the Indiana Geological Survey, on water levels and geology of the area was valuable in preparing the report.

Appreciation is expressed to the Northern Indiana Public Service Company and the Indiana Dunes State Park management for permission to enter and sample water in their area. Prof. J. E. Newman's data on precipitation quality, and Mr. E. C. Moore's cooperation in field data collection were also helpful.

GEOHYDROLOGY

General Aspects

The study area is underlain by three unconsolidated rock groups originating from glacial action and lake sedimentation. Bedrock underlying these deposits consist of shale and limestone. All these formations are sources of water; however, the quantity of water available and the quality vary among them. The unconsolidated rocks were divided into units 1, 2, and 4 by Rosenshein (1962a), consisting respectively of sand, silt till, and clay till. Unit 3 of Rosenshein's description does not extend under the National Lakeshore area. Figure 3 shows the surficial geology and geologic sections of the area. The following unit descriptions are mostly a summary of the geohydrologic properties reported by Rosenshein and Hunn (1968).

Unit 1

Unit 1 is sand interbedded with gravel, silt, or clay. Water-table conditions usually exist within the unit. Recharge to the unit is from local precipitation. Ditching of wetland, which straightened and deepened stream channels, has increased the natural stream discharge by increasing ground-water gradients along and near the streams. Storm sewers, roads, and parking lots prevent infiltration of local precipitation and reduce natural recharge. As a result, the upper part of unit 1 has been dewatered in places and some marshes have been drained (Rosenshein and Hunn, 1968, p. 16). Natural discharge from the unit is into ponds, watercourses, and Lake Michigan, and by evapotranspiration. During the growing season, evapotranspiration constitutes the major part of the discharge (Rosenshein and Hunn, 1968, p. 16).

Few data were available to define a potentiometric surface for unit 1 except at the West Beach Unit. There, the data indicate the potentiometric surface to be from approximately 580 to 585 feet (177 to 178 metres) above sea level.

Unit 1 is the second most utilized aquifer in the area. Saturated thickness varies from about 10 feet (3 metres) at the Lake Michigan shoreline to about 90 feet (27 metres) around the West Beach Unit, and well depths range from about 20 to 50 feet (6 to 15 metres) except in areas of sand dunes, where they are greater. Potential yields to properly constructed wells range from less than 40 gal/min (2.5 l/s) in areas such as around Beverly Shores to more than 500 gal/min (32 l/s) at the West Beach Unit. A more detailed description of the ground-water potential of unit 1 is given by Rosenshein and Hunn (1968, fig. 4).

Unit 2

Unit 2 is chiefly a silt till with discontinuous zones of sand and gravel. The unit is used locally for farm and domestic supplies requiring yields of about 10 gal/min (0.63 l/s). Wells in unit 2 are usually from 40 to 70 feet (12 to 21 metres) deep. Because of the low hydraulic conductivity of unit 2 and its limited areal extent within the National Lakeshore, this unit is least used in the area as a water-supply source.

Unit 4

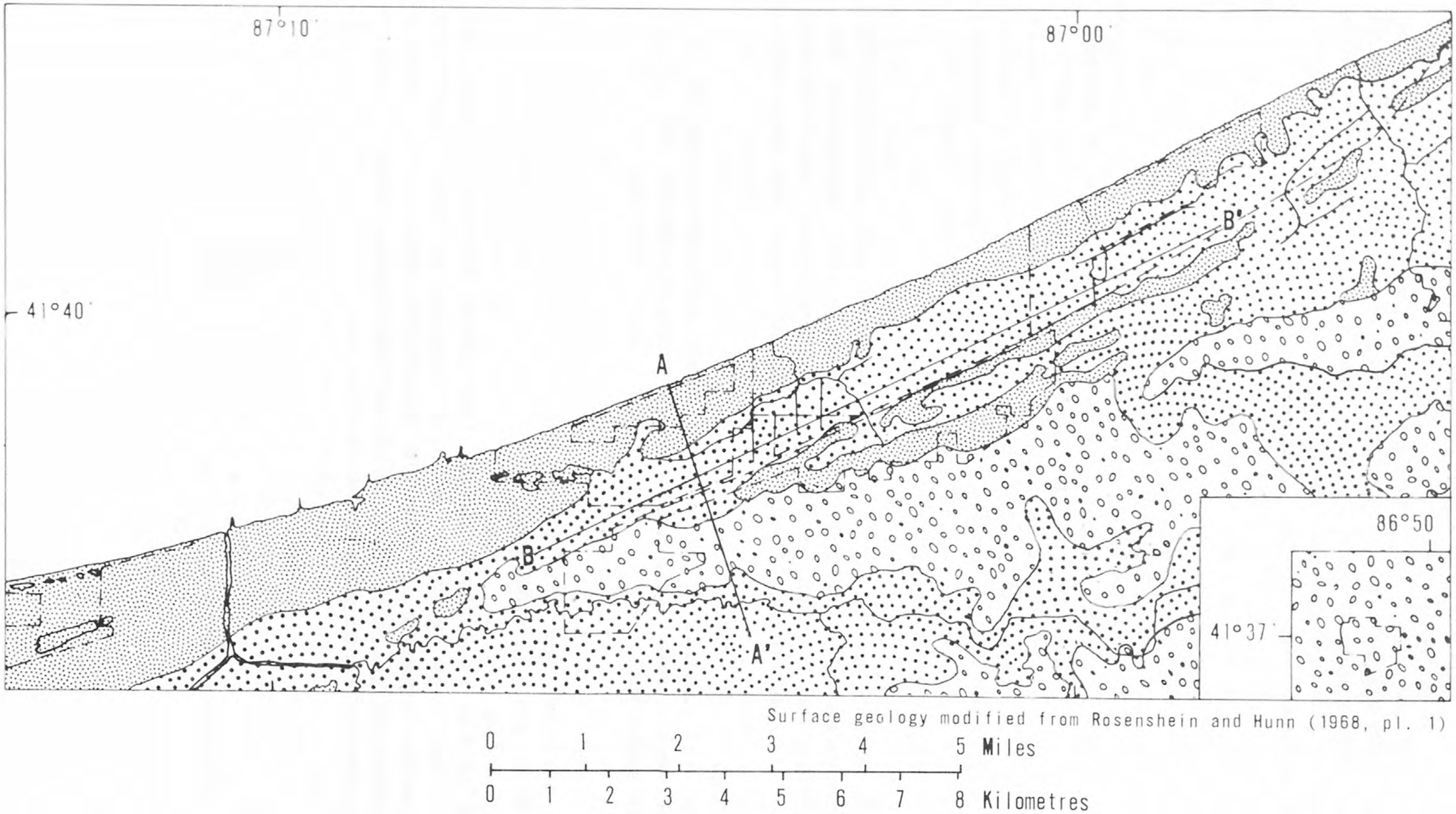
Unit 4 is a clay till with discontinuous zones of sand and gravel. Within the National Lakeshore these sand and gravel zones may be as much as 45 feet (14 metres) thick and yield as much as 65 gal/min (4 l/s). Wells tapping unit 4 range from about 40 to 100 feet (12 to 30 metres) in depth. In general, ground-water supplies for National Lakeshore purposes probably could be developed from this unit except possibly at the West Beach Unit. Data on unit 4 at the West Beach Unit are not available.

Recharge to the sand and gravel aquifers of unit 4 is limited by the low vertical hydraulic conductivity of the overlying till, which restricts the percolation of precipitation into the unit. Some recharge may come from the underlying bedrock. Discharge is mainly into Lake Michigan and the units overlying unit 4.

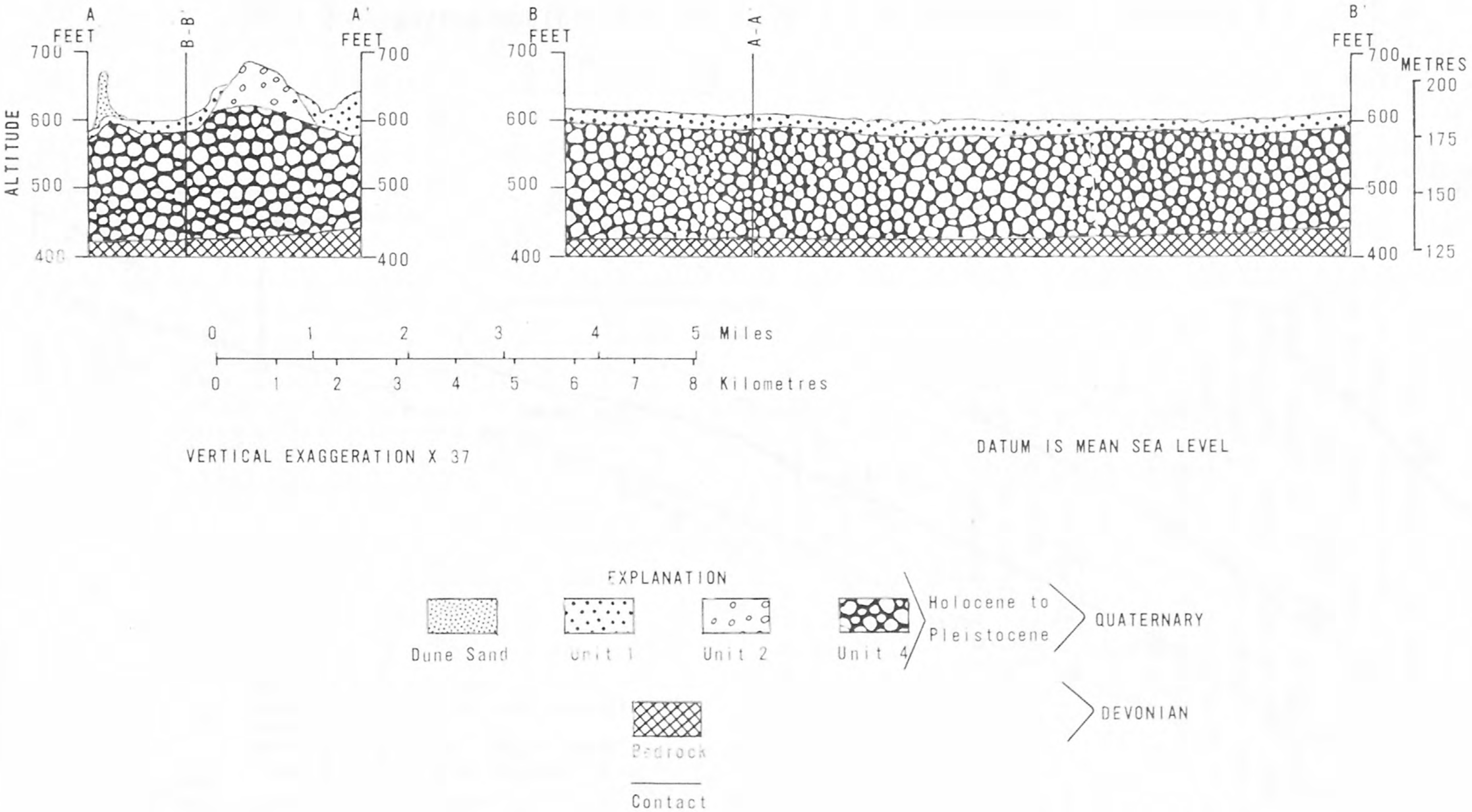
Wells within unit 4 usually provide water under artesian pressure, and in some areas the wells flow. Figure 4 shows the altitude of the potentiometric surface for unit 4.

Bedrock

Depth to bedrock in the study area ranges from about 150 to 250 feet (46 to 76 metres) below the land surface. Bedrock consists of shale underlain by dolomite and dolomitic limestone, all of Devonian age. The bedrock aquifers yield less than 10 gal/min (0.63 l/s) and are not generally used as a source of water in the National Lakeshore area.

