STREAMFLOW AND WATER QUALITY OF THE GRAND CALUMET RIVER, LAKE COUNTY, INDIANA, AND COOK COUNTY, ILLINOIS, OCTOBER 1984

By Charles G. Crawford and David J. Wangsness

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 86-4208

Prepared in cooperation with the

INDIANA STATE BOARD OF HEALTH

Indianapolis, Indiana

1987

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
6023 Guion Road, Suite 201
Indianapolis, Indiana 46254

Copies of this report
can be purchased from:

U.S. Geological Survey
Books and Open-File Reports
Box 25425, Federal Center, Bldg. 41
Denver, Colorado 80225
(Telephone: [303] 236-7476)

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

ILLUSTRATIONS--Continued

TABLES

CONVERSION FACTORS

For readers who prefer to use metric (International System) units, conversion factors for inch-pound units of measure used in this report are listed below:

Multiply inch-pound units	by	To obtain metric units
acre	0.4047	hectare
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
square foot (ft^2)	0.09294	square meter (m^2)
inch (in.)	25.4	millimeter (m)
mile (mi)	1.609	kilometer
square mile (mi^2)	2.59	square kilometer (km^2)
pound per day (lb/d)	0.4536	kilogram per day (kg/d)

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8\ °C) + 32$$

Notes on the reporting of time, altitude or elevation, and location along the stream channel:

1. Time in hours and minutes is reported in military time for the Eastern Standard Time Zone; for example 0122 is 1:22 a.m. eastern time, 1322 is 1:22 p.m. eastern time.

2. Lake Michigan water-level elevations or altitudes are reported in terms of height above the IGLD of 1955 (International Great Lakes Datum of 1955) which is a geodetic datum referenced to the mean water level at Fathers Point, Quebec, Canada. Water-level elevations for all other points are reported in feet above the NGVD of 1929 (National Geodetic Vertical Datum 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."

3. Locations on the East Branch Grand Calumet River and the Indiana Harbor Ship Canal are in river miles from the point where the Indiana Harbor Ship Canal discharges into the Indiana Harbor, Lake County, Indiana. For this report, the East Branch of the river and the Indiana Harbor Ship Canal are considered to be a single drainage. Locations on the West Branch of the river are in river miles from its confluence with the Little Calumet River, Cook County, Illinois.

All water-quality standards referred to in this report are those of the Indiana Stream Pollution Control Board as stated in 330 IAC 2-2.

ABBREVIATIONS AND SYMBOLS

Abbreviation or Symbol	Description
BOD	Biochemical-oxygen demand
$CaCO_3$	Calcium carbonate
CBOD	Carbonaceous biochemical-oxygen demand
CL	Chloride
°C	Degrees Celsius
DO	Dissolved oxygen
ds	Downstream
DS	Dissolved solids
ECWTP	East Chicago Wastewater-Treatment Plant
°F	Degree Fahrenheit
ft	Foot
ft/d	Foot per day
ft/s	Foot per second
ft^2	Square foot
ft^3/s	Cubic foot per second
g	Gram
GHT	Gage Height
GRAD	Gradient between water-surface elevation in HWTP effluent channel and the water-surface elevation in the stream channel near the Indiana East-West Toll Road
GWTP	Gary Wastewater-Treatment Plant
HWTP	Hammond Wastewater-Treatment Plant
IAC	Indiana Annotated Code
IGLD	International Great Lakes Datum
lb/d	Pound per day
mg/L	Milligram per liter
mi	Mile
mi^2	Square mile
min	Minute
N	Nitrogen
n.a.	Not applicable
n.d.	No data
NGVD	National Geodetic Vertical Datum
P	Phosphorus
PCB	Polychlorinated biphenols
pH	Negative log base-10 of the hydrogen ion activity, in moles per liter
Q	Flow
RM	River mile
SC	Specific conductance
SO_4	Sulfate
μg/L	Micrograms per liter
us	Upstream