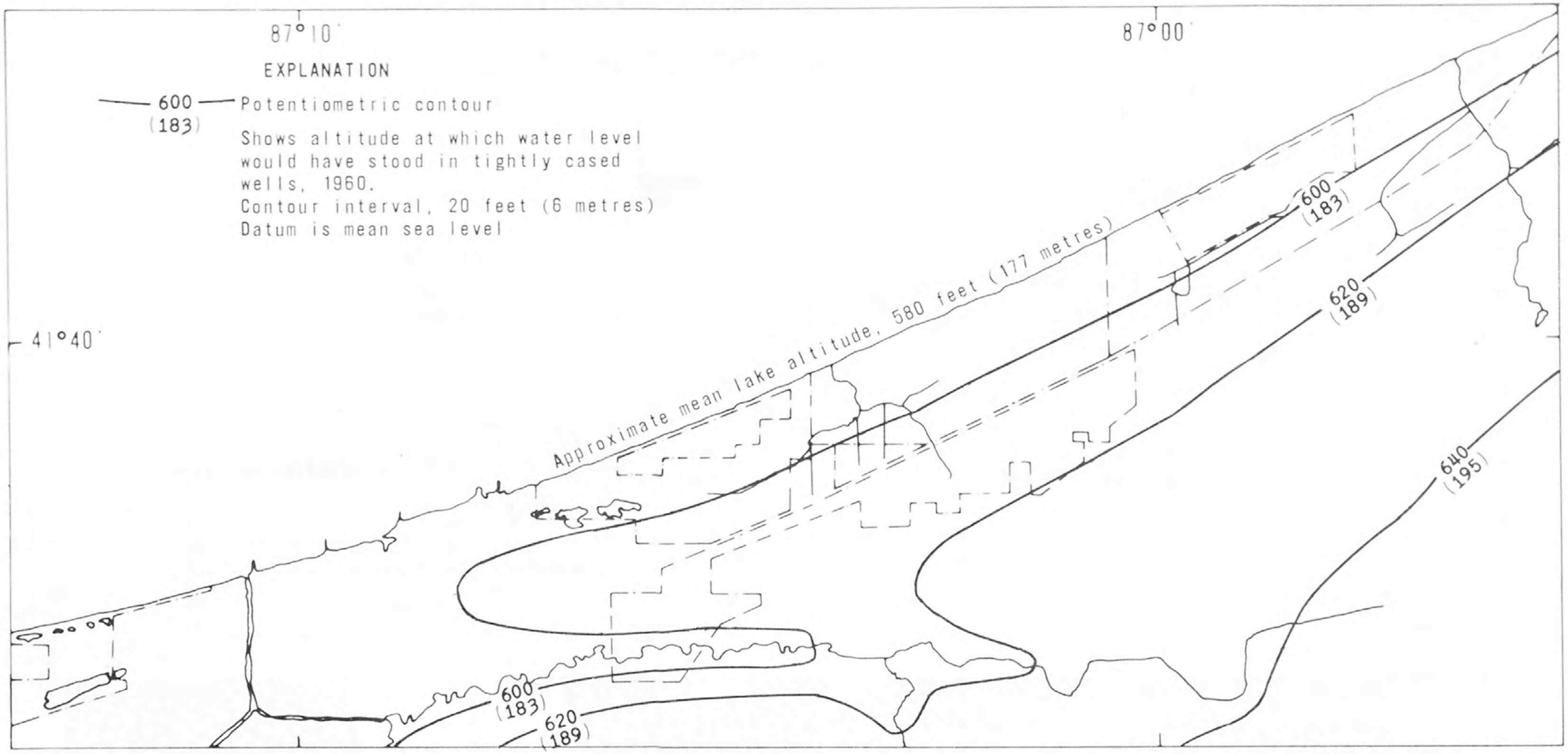


a. Surface geology



b. Generalized geologic sections

Figure 3.-- Geology



Contours from Hartke and others, 1973.
Modified by L. D. Arihood, 1974.

0 1 2 3 4 5 Miles

0 1 2 3 4 5 6 7 8 Kilometres

Figure 4.-- Potentiometric-surface of Unit 4 at the National Lakeshore area

STREAM HYDROLOGY

The major streams at the National Lakeshore, in descending size, are the Little Calumet River, Kintzele Ditch, Dunes Creek, Striebel Arm of Kintzele Ditch, Derby Ditch, and Brown Ditch. Other streams studied included Markowitz Ditch, Dunes Creek tributaries, and Derby Ditch tributaries. Average discharge of the Little Calumet River is 69.3 ft^3/s (2.0 m^3/s). Based on three discharge measurements during the year, flow in the next two largest streams, Kintzele Ditch and Dunes Creek, was approximately one-tenth that of the Little Calumet River. During April 1974, individual measurements of flow for streams excluding the Little Calumet River ranged from 0.46 ft^3/s (0.01 m^3/s) for Markowitz Ditch to 5.56 ft^3/s (0.16 m^3/s) for Dunes Creek. Table A-1 gives discharges measured.

Streams observed flowing during all four sampling trips were the six major streams, the tributaries to Dunes Creek at the State Park and at Tremont (sites 36, 37, 38, and 41), and the south tributary of Derby Ditch at U.S. 12. Most ground-water inflow to streams in the National Lakeshore is from unit 1.

WATER QUALITY

Precipitation

Average annual precipitation at the National Lakeshore is about 37 inches (940 mm) at Ogden Dunes and increases to 45 inches (1,100 mm) at Michigan City. These figures are based on the period of record from 1940 to 1967. Spring and summer are the periods of greatest precipitation.

Three precipitation collectors were installed for the study, one in the middle and one at each end of the Lakeshore (sites 18, 32, and 59, fig. 2). The collectors were exposed for 1-month periods during July and October, 1973 and February and May, 1974. Because of the month-long exposure, rainfall and dry fallout (water-soluble dust, occluded gases, and other constituents that fall on the collector between rains) are combined in the collected water. This combination will be referred to as precipitation.

Other investigators have found a recognizable pattern to the source and type of chemical ions in precipitation. Common ions include calcium, magnesium, potassium, sodium, chloride, bicarbonate, sulfate, nitrate, ammonia nitrogen, and phosphorus. Calcium, magnesium, and bicarbonate seem to come from soil dust. Sodium, potassium, and phosphorus also can be from soil as well as fertilizer dust. Possible sources for sulfate are soil dust, gaseous products from the decay of organic matter, and fossil fuel combustion. Sources of nitrate and ammonia nitrogen in the atmosphere include gaseous products from the decay of organic matter, photochemical processes in the atmosphere, transportation emissions, and agricultural fertilizers. Chloride seems to be derived mostly from the ocean (Gambell and Fisher, 1966, p. K9).

Studies by Whitehead and Feth (1964, p. 3320) have found that the concentrations of most constituents in precipitation are less than 5 mg/l (milligrams per litre), and commonly less than 1 mg/l. This is true for the National Lakeshore data also. Sulfate, bicarbonate, and calcium had the highest concentrations, averaging 7.0, 6.2, and 3.1 mg/l, respectively. The other constituents ranged from 0 to approximately 1.5 mg/l. The degree of mineralization found in precipitation was well below that in streams of the area but was comparable to certain bog waters. For example, the specific conductance of water along the northern edge of Pinhook Bog ranged from 45 to 80 micromhos, whereas the specific conductance of precipitation ranged from 20 to 56 micromhos.

The degree of mineralization of precipitation was uniform throughout the area. For the 4 months sampled, no obvious trends were evident either spatially or in time.

Data on the trace elements cadmium, zinc, lead, and copper in rainwater at the National Lakeshore were obtained from J. E. Newman (written commun., 1973). Newman's data indicated that the average concentration of dissolved lead in nine rainfall samples (excluding dry fallout) collected at Ogden Dunes from March to October, 1973 was 52 µg/l (micrograms per litre). This value is higher than concentrations found in nearby water bodies. Theodore Kneip (written commun., 1973) found a dissolved lead concentration of 17 µg/l in inter-dunal pond C (site 23) and not detectable (less than 13 µg/l) in inter-dunal pond B (site 20). Data collected by the author from Long Lake showed no lead (less than 50 µg/l detection limit). Rain samples collected by Newman at Ogden Dunes contained zinc concentrations averaging 93 µg/l. Water samples from ponds B and C (collected by Kneip) and Long Lake contained zinc concentrations of 94, 360, and 50 µg/l, respectively. It seems that rainfall has been a significant contributor of lead and zinc in the lake and ponds studied.

The concentrations of lead and zinc in the precipitation are significant. Toxic concentrations of zinc reported for aquatic life range from 10 to 300 µg/l (Brown and others, 1970, p. 159; Keffer and Bugbee, 1972, p. 34). The tolerance concentration for plants has been proposed at 5,000 µg/l (Federal Water Pollution Control Administration, 1968, p. 154). However, the concentrations of lead in the surface waters of the area and its effects on the biota are modified by two factors: (1) the ability of humic matter to substantially sorb and retain lead from the surrounding water and (2) the ability of water hardness (primarily calcium and magnesium ions) to decrease the toxicity of lead. Sorbed lead can enter the food chain, however, and be magnified biologically. Keffer and Bugbee (1972, p. 28) reported that toxic effects on aquatic life generally occur from concentrations greater than 100 µg/l. The maximum safe concentration for animal watering has been reported to be 500 µg/l (Brown and others, 1970), whereas lead concentration greater than 5,000 µg/l are toxic for plants (Federal Water Pollution Control Administration, 1968, p. 154). The source of lead is mostly by lead aerosols produced from the combustion of leaded gasoline. Another source of lead aerosols is the smelting of ores containing lead.

Ground water

Rosenshein and Hunn (1968, p. 12) and Rosenshein (1962b, p. 109-111) reported ground-water chemical data for units 1 and 4 in Porter and LaPorte Counties. These earlier analyses for iron, bicarbonate, sulfate, chloride, and hardness were used as background values for comparing data obtained at the National Lakeshore. Except for chloride, recent ground-water quality data from the National Lakeshore were comparable to earlier data.

The upper part of unit 1 at Ogden Dunes yielded water with chloride concentrations of 78 and 120 mg/l, whereas the lower part had concentrations of 26 and 3.5 mg/l. Sites 40 and 42 in unit 4 had chloride concentrations of 210 and 80 mg/l, respectively. The reason for these higher concentrations is not known. None of the National Lakeshore ground-water data, however, exceed the U.S. Public Health Service drinking water standard for chloride of 250 mg/l (1962, p. 34).

Both units are described by Rosenshein and Hunn (1968, p. 6) as being slightly to moderately calcareous. The presence of a calcareous rock type is indicated by water which has calcium and bicarbonate as major ions. Data from specific areas, however, indicate other water types. Figure 5 illustrates the water type for selected ground-water samples from unit 1 and 4 by Stiff diagrams. Each diagram illustrates the concentration of the cations, anions, and their relation to each other. The width of the pattern is an approximate indication of total ion concentration.

Also shown in figure 5 by means of a bar graph is the corresponding hardness of the water samples. Water hardness has been defined as follows (Hem, 1970, p. 225):

Hardness range (mg/l as $CaCO_3$	Description
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

Data indicated moderately hard to very hard water was present in the two units. The moderately hard water was from wells near Michigan City.

Ground-water quality in both units was virtually the same. However, the higher degree of mineralization and higher proportion of magnesium to calcium found in water from unit 4 wells 90 feet (27 metres) or more deep indicate that water is entering unit 4 from the bedrock.

The U.S. Public Health Service drinking water standards (1962, p. 42, 46) state that iron and manganese should not exceed 0.3 and 0.05 mg/l, respectively. Higher concentrations than these cause stains (reddish-brown for iron and dark brown or black for manganese) and unpleasant tastes. Three of the four unit 1 wells sampled for iron and manganese had concentrations above the recommended limits. Troublesome concentrations of iron also were present in unit 4 wells. Growth of iron bacteria, a problem commonly associated with excessive iron concentrations, was noticed at the unit 4 wells at sites 39, 40, and 47. This growth can cause problems by clogging well screens, pipes, or pumps. Manganese was not excessive in the two unit 4 wells sampled.

Trace element data for unit 1 and 4 wells were well within U.S. Public Health Service drinking water standards. The trace elements analyzed were aluminum, cadmium, chromium, cobalt, copper, lead, mercury, nickel, and zinc.

A unit 1 water-table well at the north edge of Cowles Bog (site 28) had water containing significantly higher total phosphorus, total organic carbon, ammonia nitrogen, organic nitrogen, and color values than from other National Lakeshore wells. One sampling for these constituents resulted in concentrations two to four times greater at site 28 than at the other wells sampled from units 1 and 4. Total coliform bacteria at site 28 was 410

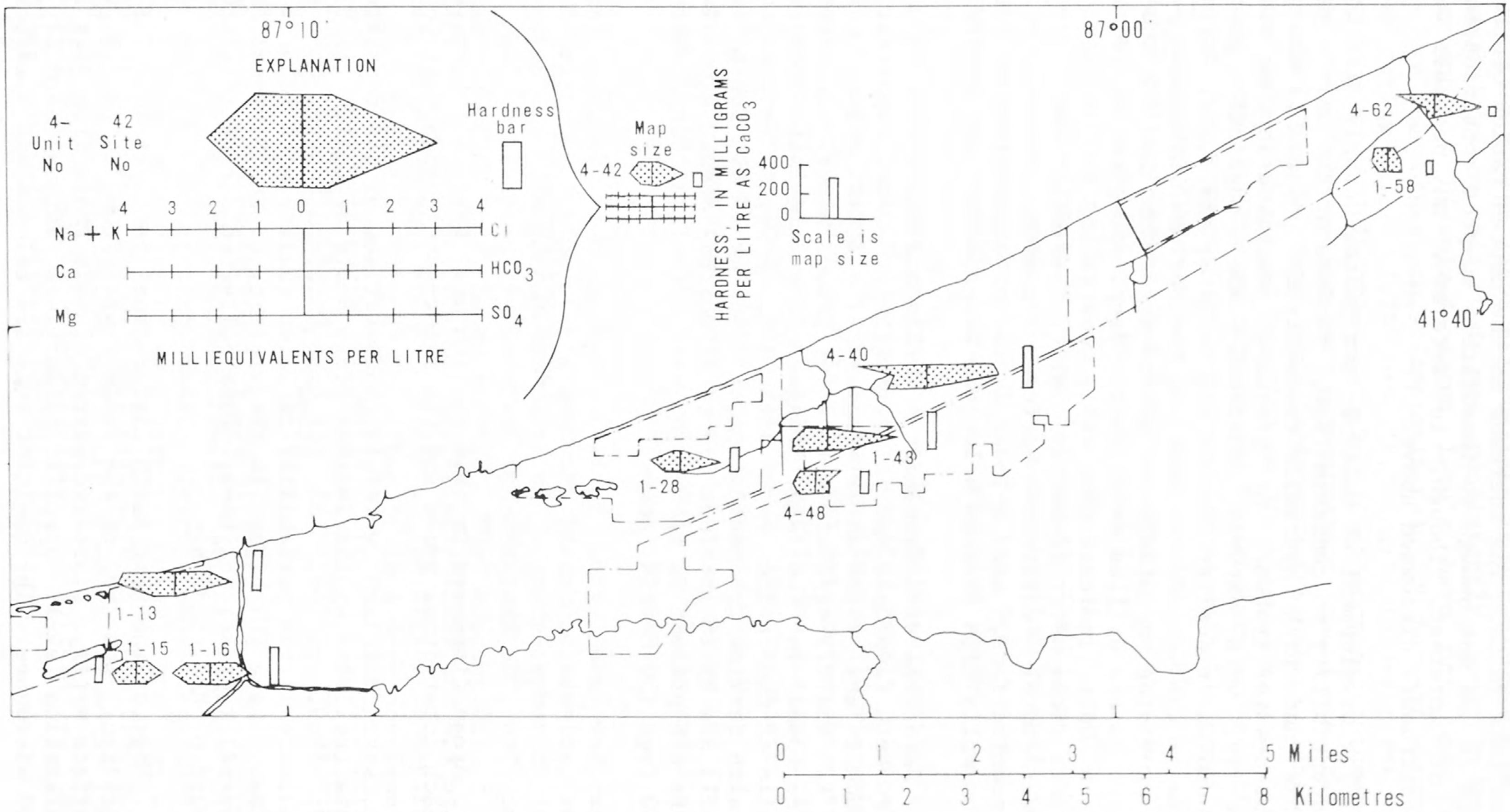


Figure 5.-- Water type and hardness of selected ground-water samples

colonies per 100 millilitres. All other well data had concentrations less than this value. The increase in the concentration of these constituents at site 28 was not enough to immediately suspect contamination of any kind. It is of interest, though, to determine any possible future change in the constituents discussed above.

The development of unit 1 for water supply is complicated by its susceptibility to contamination. Because of the unit's generally high water table and high hydraulic conductivity, pollutants can quickly enter the ground-water system. At present, contamination by man has occurred only locally, with natural chemical and physical processes determining ground-water quality (Hartke and others, 1973, p. 43). Unit 1 within the area of the West Beach Unit of the National Lakeshore presently is capable of providing uncontaminated ground-water supplies for the National Lakeshore if wells are drilled sufficiently deep. Samples collected near the West Beach Unit indicate that wells penetrating two or more interbedded clay layers yield water of better quality than wells that only penetrate sand. Lower total coliform bacteria counts, lower sodium and chloride concentrations, and a lower degree of mineralization were found in samples from wells with screens below the interbedded clay layers.

Data collected from unit 4 wells had water-quality characteristics that were both favorable and unfavorable for water supplies. Bacteria were not found in any ground-water samples. The total organic carbon concentrations of 1.5 and 2.5 mg/l are normal for ground water, and nutrient concentrations were found in the same range. The calculated dissolved solids in three wells at the State Park area did, however, exceed the 1962 U.S. Public Health Service recommendation of 500 mg/l by 300 to 400 mg/l. The three wells are 95 to 154 feet (29 to 47 metres) deep. Excessive dissolved solids were not present in two wells near Michigan City, which are approximately 100 feet (30 metres) deep.

Lakes and Ponds

Areas discussed in this section are Lake Michigan, Long Lake, the West Beach inter-dunal ponds and the inter-dunal ponds near Cowles Bog.

Lake Michigan water is characterized by its consistent water quality. Data published by the Indiana State Board of Health (1959, p. 33; 1964, p. 39; 1969, p. 46, 48) for Lake Michigan between Gary and Michigan City indicate little variability in water quality with respect to either place or time. Lake Michigan in the vicinity of the National Lakeshore is fit for general recreational uses. Data collected during this study agreed with the Board of Health data.

Most of the West Beach inter-dunal ponds are similar in quality to Lake Michigan. The pH of the ponds ranges from 7.4 to 8.3, which is common for surface water. Dissolved-oxygen levels range from just below to just above saturation level. Specific conductance values normally range from 240 to 400 micromhos. The dominant ions are calcium and bicarbonate.

The exception to the above observations is inter-dunal pond 5 (site 10). The pH measured during this study was consistently lower in pond 5 than in the other ponds. Dissolved-oxygen levels have not been consistently comparable to the other ponds (approximately 100-percent saturation). The measurement during April 1974 was 18.3 mg/l (213-percent saturation), whereas the one in July 1973 was 5.0 mg/l (57-percent saturation). This wide range of dissolved-oxygen concentration could be the result of photosynthesis, respiration, and decaying of aquatic plants. Specific conductance in pond 5 ranged from 480 to 770 micromhos, about twice as much as the other ponds, although calcium and bicarbonate are still the dominant ions at pond 5. A comparison between nutrient data for ponds 2 and 5 does not show significantly higher nutrient concentrations in pond 5. The reason for the water quality differences found in pond 5 is not known. No abnormal drainage has been observed emptying into pond 5.

The water quality of Long Lake is normal for lakes with dense plant growth on the bottom. Dissolved-oxygen concentrations ranged from 28 to 140 percent of the saturation level. The production and consumption of oxygen by the water plants probably accounts for the wide range.

The other constituents analyzed at Long Lake were constant with respect to place and time. Specific conductance remained fairly constant throughout the lake during the year, ranging between 190 and 310 micromhos. Calcium and bicarbonate were the major ions. Total phosphorus concentrations from Long Lake were 0.03 and 0.07 mg/l approximately the concentration specified by Keffer and Bugbee (1972, p. 37) as a limiting factor in preventing undesirable plant growth. Nitrate concentrations were 0.0 and 0.11 mg/l. The only trace elements found in the water were aluminum and zinc (70 and 50 ug/l). These concentrations are not toxic to plants and fish. Bacteria counts indicated fecal matter from animals was present.

Bottom material from the west end of Long Lake was analyzed for insecticide residues. None of the National Lakeshore samples, including the Long Lake sample, had detectable amounts of organophosphorus insecticides; however, the chlorinated hydrocarbon insecticides DDT, DDD, and dieldrin were found in the Long Lake sample. The concentrations of these insecticides, 1.9 µg/kg (micrograms per kilogram) DDT and 4.9 µg/kg DDD, are not extremely high but are significant. The higher concentration of DDD probably is a reflection of the fact that it is a decomposition by-product of DDT. PCB's (polychlorinated biphenyls) are an organochlorine compound commonly found in industrial wastes and in asphalt. Detectable amounts of PCB's were found in the Long Lake sample.

In the past, inter-dunal ponds B and B1 (sites 19 and 20), have received water from the Northern Indiana Public Service Company's (NIPSCO) four interconnected fly-ash settling ponds. Figure 6 shows the relative location of the inter-dunal ponds and fly-ash settling ponds. The figure is modified from a map furnished by the National Park Service. Overflow water from the fourth and final ash pond discharged into pond B from May 1969 until the discharge pipe was closed in November 1971. This increased the water level in pond B (D. E. Criner, written commun., 1973).

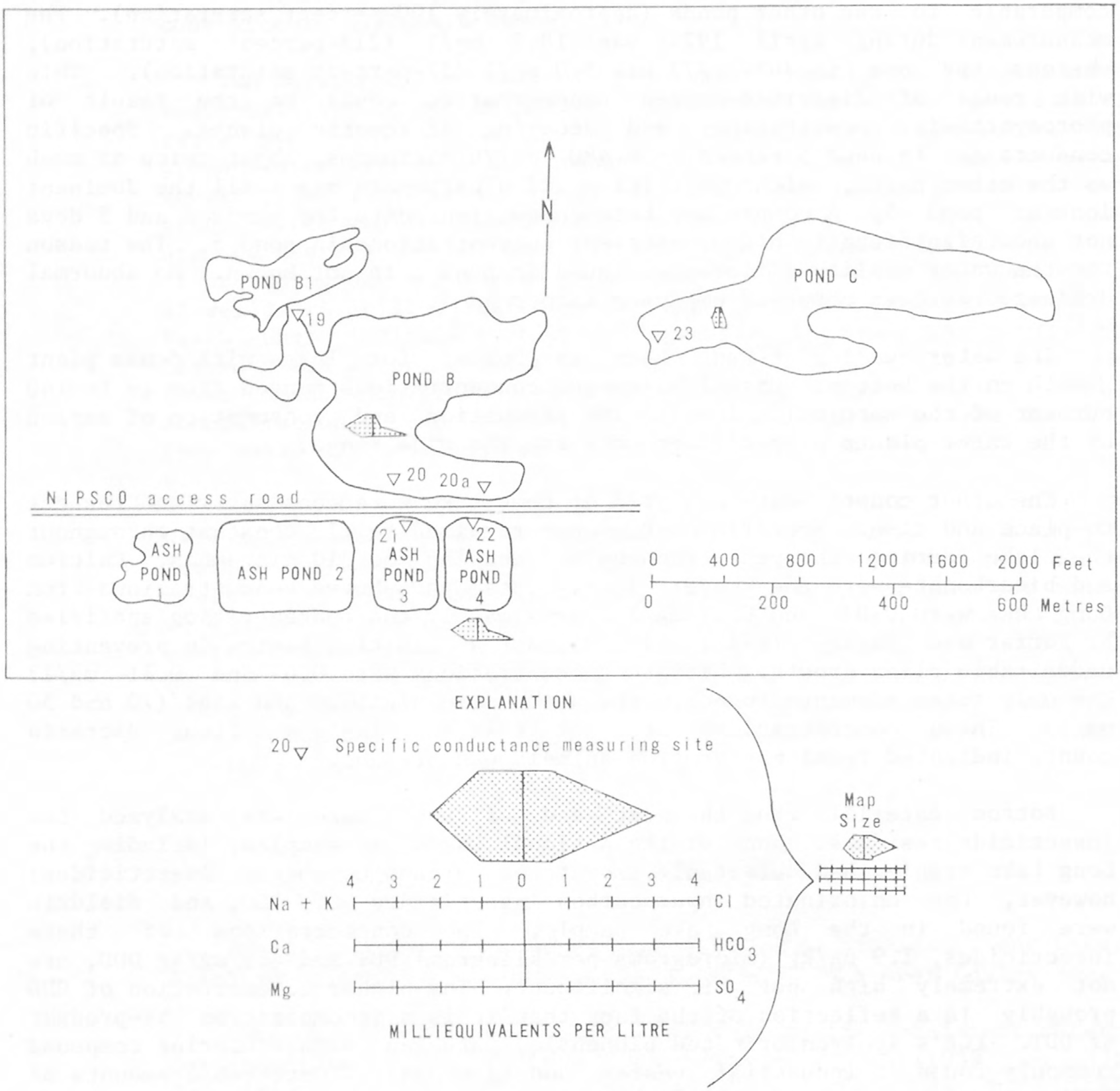


Figure 6.-- Location of inter-dunal ponds, ash ponds, and sampling sites near NIPSCO

Although the pipe is closed, the water-level difference between the ash ponds and pond B is sufficient for continued water movement through the ground between the ash ponds and pond B; however, the degree of this seepage is not known. In January 1974 there was a 6.6-foot (2.0-metre) water-level difference between ash pond 3 and pond B. Other ash ponds would have approximately the same water-level difference with pond B since the ash ponds are interconnected. During April 1974, water was observed flowing from pond B to pond B1.

A pattern was observed in the specific conductance data at inter-dunal pond B. Measurements made at sites 19, 20, and 20a had values of 470, 480, and 550 micromhos, respectively. The increasing specific conductance values toward the southeast corner of pond B could indicate a source of mineralization at that corner.

Chemical data showed water in pond B to be virtually the same as that in ash pond 4. Specific conductance measurements for water in ash ponds 3 and 4 ranged from 370 to 580 micromhos, which is virtually the same as the range of 370 to 510 micromhos found in water of pond B. Stiff diagrams of samples collected from ash pond 4 and pond B in January 1974 show that their waters were of similar type (fig. 6). On the other hand, pond C is thought to have relatively "natural" water quality with a minimum of influence by the ash ponds. The specific conductance of the water was 90 micromhos in January 1974, and the Stiff diagram (fig. 6) shows a water type different from that of pond B.

Bogs and marshland

Water-quality characteristics of bogs and marshlands in the National Lakeshore area include a pH of 5.0 to 6.5, dissolved-oxygen concentrations of 0.2 to 4.0 mg/l, specific conductance values of 40 to 150 micromhos, iron concentrations greater than 1.0 mg/l and a highly colored water. Characteristic water types are illustrated by Stiff diagrams in figure 7 (sites 27, 29, 38 and 72). Data illustrated were for the same month as much as possible. Data for other months were then used to complete the illustration of water types.

The north inlet (site 27) of Cowles Bog had the water-quality characteristics mentioned above. The conductance was low (70-120 micromhos), with pH readings of 6.7 and 5.8 and dissolved oxygen concentrations from 1.5 to 4.7 mg/l. The iron concentration was very high (7.6 mg/l), which, for that type of water, usually is due to iron contained in the organic acids that color the water a dark brown or black.