Abbreviation or Symbol	Description
μS/cm	Microsiemens per centimeter at 25 °Celsius (formerly micromhos per centimeter at 25 °Celsius)
USGS	U.S. Geological Survey
WTP	Wastewater-treatment plant

STREAMFLOW AND WATER QUALITY OF THE GRAND CALUMET RIVER, LAKE COUNTY, INDIANA, AND COOK COUNTY, ILLINOIS, OCTOBER 1984

By Charles G. Crawford and David J. Wangsness

ABSTRACT

A diel (24-hour) water-quality survey was done to investigate the sources of dry-weather waste inputs attributable to sources other than permitted point-source effluent and to provide water-quality planners and managers information necessary to evaluate the waste-load assimilative capacity of the Grand Calumet River, Lake County, Indiana, and Cook County, Illinois, in October 1984.

Flow in the Grand Calumet River consists almost entirely of municipal and industrial effluents which comprised more than 90 percent of the 500 cubic feet per second flow observed at the confluence of the East Branch Grand Calumet River and the Indiana Harbor Ship Canal during the study. At the time of the study, virtually all of the flow in the West Branch Grand Calumet River was municipal effluent. Diel variations in streamflow of as much as 300 cubic feet per second were observed in the East Branch near the ship canal. The diel variation diminished at the upstream sampling sites in the East Branch. In the West Branch, the diel variation in flow was quite drastic; complete reversals of flow were observed at sampling stations near the ship canal.

Average dissolved-oxygen concentration at stations in the East Branch ranged from 5.7 to 8.2 milligram per liter and at stations in the West Branch from 0.8 to 6.6 milligrams per liter. Concentrations of dissolved solids, suspended solids, biochemical-oxygen demand, ammonia, nitrite, nitrate, and phosphorus were substantially higher in the West Branch than in the East Branch. In the East Branch, only the Indiana Stream Pollution Control Board water-quality standards for total phosphorus and phenol were exceeded. In the West Branch, water-quality standards for total ammonia, chloride, cyanide, dissolved solids, fluoride, total phosphorus, mercury, and phenol were exceeded and dissolved oxygen was less than the minimum allowable.

Some chemical-mass discharges in the Grand Calumet River could not be accounted for by known effluents. Three areas of significant differences between cumulative effluent and instream chemical-mass discharges were identified in the East Branch and one in the West Branch. The presence of unidentified waste inputs in the East Branch were indicated by differences in the chemical-mass discharges at Virginia Avenue, Industrial Highway, and Cline Avenue. Elevated suspended solids, biochemical-oxygen demand, and ammonia chemical-mass discharges at Columbia Avenue indicated the presence of a source of what may have been untreated sewage to the West Branch during the survey.

INTRODUCTION

Background

Water quality in the Grand Calumet River has been a source of public concern for nearly 20 years. The Federal Water Pollution Control Administration (1967) sponsored the Calumet Area Surveillance Project in the mid-1960's, one of the first in-depth evaluations of water quality in the river. Investigators at a conference held in 1970 concluded that, although numerous pollution-abatement measures had been initiated in the region, water quality in general had either shown little improvement or deterioration in the Indiana Harbor and West Branch of the river but water quality in the East Branch of the river had improved (U.S. Department of Health, Education, and Welfare, 1970). It was noted during this conference that water quality in the East Branch of the river had improved. Still, Romano and others (1977) concluded that the Grand Calumet River was a major source of heavy metals to Lake Michigan. Harrison and others (1979) concluded the plume associated with the Indiana Harbor Ship Canal was the primary contributor of contaminants at the water intakes for the Chicago South Water Filtration Plant. Combinatorics, Inc. (1974) recommended advanced waste treatment for removal of suspended solids, BOD (biochemical-oxygen demand), ammonia, and phosphorus. Numerous improvements have been made to treatment facilities in the Grand Calumet River basin in the past 10 years as a result of these recommendations. HydroQual, Inc. (1984), in a study done for the Indiana State Board of Health, reported significant amounts of waste inputs not attributable to known sources. Furthermore, the investigators concluded that water-quality standards would be difficult to attain with existing technology if these sources of waste input were not identified and eliminated.