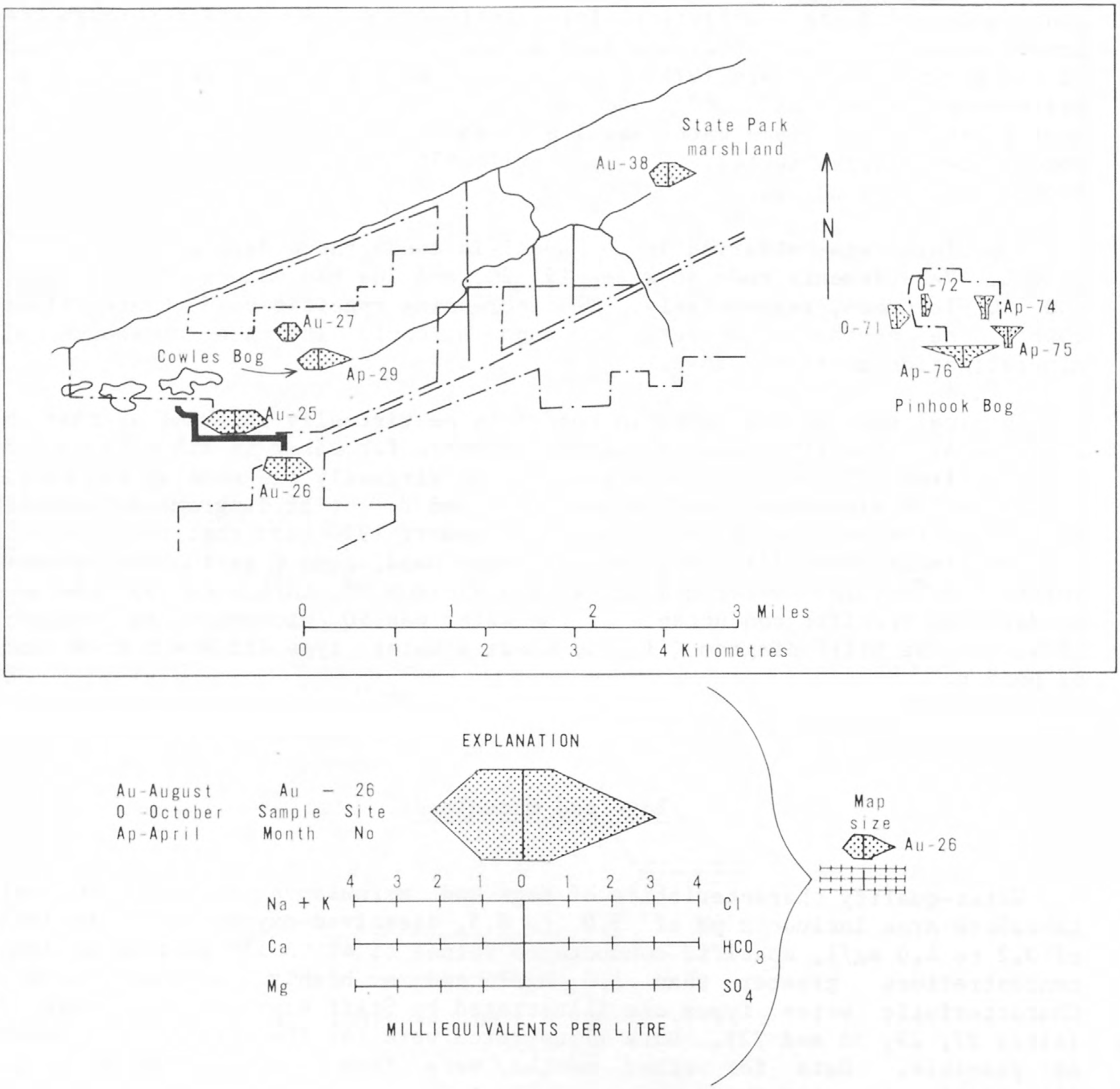


Figure 7.-- Water type of selected bog and marshland samples

In addition to these expected characteristics, the highest concentration of total phosphorus (0.71 mg/l) for any of the bog and marshland sites was found at site 27. Ground-water data near the north inlet also showed the highest concentration of phosphorus as well as total organic carbon as compared to other well samples. The reason for these higher values at the north inlet area is not known.

Field measurement data (temperature, dissolved oxygen, pH, and specific conductance) at the west inlet of Cowles Bog were similar to that at the north inlet except that the total phosphorus concentration was only 0.13 mg/l.

Points 25 and 26 indicate sampling sites of two drainage areas discharging into Cowles Bog. In one drainage area NIPSCO is using coal ash to fill a wetland bounded on the north and east by their sand dike. Site 26 is at a ditch across the southeast end of the sand dike. This ditch drains the NIPSCO wetland and some of the Bailey Homestead area south of U.S. 12. Except for somewhat higher sodium and chloride concentrations, the chemical quality at site 26 is similar to the quality of streams in the National Lakeshore. The dominant ions are calcium and bicarbonate. The range of specific conductance values shows a similar degree of mineralization in the ditch water as in stream water. The pH at site 26 ranged from slightly acid (6.7) to basic (8.2). The flow in the ditch on January 24, 1974 was 0.76 ft^3/s (0.02 m^3/s). At other times the flow was either ponded or too slow to measure.

Analysis of a sediment sample from the bottom of the ditch showed that trace element concentrations were low relative to other sites sampled.

The other drainage area directly affected by human activity is sampled by site 25, a culvert outlet. D. E. Criner (written commun., 1973) states that the outlet discharges natural surface drainage. Water-quality data at site 25 are not similar, however, to other surface drainage waters. Water temperature at the culvert outlet was consistently higher than temperatures measured the same day at surrounding sites. The temperature difference between the culvert outlet water and the maximum temperature of surrounding sites on October 17, 1973 was 10°C (Celsius). The reason for the higher temperatures is not known. Furthermore, the range of specific conductance values for streams of the area was 300 to 600 micromhos, whereas the culvert outlet water had specific conductance values ranging from 480 to 960 micromhos. Figure 8 compares water temperature and specific conductance data for the drainage outlet of Bethlehem Steel against that of nearby sites. The sample from the culvert outlet on April 25, 1974 had a chloride to bicarbonate ratio of 1.0. A characteristic chloride to bicarbonate ratio for surface drainage in the National Lakeshore is 0.3. The dissolved-oxygen concentrations, ranging from 1.4 to 3.3 mg/l, were low for surface water.

The middle section of the Cowles Bog area is sampled by site 29. This site is also the beginning of Dunes Creek. Basically, the chemical quality of water at site 29 is similar to stream and not bog quality, as evidenced by higher pH, dissolved oxygen, and specific conductance values.

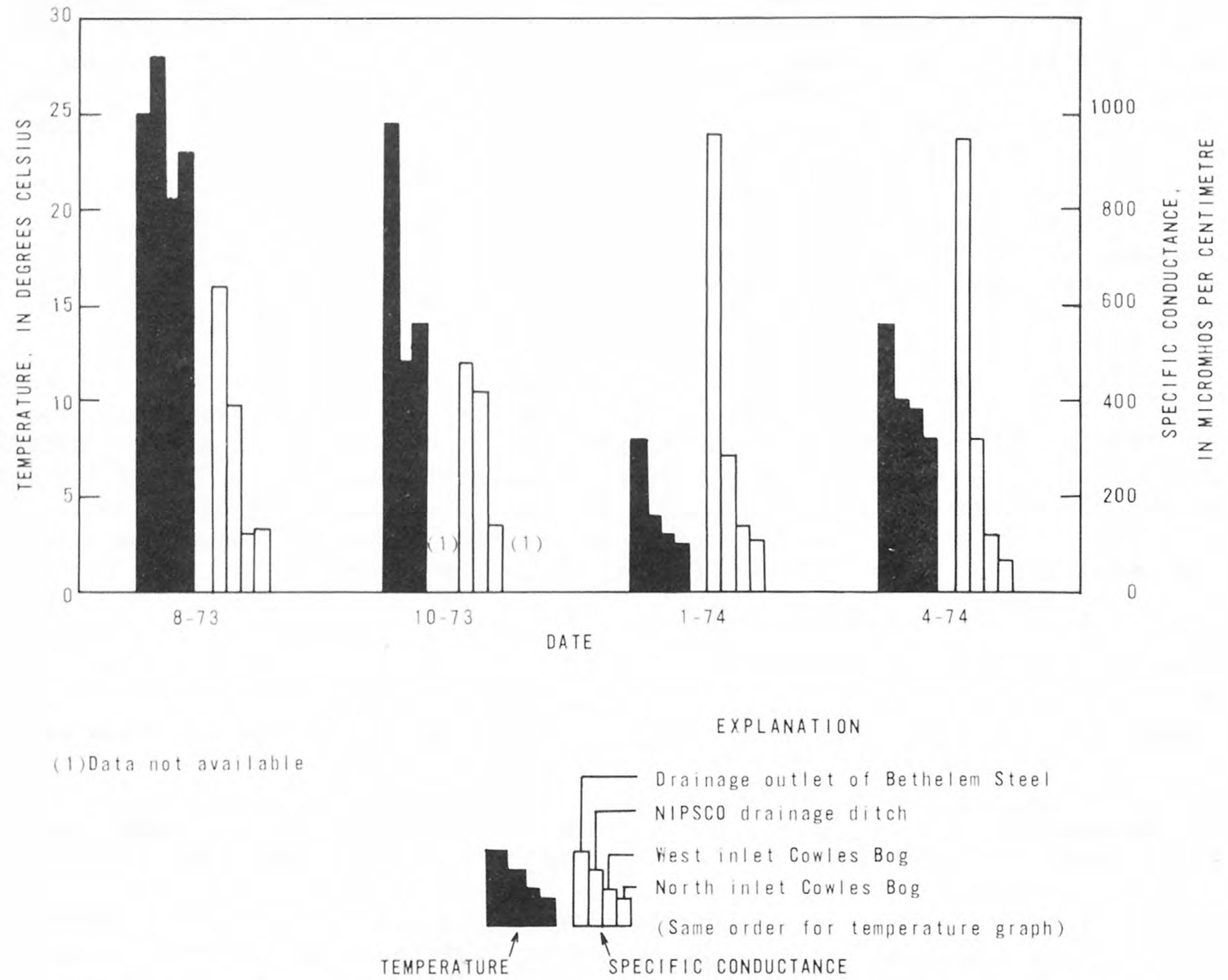


Figure 8.-- Comparison of temperature and specific conductance data of the Cowles Bog area

The marshland in the Indiana Dunes State Park was sampled at its outlet (site 38). Samples from this site had water-quality characteristic of waters with high organic growth. The only exceptions to the typical marshland water were a slightly higher specific conductance range (160-260 micromhos) and dissolved-oxygen concentrations occasionally as high as 10.0 mg/1.

The water quality of Pinhook Bog is being changed by two factors: agricultural runoff and runoff from road salting. Agricultural fields make up the western section of the bog drainage area. The runoff into the western edge of the bog was turbid and light brown, not the clear, dark brown water characteristic of the bog. The runoff has also increased the specific conductance somewhat. Normally the specific conductance of the bog water ranges from 45 to 85 micromhos, but values of 140 and 160 micromhos were measured in the bog at Wozniak Road. This increase was due to approximately proportional increases in most of the major ions.

Specific conductance and chloride data were used to study the problem of runoff from road salt. The data indicated a highly mineralized water dominant in sodium chloride mixing with a lower mineralized water dominant in calcium bicarbonate. The latter water type is normal for the bog. Salt concentration was highest in the water at site 76 near a culvert outlet of Interstate 80-94. This water mixes with water from the west section of the bog. Water then leaving the main section of the bog at site 74 (east side) is a mixture having a salt concentration between that of sites on the west side of Pinhook Bog and sites near the culvert outlet. The following table lists specific conductance and chloride data for Pinhook Bog sites (fig. 2) in the order discussed. Data for both October 1973 and April 1974 were used to have sufficient chloride data to cover all sites.

Site		Date Collected	Specific Conductance (micromhos per centimetre)	Chloride (milligrams per litre)	
76	Pinhook Bog at I-80	4-24-74	580	130	Water of high salt concentration
77	Pinhook Bog at salt-storage area	10-16-73	1,380	340	
		4-24-74	90	----	
71	Pinhook Bog at Wozniak Road	10-16-73	160	17	Water of low salt concentration
		4-24-74	60	----	
72	Pinhook Bog at open water	10-16-73	75	5.5	
75	Southeast inlet Pinhook Bog	10-16-73	170	----	Mixture of the two waters
		4-24-74	210	52	
74	Pinhook Bog northeast	8-3-73	200	25	
		4-24-74	120	27	

The sodium adsorption ratio (SAR) is a measure of the potential for sodium to replace calcium and magnesium adsorbed on soil particles, which damages soil structure. SAR values between 8 and 18 indicate the permeability of the soil may be decreased. The salt storage retention pond (site 78) has had water with SAR values of 12 and 49. This pond has overflowed into adjacent farmland. Pinhook Bog water at the salt storage area (site 77) has had a SAR of 10. Waters of the National Lakeshore normally had SAR values of less than 1.

Water entering the northeast inlet of Pinhook Bog, site 68, comes from a pond at Forrester Road, then flows behind several houses and finally through a small artificial pond. Two samples from site 68 contained some bacteria and insecticides. The ratio of fecal coliform to fecal streptococci bacteria colonies indicates that animal fecal matter is the source of the bacteria. The number of bacteria, however, were comparable to background levels found in the National Lakeshore. The insecticide DDD, a chlorinated hydrocarbon, was found in an analysis of some of the bottom material.

Streams

Specific conductance values of 300 to 600 micromhos, a pH of 6.5 to 8.1, and calcium and bicarbonate as the dominant ions are characteristic of stream quality in the National Lakeshore area. Other water-quality characteristics include dissolved-oxygen concentrations near saturation (7.7 to 12.9 mg/l) and chloride concentrations less than sulfate or bicarbonate. Figure 9 shows Stiff diagrams of the water types in the streams. Diagrams for bog and marshland samples were included when they were at the beginning of a stream. Stiff diagrams for the same month were used as much as possible. Diagrams for other months were then used to complete the illustration of water types.

Streams were the only water environment in which bacteria counts indicated human influences. The fecal coliform and fecal streptococcus bacteria groups are found in both man and animals. The source of bacteria can be indicated by the ratio of fecal coliform to fecal streptococcus bacteria (Geldrich, 1966, p. 102). In humans this ratio is 4.4 or higher, whereas for animals the ratio ranges from approximately 0.04 to 0.6. Ratios of samples at the National Lakeshore indicated that animals usually were the source of the bacteria. Figure 10 illustrates the bacteria data collected during the study. Considering all data, the highest concentration of bacteria usually was in the summer.

The Little Calumet River is the largest and one of the most mineralized streams in the area. Bacteria data for the Little Calumet at sites 31 and 45 indicate no trend in bacterial quality between the two points. In August 1973, however, data for the river at the park boundary did indicate human fecal matter was the source of the bacteria. The rest of the data indicated the bacteria was from animal sources.

Keffer and Bugbee (1972, p. 37) state that a maximum concentration of 0.1 mg/l of phosphorus should be allowed in rivers to avoid the danger of supporting undesirable growths. At site 31 a total phosphorus concentration of 0.19 mg/l was found--the highest for streams in the National Lakeshore.

The highest concentration of trace elements in the National Lakeshore was found in bottom sediments of the river at site 31. Significant amounts of the chlorinated hydrocarbon insecticide residues, chlordane and DDD, also were present in a bed material sample from the river.

Septic tank discharge was sampled at site 30. Chloride and nitrate concentrations were 120 and 27 mg/l, respectively. A fecal coliform to fecal streptococcus bacteria ratio was 28.8, indicative of human excreta. This discharge drains into the Little Calumet River.

The water quality of Markowitz Ditch was different from the other streams in the area. Specific conductance ranged from 510 to 620 micromhos, high for the smaller streams in the area, and sodium, chloride, and bicarbonate were the dominant ions. Chloride concentrations were always twice as great as sulfate and once slightly greater than bicarbonate.

Markowitz Ditch had the greatest organic contamination-- more insecticides were found in there than in the other streams. Chlordane, DDD, DDT, and dieldrin were present in significant quantities. The highest concentration of PCB's (15 μg/kg) found in the National Lakeshore also was at Markowitz Ditch. PCB's are usually indicative of industrial effluent.

Dunes Creek receives water from a large area including Cowles Bog, the State Park marshland, cropland, and residential areas. Though there are high concentrations of some chemical constituents in certain Dunes Creek tributaries, the greater quantity of water flowing in Dunes Creek dilutes these concentrations and resultant stream quality is typical for the area. For example, chloride was 130 mg/l at Markowitz Ditch, a tributary of Dunes Creek, whereas Dunes Creek at its mouth (site 33) had only 32 mg/l chloride. High flow during January 1974 diluted all constituents in Dunes Creek as shown on figure 9. The dilution, however, should have decreased all constituents a proportional amount. The increased proportion in certain constituents indicates the variability of direct runoff. Stiff diagrams for Kintzele Ditch also show the effect of dilution occurring during January.

Dunes Creek, its tributaries, and most other streams have drainage areas consisting mostly of marshland containing wildlife. As a result, the water in these streams had the characteristics of colored water and bacterial populations from animal sources.

Derby Ditch has an extensive drainage ditch tributary system. Specific conductance values for Derby Ditch and its tributaries are high (300 to 450 micromhos) for a marshy area. Specific conductance data for the east Derby Ditch tributary shows that the water becomes less mineralized as it travels downstream, which is not common for streams of the area. No reason is apparent for this phenomena.

Bacteria data show that human waste occasionally enters Derby Ditch. The fecal coliform to fecal streptococcus ratio was 6.5 in April 1974, but only 0.2 in August 1973.

Kintzele Ditch is another stream containing more mineralized water than would be expected from a marshland area. The ditch drains both residential-business areas and rural, non-farm area. The major source of dissolved solids is from the tributary draining areas of Michigan City (site 66). Non-similarities to other streams include chloride concentration greater than sulfate in the August 1973 data and the dominant ions including sodium as well as calcium and bicarbonate. The increased proportion of sodium characteristic of ground water of the area southwest of Michigan City occurred in the stream also. Trace element analysis of a bottom sediment sample at site 63 indicated low concentrations relative to other trace element data. The insecticide chlordane and PCB's were detected in a bed sample from Kintzele Ditch.

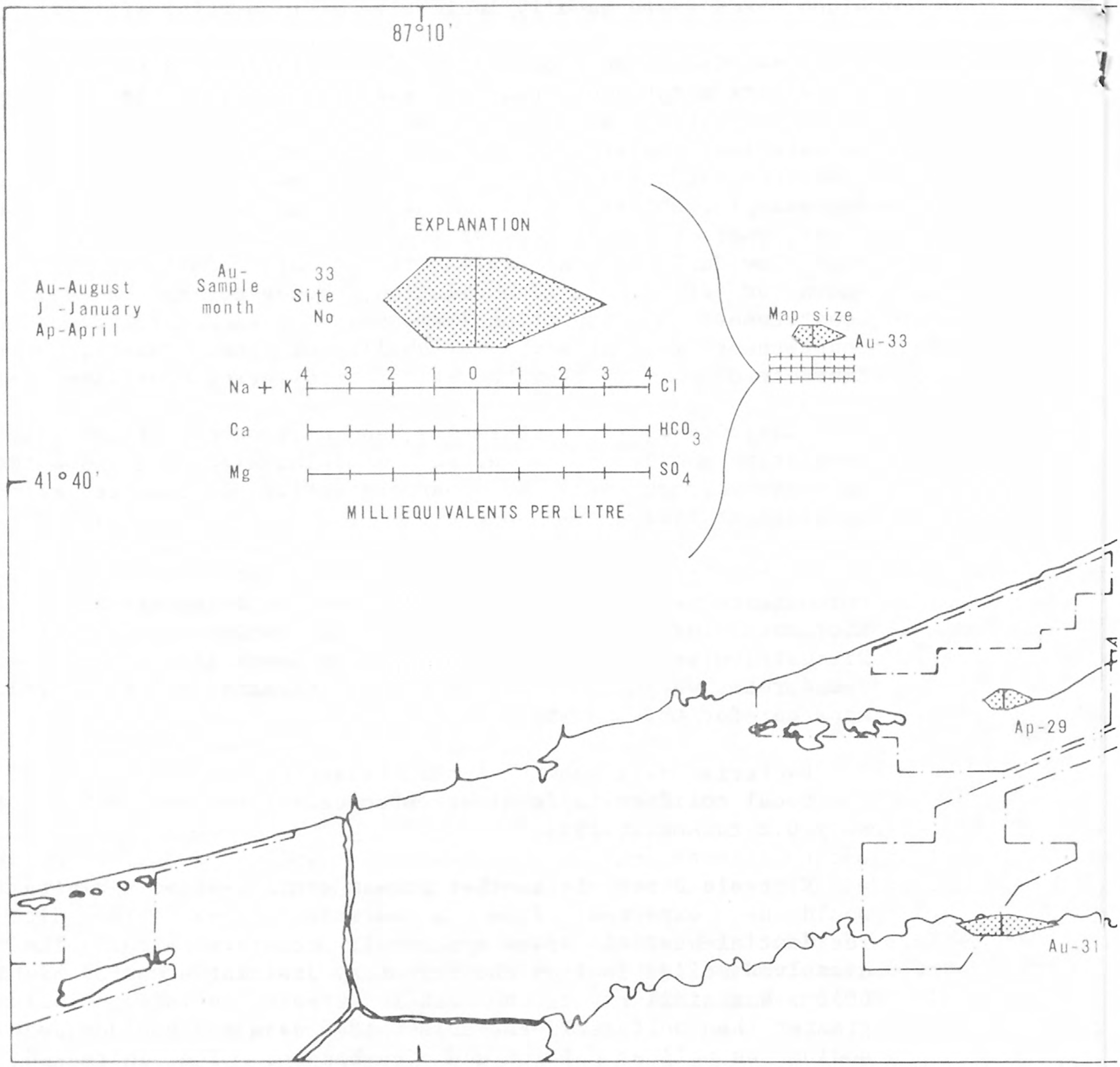
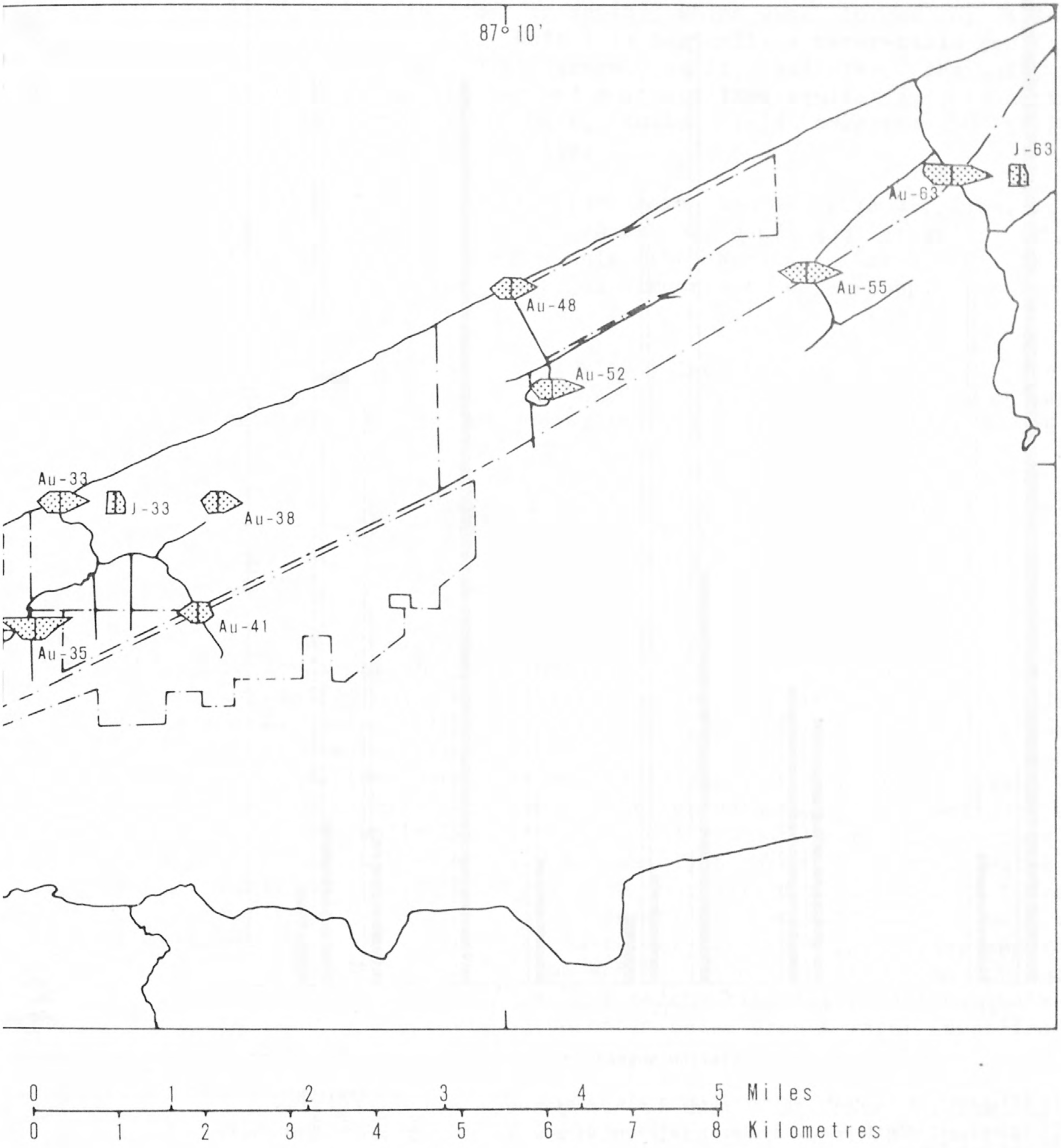