Purpose and Scope

The U.S. Geological Survey, in cooperation with the Indiana State Board of Health, began a study to investigate the sources of dry-weather waste inputs to the Grand Calumet River attributable to other than point-source effluent and to provide water-quality planners and managers with the information necessary to evaluate the waste-load assimilative capacity of the river. Major differences between this study and previous studies were an increased frequency of sample collection and the measurement of effluent discharge or streamflow at all sampling locations at the time of sample collection. The report contains an analysis of streamflow and water-quality data collected during a 24-hour period of dry-weather flow in October 1984 and the results of a small follow-up study done in September 1985 to answer questions about the flow balance in the West Branch Grand Calumet River not resolved by the original study.

Acknowledgments

The authors received assistance and cooperation from many people during the study. T. P. Chang and John Winters of the Indiana State Board of Health assisted in planning the study and provided personnel and equipment to help with sample collection. Personnel of DuPont, E. I. DeNemours and Company, Gary Sanitary District, Hammond Sanitary District, and U.S. Steel Corporation provided access to properties or assisted with sample collection. Personnel of the East Chicago Sanitary District assisted with sample collection and provided facilities for a temporary field laboratory during the study.

THE GRAND CALUMET RIVER BASIN

The Grand Calumet River system extends along the southern shoreline of Lake Michigan in northwest Indiana and includes parts of the cities of Gary, East Chicago, and Hammond (fig. 1). The river system drains about 25 mi^2 (square miles) and consists of three parts: The East Branch, the West Branch, and the Indiana Harbor Ship Canal and Indiana Harbor. The East Branch of the river is about 10 mi (mile) long and flows from its headwaters near the U.S. Steel Corporation Gary Works to its confluence with the Indiana Harbor Ship Canal. The East Branch ranges in depth from about 3-4 ft (feet) in the upstream reaches to about 8-10 ft near its confluence with the ship canal. Average stream velocity is approximately 1 ft/s.

The West Branch Grand Calumet River flows from its confluence with the Indiana Harbor Ship Canal to its confluence with the Little Calumet River in Illinois, a distance of 6 mi. West of Columbia Avenue in Hammond (fig. 1), the river flows to the west. East of Columbia Avenue, the river flows east or west depending on the water level in Lake Michigan, effluent flow in the two branches of the river and the ship canal, and the influence of wind direction and velocity. The West Branch is shallower than the East Branch and has a depth of about 2 ft. Average stream velocity is highly variable and ranges from about 0.2 to 1 ft/s.

The Indiana Harbor Ship Canal flows northward from its confluence with the Grand Calumet River and discharges into Lake Michigan. The ship canal is virtually an extension of the East Branch. Depth of the canal ranges from 5 to 10 ft near its confluence with the river to a depth of about 30 ft downstream from the Lake George Canal (fig. 1). Downstream from the Lake George Canal, the canal is maintained at a 30-ft depth by dredging to enable ship traffic to pass through the canal.

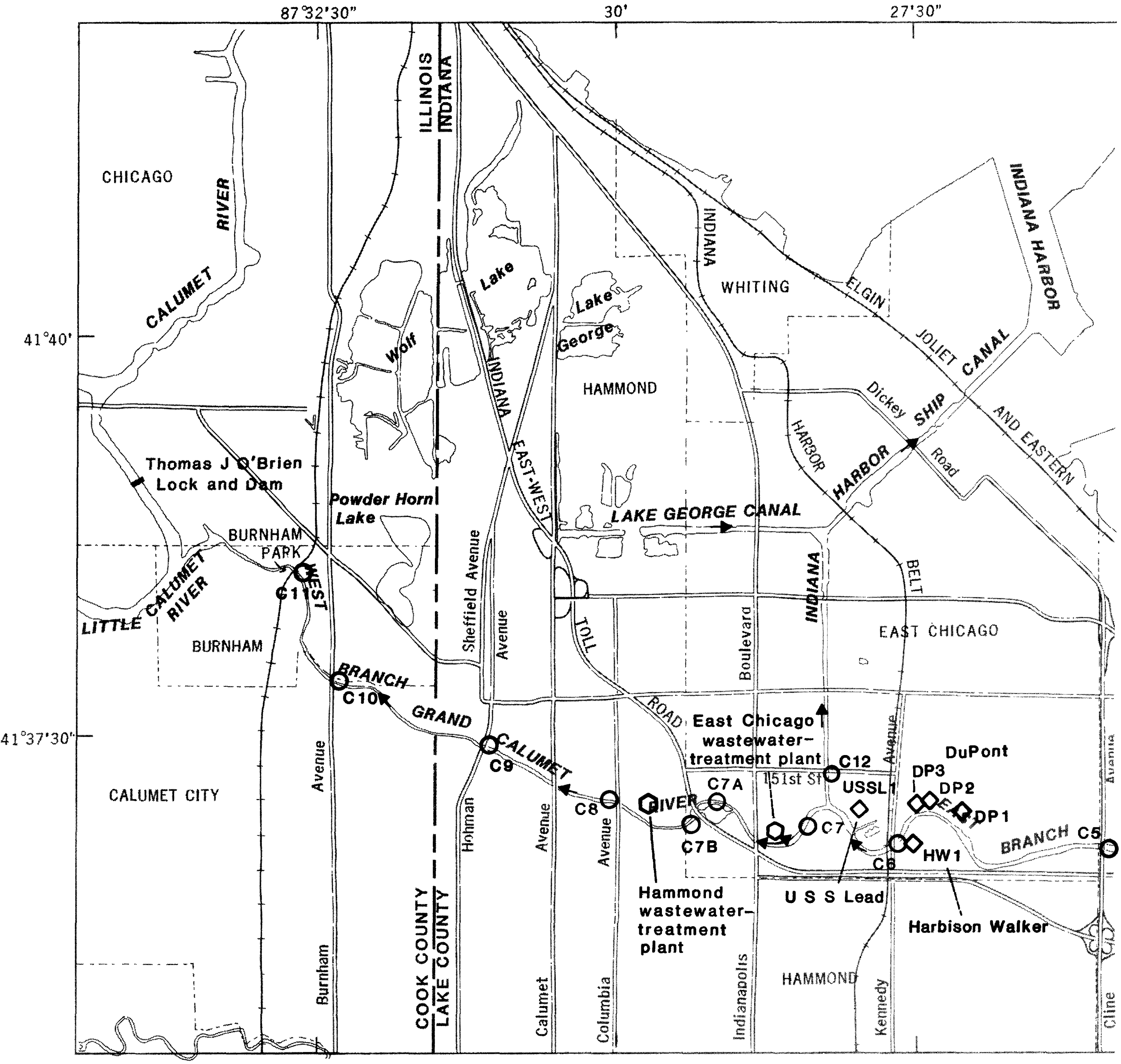