Figure 9.-- Water type of



selected stream samples

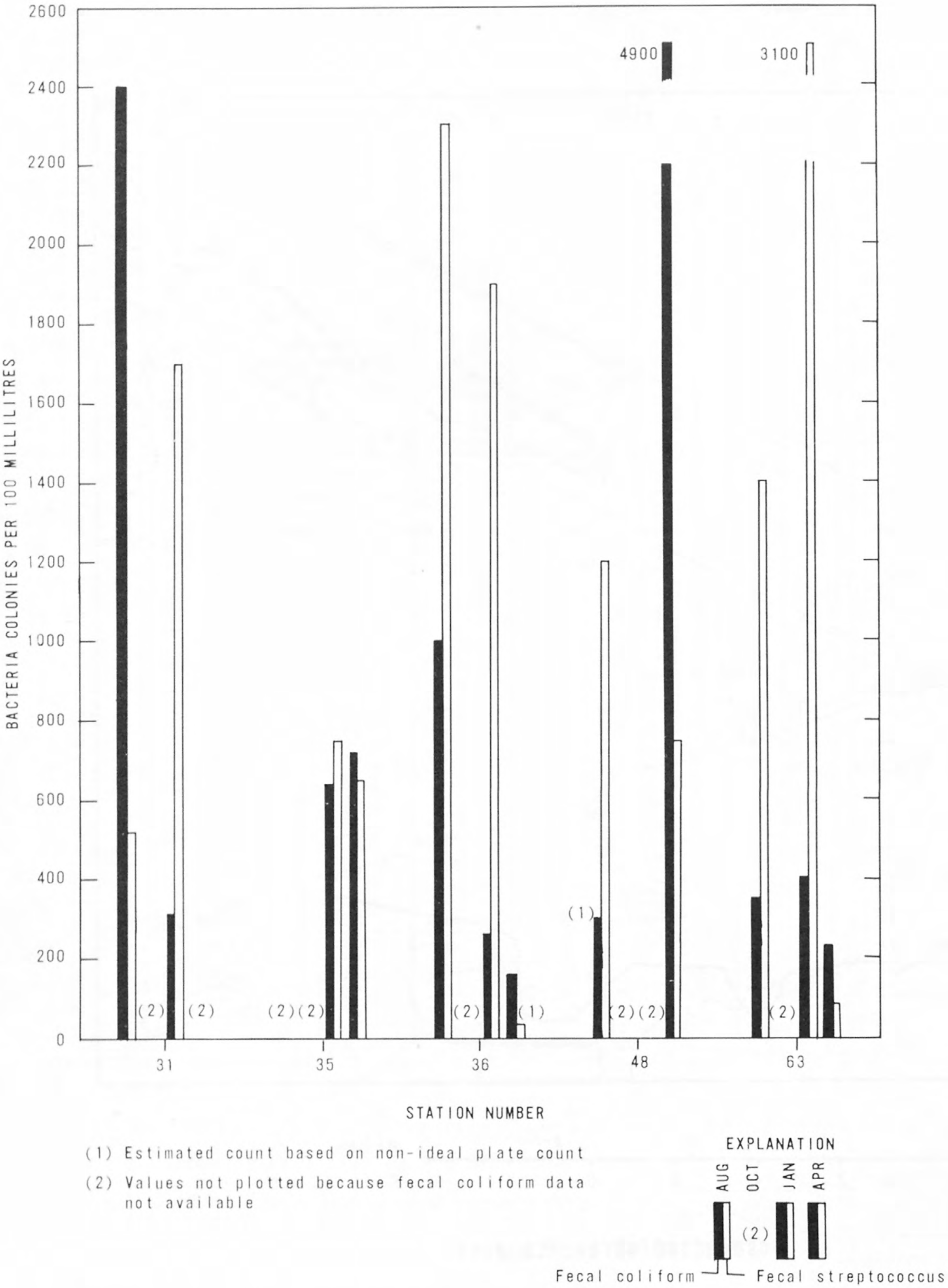


Figure 10. -- Bacteria concentrations at selected stream sites

SUMMARY

The study area is underlain by three unconsolidated rock groups, units 1, 2, and 4 (in order of depth), which were formed by glacial action and lake sedimentation. Unit 1 is basically a water-table aquifer consisting of sand interbedded with gravel, silt, and clay. The unit, though slightly dewatered, is the second most utilized aquifer and, in certain areas, such as the West Beach Unit, could yield more than 500 gal/min (32 l/s) to properly constructed wells.

Unit 2, used locally for farm and domestic supplies, is chiefly a silt till with discontinuous zones of sand and gravel. Because of the its limited areal extent within the National Lakeshore and low hydraulic conductivity, it is not an important water-supply source for National Lakeshore purposes.

Unit 4 is a clay till with discontinuous zones of sand and gravel. Within the National Lakeshore these zones may be as much as 45 feet (14 metres) thick and according to available data, yield as much as 65 gal/min (4 l/s).

Depth to bedrock ranges from 150 to 250 feet (46 to 76 metres) below the land surface. The bedrock, which is of Devonian age, consists of shale underlain by dolomite and dolomitic limestone and yields less than 10 gal/min (0.63 l/s).

Samples of precipitation were collected at three sites in and near the National Lakeshore. Chemical quality of these samples was normal for precipitation, and no trends were discernible. Samples collected at Ogden Dunes were slightly higher in lead and zinc than those from nearby surface-water sites.

Chloride concentrations of 78 and 120 mg/l in the Ogden Dunes area were considered high relative to earlier data from the National Lakeshore area. Data from wells in units 1 and unit 4 indicate that ground water at the National Lakeshore is moderately hard to very hard. Water from unit 1 contained iron and manganese concentrations sufficient to cause stains and unpleasant tastes. Trace element concentrations in both units, however, were within U.S. Public Health Service drinking water standards. Water from unit 1 usually had calcium and bicarbonate as the dominant ion pair. Unit 1 within the area of the West Beach Unit of the National Lakeshore presently is capable of providing uncontaminated ground-water supplies if wells are drilled sufficiently deep.

Water from the upper parts of unit 4 may have calcium and bicarbonate as the dominant ion; however, few data were obtained from the upper section of this unit. At depths of 90 feet (27 metres) and more, however, magnesium also was a major ion.

In general, surface water throughout the National Lakeshore is of normal quality for the area. There are, however, some problem areas. Inter-dunal pond 5 is more highly mineralized than other West Beach inter-dunal ponds. Inter-dunal pond B is similar in chemical quality to ash pond 4 of NIPSCO.

The Bethlehem Steel culvert outlet discharged water of consistently higher temperature and mineralization than that from surrounding sites. At Pinhook Bog, salt contamination was occurring on the south side and spreading through the bog. The Little Calumet River and sewage at site 30 contained bacteria concentrations indicating a source of human fecal matter.

Other surface-water sites were recognized as potential problem areas from a water-quality standpoint. Pinhook Bog at Wozniak Road contained agricultural runoff that was turbid and more mineralized than other areas of the bog. Both the NIPSCO ditch site and Markowitz Ditch had water containing a higher proportion of chloride than in other streams. Bottom sediment from the Little Calumet River at Porter contained significantly higher trace elements than other streams. Data from Derby Ditch indicate that human fecal matter was the source of bacteria in the water. Pesticide residue concentrations at the National Lakeshore area were not extremely high, but were significant at Long Lake, Pinhook Bog at the northeast inlet, Little Calumet River, Markowitz Ditch, and Kintzele Ditch.

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BASIC DATA

Table A-1.--Field analyses

Site	Site name	Date Measured	Temperature (°Celsius)	Specific Conductance (micromhos per cm)	Dissolved oxygen (mg/l)	pH	Streamflow (ft^3/s)
1	Lake Michigan 1	10-18-73	14.0	260	9.6	7.3	-------
2	Lake Michigan 2	10-18-73	15.0	260	10.2	7.2	-------
3	Lake Michigan 3	10-18-73	14.5	240	9.7	7.8	-------
4	Lake Michigan 4	10-18-73	14.0	210	9.7	7.6	-------
5	Lake Michigan 5	10-18-73	14.0	230	9.6	7.8	-------
6	West Beach inter-dunal pond 1	07-31-73	23.0	350	7.3	7.4	-------
		10-18-73	14.0	400	11.3	7.4	-------
		01-24-74	4.0	260	12.5	---	-------
		04-25-74	10.5	380	13.5	8.1	-------
7	West Beach inter-dunal pond 2	07-31-73	23.0	305	7.2	7.7	-------
		10-18-73	14.5	240	12.5	7.6	-------
		04-25-74	11.0	290	12.3	8.1	-------
8	West Beach inter-dunal pond 3	07-31-73	23.0	290	8.8	8.0	-------
9	West Beach inter-dunal pond 4	07-31-73	23.0	350	9.5	---	-------
10	West Beach inter-dunal pond 5	07-31-73	22.5	520	5.0	7.2	-------
		10-18-73	14.5	750	11.4	7.3	-------
		01-24-74	6.5	480	10.2	---	-------
		04-25-74	23.0	770	18.3	7.7	-------

11	West end Long Lake	07-31-73	22.5	260	2.4	6.6	-------
		10-18-73	14.0	310	7.6	6.9	-------
		01-24-74	5.0	190	7.0	---	-------
		04-25-74	11.0	300	12.0	7.8	-------
12	East end Long Lake	07-26-73	28.5	210	11.0	8.7	-------
		10-18-73	14.0	270	10.2	7.2	-------
		01-24-74	4.0	220	6.8	---	-------
		04-25-74	11.0	290	12.6	8.1	-------
13	Unit 1 water-table well at Ogden Dunes	04-27-74	14.0	1,080	----	7.0	-------
14	Unit 1 artesian well 4 at Ogden Dunes	04-26-74	13.0	300	----	6.8	-------
15	Unit 1 artesian well 3 at Ogden Dunes	10-10-73	15.0	380	----	8.0	-------
		04-26-74	14.0	400	----	7.2	-------
16	Unit 1 artesian well 1 at Ogden Dunes	10-10-73	14.5	750	----	8.0	-------
		04-25-74	12.5	710	----	6.8	-------
17	Unit 1 artesian well 2 at Ogden Dunes	04-26-74	15.0	530	----	6.9	-------
18	Precipitation quality site at Ogden Dunes	07-73	----	28	----	6.9	-------
		10-73	----	26	----	7.6	-------
		02-74	----	40	----	6.7	-------
		05-74	----	23	----	5.3	-------
19	Inter-dunal pond B1 at Dune Acres	04-25-74	10.5	470	----	---	-------
20	Inter-dunal pond B at Dune Acres	08-01-73	25.0	510	10.0	7.2	-------
		10-18-73	12.0	420	6.1	6.7	-------
		01-24-74	3.0	370	7.9	---	-------
		04-25-74	11.0	480	12.0	7.1	-------

Table A-1.--Field analyses (Continued)

Site	Site name	Date Measured	Temperature (°Celsius)	Specific Conductance (micromhos per cm)	Dissolved oxygen (mg/l)	pH	Streamflow (ft^3/s)
20a	Inter-dunal pond B at Dune Acres	04-25-74	10.5	550	----	---	-------
21	NIPSCO ash-settling pond 3	08-01-73	26.0	380	----	7.2	-------
		10-17-73	----	470	----	---	-------
22	NIPSCO ash-settling pond 4	10-18-73	----	370	----	---	-------
		01-24-74	2.5	420	8.0	---	-------
		04-25-74	10.0	580	----	---	-------
23	Inter-dunal pond C at Dunes Acres	01-24-74	3.0	90	7.8	---	-------
24	West inlet Cowles Bog	08-02-73	20.5	120	.7	7.3	-------
		10-18-73	14.0	140	----	6.3	-------
		01-24-74	3.0	140	3.6	---	-------
		04-25-74	9.5	120	3.9	5.9	-------
25	Drainage outlet of Bethlehem Steel	08-02-73	25.0	640	1.6	7.3	-------
		10-17-73	24.5	480	1.4	6.8	0.17
		01-24-74	8.0	960	2.2	---	-------
		04-25-74	14.0	950	3.3	6.6	-------
26	NIPSCO drainage ditch	08-02-73	28.0	390	12.0	8.2	-------
		10-18-73	12.0	420	6.9	6.7	-------
		01-24-74	4.0	290	6.5	---	.76
		04-25-74	10.0	320	12.4	6.8	-------
27	North inlet Cowles Bog	08-02-73	23.0	130	1.5	6.7	-------
		01-23-74	2.5	110	4.7	---	-------
		04-25-74	8.0	70	3.8	5.8	-------

28	Unit 1 water-table well at Dune Acres	10-09-73	16.0	380	----	7.8	-------
29	Cowles Bog at 100 West Road	10-17-73	----	570	----	---	-------
		01-23-74	----	240	----	---	-------
		04-25-74	8.0	350	9.9	7.4	-------
30	Sewage outlet	08-02-73	18.5	1,320	6.8	7.5	-------
		10-17-73	17.0	1,290	9.0	6.6	-------
		01-23-74	7.0	1,060	4.7	6.9	-------
		04-25-74	9.0	1,080	11.2	7.4	-------
31	Little Calumet River at Porter	08-02-73	18.0	540	7.5	8.0	50
		10-17-73	12.0	650	9.4	6.8	45
		01-23-74	3.0	390	12.0	7.1	508
		04-24-74	11.0	630	11.8	8.5	62
32	Precipitation quality site at Dunes State Park	07-73	----	33	---	6.9	-------
		10-73	----	32	----	4.8	-------
		02-74	----	17	----	6.9	-------
		05-74	----	38	----	6.2	-------
33	Dunes Creek at outlet	08-02-73	19.0	370	7.1	7.6	-------
		10-17-73	12.0	420	9.4	6.4	1.93
		01-22-74	2.0	230	12.4	7.3	50.2
		04-23-74	10.0	250	12.9	7.6	5.56
34	Dunes Creek at west State Park boundary	10-17-73	----	490	----	---	-------
		01-23-74	----	280	----	---	-------
		04-25-74	5.0	390	----	---	-------
35	Markowitz ditch at outlet	08-02-73	20.0	600	7.2	7.6	-------
		10-17-73	13.0	620	----	6.4	.15
		01-23-74	3.5	510	11.9	6.9	2.87
		04-25-74	6.0	600	12.8	7.4	.46

Table A-1.--Field analyses (Continued)

Site	Site name	Date Measured	Temperature (°Celsius)	Specific Conductance (micromhos per cm)	Dissolved oxygen (mg/l)	pH	Streamflow (ft^3/s)
36	Tributary 1 at south State Park boundary	08-08-73	18.5	240	10.6	7.6	-------
		10-17-73	11.0	310	10.0	7.5	.12
		01-22-74	----	310	----	7.2	-------
		04-23-74	8.0	250	10.8	6.7	-------
37	Tributary 2 at south State Park boundary	08-08-73	20.0	425	11.0	7.5	-------
		10-17-73	----	380	9.3	7.5	-------
		01-22-74	----	370	----	---	-------
38	Marshland outlet at Dunes State Park	08-02-73	22.0	260	.8	6.9	-------
		10-17-73	11.0	260	1.8	6.4	.13
		01-22-74	2.0	200	7.6	7.3	-------
		04-23-74	12.5	160	10.0	6.7	-------
39	Unit 4 artesian well 1 at Dunes State Park	10-09-73	16.0	920	2.6	7.6	-------
40	Unit 4 artesian well 2 at Dunes State Park	04-23-74	9.0	1,140	----	7.4	-------
41	Tributary to Dunes Creek at Tremont	08-02-73	19.5	280	8.5	7.7	-------
		10-16-73	12.5	350	9.0	---	.16
		01-22-74	----	340	----	7.5	5.07
		04-24-74	13.5	340	10.4	---	.60
42	Unit 4 artesian well at Tremont	04-23-74	13.0	470	----	6.2	-------
43	Unit 1 water-table well at Tremont	04-23-74	11.0	600	----	7.0	-------