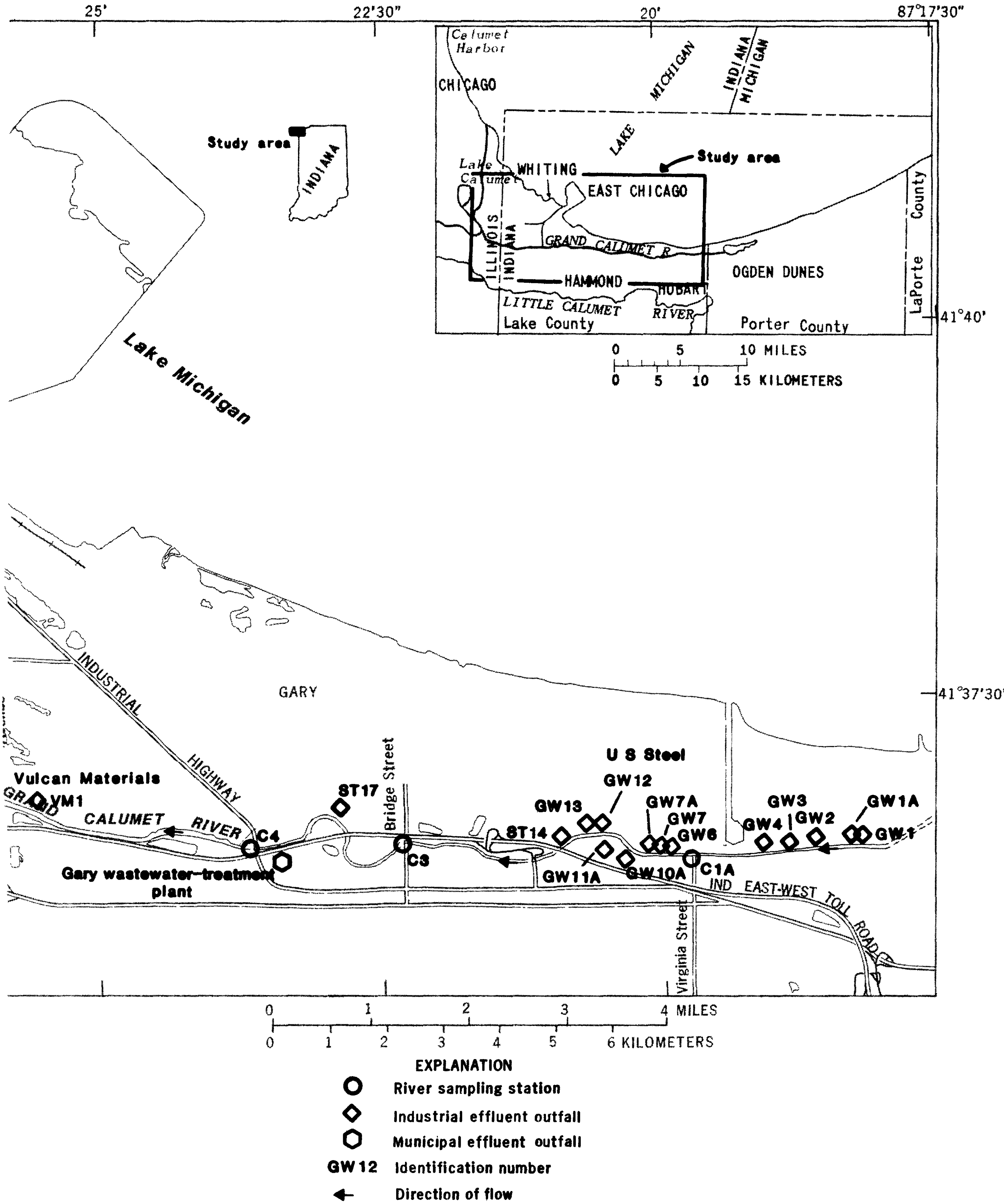


Figure 1.-- Study area and locations of sampling stations.


25'
22'30"
20'
87°17'30"
41°40'
41°37'30"
Study area
INDIANA
Lake Michigan
Calumet Harbor
CHICAGO
MICHIGAN
INDIANA
MICHIGAN
LAKE
Study area
Lake Calumet
WHITING
EAST CHICAGO
ILLINOIS
INDIANA
GRAND CALUMET R
HAMMOND
HOBART
OGDEN DUNES
LITTLE CALUMET
RIVER
Lake County
Porter County
LaPorte County
0 5 10 MILES
0 5 10 15 KILOMETERS
INDUSTRIAL HIGHWAY
GARY
Vulcan Materials
VM1
GRAND CALUMET RIVER
C4
Gary wastewater-treatment plant
ST17
Bridge Street
C3
U S Steel
GW12
GW13
ST14
GW11A
GW7A
GW7
GW6
GW10A
C1A
GW3
GW4
GW2
GW1A
GW1
IND EAST-WEST TOLL ROAD
Virginia Street
0 1 2 3 4 MILES
0 1 2 3 4 5 6 KILOMETERS
EXPLANATION
River sampling station
Industrial effluent outfall
Municipal effluent outfall
GW12 Identification number
Direction of flow

The hydrology of the Grand Calumet River has been greatly altered by human activities. On early maps of the region (circa 1790), the Grand and Little Calumet Rivers of today are shown as a single river (Cook and Jackson, 1978). The river began in what is now Laporte County, Ind., near the headwaters of the present-day Little Calumet River, and flowed westward into Illinois. The river made a hairpin turn in Illinois, flowed back into Indiana, and discharged into Lake Michigan near present-day Gary, Ind. A second small river drained Lake Calumet into Lake Michigan. By the early 1800's, a portage connecting the two rivers was shown on at least one map of the area. A canal in the vicinity of the previously mapped portage was shown on a map drawn in 1812 (Cook and Jackson, 1978). The names "Grand Calumet" and "Little Calumet" were used as early as 1821 by John Tipton in his report of the Indiana-Illinois boundary survey (Robertson and Riker, 1942, p. 269). At this time, the river flowed into Lake Michigan at two points, one in Indiana and one in Illinois. During this survey, Tipton reported that the Grand Calumet River had little or no current (Robertson and Riker, 1942, p. 271). The word Calumet derives from Potawatomi and Delaware Indian words signifying a body of deep, still water (Dunn, 1919, p. 87). Both mouths frequently became clogged with sand, refuse, and weeds. The clearing of the channel during the development of a harbor at the Illinois mouth in the 1870's made it easier for water to flow toward Illinois and the river mouth in Indiana eventually became permanently clogged. Plans for the Indiana Harbor Ship Canal were made in 1877, but the first mile was not completed until 1909 (Romano, 1976). Heavy industry's need of the lake for transport of raw materials and finished products, as well as a source of process water and location for waste disposal, brought about industrialization of the area in the late 1800's and the early 1900's. The region is one of the most industrialized areas in the United States, and major industries include American Steel Foundries, Inland Steel Company, LTV Steel Corp., and U.S. Steel Corporation; Amoco Oil Company, and DuPont, E. I. DeNemours and Company.

With the growth of industry came urbanization of the region. The major population centers in the drainage basin are East Chicago, Gary, Hammond, and Whiting. According to the 1980 census, the combined population of these cities is about 290,000 (U.S. Department of Commerce, 1982).

Flow in the river system is controlled mainly by the intake and discharge of water by industries and municipal wastewater-treatment plants. During dry weather, streamflow is about 90 percent effluent. Drastic changes (plus or minus 100 percent) in streamflow occur within a few hours because of fluctuations in effluent discharges. The contribution of surface runoff is relatively small owing to the small drainage area and sandy texture of the soils. Consequently, seasonal fluctuations associated with more natural river systems (such as flooding or low flows in summer and fall) are small.

DATA-COLLECTION PROCEDURES

Study Duration and Sampling Frequency

The Grand Calumet River water-quality survey was a diel survey that began at 0900 on October 3, 1984 (day 1), and ended with the final sampling at 0900 on October 4, 1984 (day 2). At U.S. Steel Corporation outfalls, the effluents were sampled and water discharge measured every 4 to 6 hours. At the remaining stations, samples were collected and water discharge measured every 2 hours for a total of 13 samples and measurements per station during the 24-hour period.