44	Tributary to Dunes Creek at U.S. 20	01-22-74	----	420	----	6.9	-------
		04-24-74	11.5	1,060	----	---	-------
45	Little Calumet River at Chesterton	08-07-73	23.5	440	11.2	8.1	-------
		10-17-73	14.0	570	10.2	6.9	-------
		01-23-74	2.0	350	12.0	7.4	-------
		04-24-74	10.0	550	12.7	7.8	-------
46	Coffee Creek at Chesterton	01-23-74	3.5	520	----	---	-------
		04-24-74	11.0	640	----	---	-------
47	Unit 4 artesian well at east State Park boundary	04-23-74	9.0	1,040	----	7.5	-------
48	Derby ditch at outlet	08-02-73	21.0	340	8.1	7.5	-------
		10-16-73	----	410	9.1	---	0.36
		01-22-74	1.0	290	12.6	7.2	23.9
		04-23-74	9.0	300	10.8	7.0	3.98
49	West Derby ditch tributary	10-15-73	----	520	----	---	-------
50	South Derby ditch tributary 1	10-15-73	----	440	----	---	-------
51	South Derby ditch tributary 2	10-15-73	----	220	----	---	-------
		01-22-74	1.0	180	----	7.4	-------
		04-23-74	10.0	345	----	---	-------
52	South Derby ditch tributary 3	08-02-73	21.0	380	4.5	7.5	-------
		10-15-73	20.0	400	5.7	7.1	-------
		01-22-74	1.0	300	11.8	7.5	-------
		04-23-74	9.5	350	9.1	6.8	-------
53	East Derby ditch tributary at Broadway St.	08-02-73	23.0	230	4.1	---	-------
		10-15-73	----	350	----	---	-------
		01-22-74	.0	330	----	7.3	-------
		04-23-74	9.0	300	----	---	-------

Table A-1.--Field analyses (Continued)

Site	Site name	Date Measured	Temperature (°Celsius)	Specific Conductance (micromhos per cm)	Dissolved oxygen (mg/1)	pH	Streamflow (ft^3/s)
54	East Derby ditch tributary at Wells St.	01-22-74	----	380	----	7.0	-------
		04-23-74	9.5	320	----	---	-------
55	Brown ditch at Town of Pines	08-02-73	23.0	430	6.7	7.5	-------
		10-15-73	19.0	600	9.5	7.2	1.02
		01-22-74	1.0	310	12.8	7.2	18.5
		04-23-74	8.0	360	11.2	6.9	2.60
56	West Brown ditch tributary at Town of Pines	01-22-74	----	180	----	---	-------
		04-23-74	7.5	330	----	---	-------
57	East Brown ditch tributary at Town of Pines	01-22-74	----	360	----	7.2	-------
		04-23-74	7.0	420	----	---	-------
58	Unit 1 water-table well at Town of Pines	04-22-74	12.0	240	----	6.8	-------
59	Precipitation quality site near Michigan City	07-73	----	27	----	7.1	-------
		10-73	----	29	----	5.6	-------
		02-74	----	56	----	5.6	-------
		04-74	----	20	----	5.0	-------
60	Kintzele ditch at Beverly Drive	10-15-73	----	630	----	---	-------
		01-21-74	----	240	----	---	-------
		04-22-74	17.0	440	----	---	-------
61	Unit 1 artesian well at Michigan City	10-09-73	15.0	360	----	8.0	-------
		04-22-74	11.5	320	----	7.2	-------

62	Unit 4 artesian well 1 at Michigan City	10-09-73	15.0	420	----	8.2	-------
		04-22-74	12.0	390	----	7.7	-------
63	Kintzele ditch near U.S. 12	08-02-73	23.0	530	7.7	7.9	-------
		10-15-73	18.0	560	12.3	7.2	2.19
		01-21-74	3.0	250	11.6	---	73.8
		04-22-74	18.5	630	12.3	8.0	4.29
64	Unit 4 artesian well 2 at Michigan City	04-22-74	13.5	440	----	7.5	-------
65	Kintzele ditch at U.S. 20	01-21-74	4.5	130	----	7.0	-------
		04-22-74	18.0	240	----	---	-------
66	Striebel arm at U.S. 20	01-21-74	7.0	220	----	---	-------
		04-22-74	19.5	810	----	7.5	-------
67	Northeast inlet Pinhook Bog at Forrester Rd.	01-23-74	2.0	190	----	7.5	-------
		04-24-74	6.5	250	----	---	-------
68	Northeast inlet Pinhook Bog at north boundary	08-07-73	22.0	280	8.7	7.8	-------
		01-23-74	3.0	220	12.5	7.5	-------
		04-24-74	8.0	380	11.8	7.6	-------
69	East inlet Pinhook Bog	08-07-73	24.5	160	2.8	7.2	-------
70	West inlet Pinhook Bog at Wozniak Rd.	10-16-73	----	105	----	---	-------
71	Pinhook Bog at Wozniak Rd.	08-03-73	23.0	85	.9	6.2	-------
		10-16-73	11.0	160	1.7	6.9	-------
		01-23-74	1.0	140	8.0	6.9	-------
		04-24-74	11.0	60	6.8	7.6	-------
72	Pinhook Bog at open water	10-16-73	13.0	75	7.0	---	-------
		01-23-74	1.0	80	7.1	4.4	-------

Table A-1.--Field analyses (Continued)

Site	Site name	Date Measured	Temperature (°Celsius)	Specific Conductance (micromhos per cm)	Dissolved oxygen (mg/1)	pH	Streamflow (ft^3/s)
73	Pinhook Bog north end	10-16-73	----	50	----	---	-------
		01-23-74	----	80	----	---	-------
		04-24-74	----	45	----	---	-------
74	Pinhook Bog northeast	08-03-73	24.5	200	5.8	6.8	-------
		10-16-73	----	120	----	7.3	-------
		01-23-74	.0	170	2.6	5.2	-------
		04-24-74	9.0	120	3.1	6.1	-------
75	Southeast inlet Pinhook Bog	08-03-73	20.5	145	1.4	6.8	-------
		10-16-73	----	170	----	---	-------
		01-23-74	----	500	----	---	-------
		04-24-74	10.0	210	5.1	6.3	-------
76	Pinhook Bog at I-80	04-24-74	16.0	580	8.9	8.1	-------
77	Pinhook Bog at salt-storage area	08-03-73	24.0	95	3.9	7.4	-------
		10-16-73	13.0	1,380	9.6	---	-------
		04-24-74	12.5	90	7.8	7.5	-------
78	Retention pond at salt-storage area	08-03-73	26.5	5,380	9.5	8.4	-------
		10-16-73	15.0	-----	11.2	8.9	-------
		01-23-74	1.5	960	11.2	9.1	-------

Table A-2.--Chemical Analyses

(Constituents are in milligrams per litre except as otherwise noted)

Site	Date collected	Alkalinity as $CaCO_3$	Bicar-bonate	Total hardness as $CaCO_3$	Calcium, diss.	Magnesium, diss.	Iron,[a] total	Manganese,[a] total	Potassium, diss.	Sulfate, diss.
7	10-18-73	133	162	150	39	13	300	20	0.8	24
10	04-25-74	211	258	270	73	21	----	---	4.1	55
11	07-31-73	95	116	---	28[b]	11[b]	110	150	.5	4.7
12	07-26-73	76	93	99	23	10	620	10	.4	8.1
13	04-27-74	263	321	310	120	21	----	---	10	53
14	04-26-74	138	168	170	47	13	----	---	.8	33
15	10-10-73	123	150	190	52	14	2100	140	1.4	30
	04-26-74	122	149	180	39	19	----	---	----	36
16	10-10-73	176	215	260	66	24	100	130	1.2	82
	04-25-74	172	210	260	61	25	----	---	----	75
17	04-26-74	258	315	280	70	25	----	---	2.0	29
18	07-73	8	10	---	2.6[b]	0.0[b]	----	---	.3	5.4
	10-73	3	4	9	2.8	.4	----	---	.3	6.6
	02-74	7	8	13	4.1	.6	----	---	.2	7.3
	05-74	3	4	10	4.1	.7	----	---	.4	5.4
20	08-01-73	28	34	250	76	15	440	70	12	230
	01-24-74	30	37	190	50	15	----	---	6.3	150
22	01-24-74	37	45	180	49	13	----	---	7.8	150
23	01-24-74	25	30	65	14	5.3	----	---	1.7	30
25	08-02-73	148	180	210	59	15	1400	240	3.3	45
	10-17-73	143	174	190	53	14	----	---	2.9	43
	01-24-74	189	231	310	85	24	----	---	11	88
26	08-02-73	128	156	140	40	9.7	3100	170	4.6	15

Table A-2.--Chemical Analyses (Continued)

(Constituents are in milligrams per litre except as otherwise noted)

Site	Date collected	Alkalinity as $CaCO_3$	Bicar- bonate	Total hardness as $CaCO_3$	Calcium, diss.	Magnesium, diss.	Iron,[a] total	Manganese,[a] total	Potassium, diss.	Sulfate, diss.
27	08-02-73	61	74	87	26	5.4	7600	170	1.9	23
28	10-09-73	184	224	180	49	15	4100	150	5.3	10
29	04-25-74	176	215	190	43	19	----	---	3.0	17
30	08-02-73	279	340	---	-----	-----	----	---	----	130
31	08-02-73	267	326	330	83	30	2300	210	2.1	54
32	07-73	8	10	---	3.2[b]	1.0[b]	----	---	.2	7.1
	10-73	.8	1	11	3.3	.7	----	---	.9	5.9
	02-74	5	6	7	1.8	.5	----	---	.8	1.7
	05-74	3	4	16	5.2	.7	----	---	.4	6.6
33	08-02-73	146	178	170	42	16	1100	240	1.7	28
	01-22-74	48	59	89	16	12	----	---	3.9	43
35	08-02-73	99	121	160	39	15	490	50	3.4	48
	04-25-74	140	171	180	40	19	----	---	4.3	33
38	08-02-73	113	138	122	29	12	3600	470	1.3	8.4
	04-23-74	66	80	96	22	10	----	---	.8	26
39	10-09-73	481	587	390	69	53	140	30	8.2	2.5
40	04-23-74	325	396	310	56	41	----	---	11	1.2
41	08-02-73	98	120	140	32	15	430	70	2.0	38
42	04-23-74	52	63	160	38	16	----	---	3.0	54
43	04-23-74	328	400	290	57	36	----	---	4.0	4.6
48	08-02-73	126	153	160	42	14	2800	290	2.3	30
52	08-02-73	164	200	180	44	16	4000	150	2.4	17

55	08-02-73	175	213	230	56	21	2100	240	2.8	44
	10-15-73	121	147	230	60	20	----	---	3.7	100
58	04-22-74	58	71	110	27	50	----	---	8.0	65
59	07-73	7	9	---	2.3[b]	1.0[b]	----	---	.3	5.6
	10-73	2	3	8	2.8	.3	----	---	.3	6.4
	02-74	2	3	14	4.0	1.0	----	---	.2	11
	05-74	2	2	9	2.8	.5	----	---	.6	3.8
61	10-09-73	160	194	120	34	9.4	890	30	5.3	10
	04-22-74	157	191	120	33	10	----	---	----	10
62	10-09-73	202	246	71	19	5.8	420	20	3.2	1.6
	04-22-74	202	247	67	17	6.0	----	---	----	1.1
63	08-02-73	208	254	210	50	20	980	80	3.4	42
	01-21-74	46	56	86	18	10	----	---	2.2	41
64	04-22-74	249	304	180	33	23	----	---	4.2	.5
71	08-03-73	39	47	40	10	3.7	9000	620	2.2	4.2
	10-16-73	60	73	58	14	5.5	----	---	8.1	9.2
72	10-16-73	26	32	33	8.4	2.8	1600	250	5.6	5.2
74	08-03-73	26	32	34	8.5	3.0	2400	350	2.7	8.0
	04-24-74	11	13	27	7.0	2.2	----	---	3.0	14
75	01-23-74	---	---	---	----	----	0	---	----	----
	04-24-74	17	21	30	7.0	3.0	----	---	3.3	11
76	04-24-74	60	73	57	16	4.2	----	---	6.1	14
77	08-03-73	---	---	---	9.1[b]	----	----	---	----	----
	10-16-73	123	150	110	28	8.5	----	---	7.4	48
78	08-03-73	---	---	---	37[b]	----	----	---	----	----
	10-16-73	88	101	110	37	5.1	----	---	2.9	35
	01-23-74	54	46	41	12	2.7	----	---	3.3	14

Table A-2.--Chemical Analyses (Continued)

(Constituents are in milligrams per litre except as otherwise noted)

Site	Date collected	Sodium percent	Sodium adsorption ratio	Sodium, diss.	Chloride, diss.	Phosphorus, total	Nitrite as N, total	Nitrate as N, total	Ammonia nitrogen as N, total	Organic nitrogen as N, total
7	10-18-73	4	0.1	3.0	3.6	------	0.00	0.04	----	120
	01-24-74	--	---	---	----	0.00	.00	.37	0.20	.10
10	07-31-73	--	---	---	----	.04	.01	.07	----	------
	01-24-74	--	---	---	----	.00	.01	.79	.08	.28
	04-25-74	27	1.2	47	83	-----	----	----	----	------
11	07-31-73	---	---	11	24	.07	.00	.00	----	------
12	07-26-73	18	.4	10	23	.03	.00	.11	----	------
13	04-27-74	37	2.1	86	120	-----	----	----	----	------
14	04-26-74	2	.1	1.8	3.5	-----	----	----	----	------
15	10-10-73	5	.1	4.6	26	.06	.00	.06	.13	------
	04-26-74	---	---	----	32	-----	----	----	----	------
16	10-10-73	29	1.3	50	78	.05	.00	.01	.45	.05
	04-25-74	---	---	----	73	-----	----	----	----	------
17	04-26-74	6	.2	8.6	7.6	-----	----	----	----	------
18	07-73	---	---	.5	1.4	.00	.02	.68	----	------
	10-73	11	.1	.5	.7	-----	.04	.53	----	------
	02-74	16	.1	1.1	.9	-----	.01	.58	.71	------
	05-74	3	.0	.2	.2	-----	----	----	.23	------
20	08-01-73	8	.3	11	9.4	.03	.00	.01	----	------
	01-24-74	11	.4	11	11	-----	----	----	----	------
22	01-24-74	13	.4	13	8.1	-----	----	----	----	------
23	01-24-74	13	.2	4.7	6.0	-----	----	----	----	------
24	08-02-73	---	---	-----	-----	0.13	----	0.05[c]	----	------

25	08-02-73	27	1.1	37	68	.02	.02	.19	----	------
	10-17-73	26	1.0	32	58	----	----	----	----	------
	01-24-74	35	2.0	79	130	----	----	----	----	------
26	08-02-73	34	1.3	35	56	.02	.00	.00	----	------
27	08-02-73	6	.1	2.5	9.1	.71	.01	.02	----	------
28	10-09-73	8	.2	7.1	11	.12	.00	.01	1.2	.40
29	04-25-74	15	.5	15	24	-----	----	----	----	------
30	08-02-73	---	---	-----	120	6.0	.00	27	.09	------
31	08-02-73	7	.3	12	19	.19	.01	.47	----	------
32	07-73	---	---	1.2	1.1	.00	.01	.93	----	------
	10-73	5	.0	.3	.7	----	.01	.87	----	------
	02-74	24	.2	1.1	.7	----	.01	.03	.15	------
	05-74	1	.0	.1	1.6	----	----	-----	.50	------
33	08-02-73	20	.7	20	32	.08	.01	.28	----	------
	01-22-74	24	.6	14	23	----	----	-----	----	------
35	08-02-73	53	2.9	83	130	.11	.01	.99	----	------
	04-25-74	37	1.6	50	84	----	----	-----	----	------
38	08-02-73	14	.4	8.9	13	.12	.00	.00	----	------
	04-23-74	18	.4	10	13	----	----	-----	----	------
39	10-09-73	24	1.3	59	29	.04	.01	.00	.57	.00
40	04-23-74	47	3.2	130	210	----	----	-----	----	------
41	08-02-73	18	.5	15	23	.05	.01	1.09	----	------
42	04-23-74	25	.9	25	80	----	----	-----	----	------
43	04-23-74	16	.7	26	11	----	----	-----	----	------
48	08-02-73	20	.6	19	30	.08	.00	1.2	----	------
52	08-02-73	21	.7	22	29	.09	.00	.05	----	------
55	08-02-73	18	.7	23	31	.05	.00	.46	----	------
	10-15-73	24	1.0	34	56	----	----	-----	----	------
58	04-22-74	23	.7	16	12	----	----	-----	----	------

Table A-2.--Chemical Analyses (Continued)

(Constituents are in milligrams per litre except as otherwise noted)

Site	Date collected	Sodium percent	Sodium adsorption ratio	Sodium, diss.	Chloride, diss.	Phosphorus, total	Nitrite as N, total	Nitrate as N, total	Ammonia nitrogen as N, total	Organic nitrogen as N, total
59	07-73	--	----	1.0	1.1	.00	.01	0.68	----	-------
	10-73	9	.1	.4	.8	----	.02	.89	----	-------
	02-74	16	.2	1.3	1.8	----	.01	1.49	0.85	-------
	05-74	2	.0	.1	.4	----	----	-----	.17	-------
61	10-09-73	36	1.3	33	20	.06	.00	.00	.55	0.27
	04-22-74	--	----	------	16	----	----	-----	----	-------
62	10-09-73	69	3.9	76	22	.02	.00	.00	.41	.00
	04-22-74	--	----	------	21	----	----	-----	----	-------
63	08-02-73	37	1.8	58	60	.07	.01	.29	----	-------
	01-21-74	31	.8	18	26	----	----	-----	----	-------
64	04-22-74	36	1.5	47	13	----	----	-----	----	-------
71	08-03-73	8	.1	1.8	2.1	.11	.01	.00	----	-------
	10-16-73	28	.7	12	17	----	----	-----	----	-------
72	10-16-73	13	.2	27	5.5	----	.00	.00	----	-------
74	08-03-73	45	1.1	14	25	.05	.00	.02	----	-------
	04-24-74	53	1.4	16	27	----	----	-----	----	-------
75	04-24-74	69	2.8	35	52	----	----	-----	----	-------
76	04-24-74	75	5.1	88	130	----	----	-----	----	-------
77	08-03-73	--	----	------	32	----	----	-----	----	-------
	10-16-73	82	10	240	340	----	----	-----	----	-------
78	08-03-73	--	----	------	82	----	----	-----	----	-------
	10-16-73	96	49	1200	1900	----	----	-----	----	-------
	01-23-74	90	12	180	270	----	----	-----	----	-------

a Units are micrograms per litre
b Value represents the total phase rather than dissolved
c Value represents nitrite and nitrate sum

Table A-3.--Trace element analyses

(Constituents are in micrograms per kilogram except as otherwise noted)

Site	Date Collected	Aluminum, total[a]	Cadmium, bed material	Chromium, bed material	Cobalt, bed material	Copper, bed material	Cyanide, bed material	Lead, bed material	Mercury, bed material	Nickel, total[a]	Zinc, bed material
a 11	07-31-73	70	10	0	------	10	-----	50	0.0	25	50
a 15	10-10-73	70	2	0	0	2	-----	12	0	0	70
a 16	10-10-73	90	2	0	1	2	-----	12	0	1	240
20	08-01-73	0	0	8,000	<3,000	6,000	1,000	25,000	20	< 25	18,000
26	08-02-73	0	0	7,000	<3,000	3,000	2,000	5,000	20	<25	12,000
a 28	10-09-73	110	2	0	0	3	-----	7	0	1	470
31	08-02-73	0	0	20,000	18,000	73,000	0	65,000	90	<25	195,000
35	08-02-73	0	1,000	5,000	<3,000	4,000	1,000	30,000	40	<25	43,000
a 39	10-09-73	100	0	0	0	1	-----	4	0	0	40
a 61	10-09-73	80	0	0	0	4	-----	5	0	1	50
a 62	10-09-73	130	1	0	0	2	-----	6	0	0	90
63	08-02-73	0	0	5,000	<3,000	11,000	2,000	10,000	40	<25	27,000

a Values are in micrograms per litre

Table A-4.--Organic analyses

(Constituents are in micrograms per kilogram unless otherwise noted)

Site	Date Collected	Total organic carbon[a]	Aldrin	Chlordane	DDD	DDE	DDT	Diazinon	Dieldrin	Endrin	Ethyl parathion	Ethyl trithion
11	04-25-74	---	0.0	0	4.9	0.0	1.9	0.0	1.0	0.0	0.0	0.0
16	10-10-73	3.0	---	-	---	---	---	---	---	---	---	---
28	10-17-73	8.0	---	-	---	---	---	---	---	---	---	---
31	04-24-74	---	.0	4	1.4	.0	.5	.0	.4	.0	.0	.0
35	04-25-74	---	.0	6	1.5	.0	1.6	.0	1.3	.0	.0	.0
39	10-09-73	2.5	---	-	---	---	---	---	---	---	---	---
41	04-24-74	---	.0	0	.0	.0	.0	.0	.3	.0	.0	.0
48	04-23-74	---	.0	0	.0	.0	.0	.0	.1	.0	.0	.0
55	04-23-74	---	.0	0	.0	.0	.0	.0	.2	.0	.0	.0
61	10-09-73	4.0	---	-	---	---	---	---	---	---	---	---
62	10-09-73	1.5	---	-	---	---	---	---	---	---	---	---
63	04-22-74	---	.0	5	.6	.0	.4	.0	.1	.0	.0	.0
68	04-24-74	---	.0	0	1.5	.0	.0	.0	.2	.0	.0	.0
71	04-24-74	---	.0	0	.9	.0	.0	.3	.0	.0	.0	.0

Table A-4.--Organic analyses (Continued)

(Constituents are in micrograms per kilogram unless otherwise noted)

Site	Date Collected	Ethion	Heptachlor epoxide	Heptachlor	Lindane	Malathion	Methyl parathion	Methyl trithion	PCB	PCN	Toxa-phene
11	04-25-74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	<5	0	0
31	04-24-74	.0	.0	.0	.0	.0	.0	.0	0	0	0
35	04-25-74	.0	.0	.0	.0	.0	.0	.0	15	0	0
41	04-24-74	.0	.0	.0	.0	.0	.0	.0	0	0	0
48	04-23-74	.0	.0	.0	.0	.0	.0	.0	0	0	0
55	04-23-74	.0	.0	.0	.0	.0	.0	.0	0	0	0
63	04-22-74	.0	.0	.0	.0	.0	.0	.0	<5	0	0
68	04-24-74	.0	.0	.0	.0	.0	.0	.0	0	0	0
71	04-24-74	.0	.0	.0	.0	.0	.0	.0	0	0	0

a Milligrams per litre

Table A-5.--Bacteriological Analyses

(Values are in colonies per 100 millilitres)

Site	Date collected	Total coliform	Fecal coliform	Fecal streptococcus
1	10-18-73	1,000	--------	a5
2	10-18-73	1,000	--------	a5
3	10-18-73	320	--------	<5
4	10-18-73	200	--------	a5
5	10-18-73	340	--------	a4
7	10-18-73	940	--------	<5
10	10-18-73	a500	--------	a10
11	07-31-73	a21,000	1,900	8,800
	10-18-73	--------	--------	9,700
	01-24-74	--------	a18	a15
	04-25-74	--------	<7	<5
12	08-07-73	a500	<50	a25
15	10-10-73	<4	--------	---------
16	10-10-73	a20	--------	---------
20	08-07-73	a450	<50	<25
24	08-07-73	>16,000	a200	1,500
	10-18-73	--------	--------	a220
	01-24-74	--------	<2	a10
25	08-07-73	1,600	<50	a180
	01-24-74	--------	<50	<5
26	08-07-73	--------	<50	a50
27	08-07-73	10,000	a150	a19,000
	01-23-74	--------	a22	350
	04-25-74	--------	a2	850
28	10-09-74	410	--------	---------
	10-17-74	140	--------	<5
29	04-25-74	--------	a7	240
30	08-07-73	>110,000	46,000	1,600
	10-17-73	--------	--------	750
	01-23-74	--------	a250,000	>10,000
31	08-07-73	22,000	2,400	520
	10-17-73	--------	--------	520
	01-23-74	--------	310	1,700
	04-24-74	--------	<7	a10
33	10-17-73	>4,000	--------	190
	01-22-74	--------	220	2,000
	04-23-74	--------	a64	88

Table A-5.--Bacteriological Analyses (Continued)

(Values are in colonies per 100 millilitres)

Site	Date collected	Total coliform	Fecal coliform	Fecal streptococcus
35	10-17-73	6,400	--------	480
	01-23-74	--------	640	750
	04-25-74	--------	720	650
36	08-08-73	a52,000	1,000	2,300
	10-17-73	--------	--------	750
	01-22-74	--------	260	1,900
	04-23-74	--------	160	a30
37	08-08-73	a84,000	>8,600	42,000
	10-17-73	--------	--------	a5,000
	01-22-74	--------	900	1,300
38	10-17-73	1,600	--------	76
39	10-09-73	<4	--------	---------
41	08-08-73	18,000	a150	800
	10-16-73	a2,000	--------	400
	01-22-74	--------	600	1,500
	04-24-74	--------	a14	a5
45	08-07-73	4,400	a700	700
	10-17-73	--------	--------	440
	01-23-74	--------	290	2,200
	04-24-74	--------	a7	a60
48	08-08-73	18,000	a300	1,200
	04-23-74	--------	a4,900	750
52	08-08-73	20,000	a100	1,300
	10-15-73	--------	--------	320
55	08-08-73	>4,000	a350	2,100
	10-15-73	--------	--------	880
	01-22-74	--------	170	1,900
61	10-09-73	<4	--------	---------
63	08-08-73	20,000	a350	1,400
	10-15-73	--------	--------	360
	01-21-74	--------	400	3,100
	04-22-74	--------	230	83
68	08-07-73	--------	a50	1,600
	01-23-74	--------	370	980
	04-24-74	--------	<7	a85
69	08-07-73	3,800	a100	a300
71	10-16-73	1,400	--------	100
	01-23-74	--------	a2	220

Table A-5.--Bacteriological Analyses (Continued)
(Values are in colonies per 100 millilitres)

Site	Date collected	Total coliform	Fecal coliform	Fecal streptococcus
72	10-16-73	1,600	--------	a15
75	08-07-73	3,300	50	600
	04-24-74	-------	a29	---------

a Estimated count based on non-ideal plate count