Selection of Sampling Stations

Sampling stations were selected on the basis of information from previous studies and a reconnaissance of the area in September 1984. Color infrared aerial photographs (scale 1:500) of the river channel were also used to determine areas of possible non-point source contributions. Sampling locations were selected to represent conditions upstream and downstream of major effluent discharges. Within these locations, sampling stations were selected to meet necessary criteria for accurate measurement of flow and collection of representative water samples. Station security and safety of personnel were also considered.

Eleven sampling stations were chosen on the Grand Calumet River: five on the East Branch (C1A, C3, C4, C5, and C6) and six on the West Branch (C7, C7A, C8, C9, C10, and C11). One station (C12) was on the Indiana Harbor Ship Canal, immediately downstream from the confluence with the Grand Calumet River. Effluent was sampled at all 23 known municipal and industrial outfalls discharging effluents to the river. The major dischargers are U.S. Steel Corporation (14 outfalls); DuPont, E. I. DeNemours and Company (3 outfalls), and the ECWTP (East Chicago Wastewater Treatment Plant); GWTP (Gary Wastewater Treatment Plant); HWTP (Hammond Wastewater Treatment Plant) (3 effluents)[1]. The locations of all sampling stations and effluent outfalls are shown in figure 1. Stations are described in table 1. For consistency, station identifiers used by a previous investigator (HydroQual, Inc., 1984) were retained for this study.

---

[1]Use of trade, product, industry, or firm names in this report is for identification or location purposes only, and does not constitute endorsement of products by the U.S. Geological Survey, nor impute responsibility for any present or potential effects on natural resources.

Table 1.--Stations sampled in the Grand Calumet River basin, October 3-4, 1984

Station ID	Station description	River mile	River segment
C1A	East Branch Grand Calumet River at Virginia Street	12.4	East
C3	East Branch Grand Calumet River at Bridge Street	10.0	East
C4	East Branch Grand Calumet River at Industrial Highway	8.5	East
C5	East Branch Grand Calumet River at Cline Avenue	6.5	East
C6	East Branch Grand Calumet River at Kennedy Avenue	4.7	East
C12	Indiana Harbor Ship Canal at 151st Street	3.8	East
GW1	U.S. Steel outfall 002	13.5	East
GW1A	U.S. Steel outfall 005	13.5	East
GW2	U.S. Steel outfall 007	13.3	East
GW3	U.S. Steel outfall 010	13.1	East
GW4	U.S. Steel outfall 015	12.9	East
GW6	U.S. Steel outfall 018	12.4	East
GW7	U.S. Steel outfall 019	12.3	East
GW7A	U.S. Steel outfall 020	12.2	East
GW10A	U.S. Steel outfall 028	11.8	East
GW11A	U.S. Steel outfall 030	11.6	East
GW12	U.S. Steel outfall 031	11.5	East
GW13	U.S. Steel outfall 032	11.5	East
ST14	U.S. Steel outfall 033	11.3	East
ST17	U.S. Steel outfall 034	9.2	East
GWTP	Gary wastewater-treatment plant	8.8	East
VM1	Vulcan Materials outfall 001	6.8	East
DP1	Dupont outfall 001	5.2	East
DP2	Dupont outfall 002	4.9	East
DP3	Dupont outfall 003	4.9	East
HW1	Harbison-Walker Refactories outfall 001	4.8	East
USSL1	U.S.S. Lead outfall 001	4.2	East
C7	West Branch Grand Calumet River near Indianapolis Blvd.	5.5	West
C7A	West Branch Grand Calumet River near Indiana Toll Road	4.8	West
C8	West Branch Grand Calumet River at Columbia Avenue	4.1	West
C9	West Branch Grand Calumet River at Hohman Avenue	3.0	West
C10	West Branch Grand Calumet River at Burnham Avenue	1.8	West
C11	West Branch Grand Calumet River near Burnham Park	0.9	West
ECWTP	East Chicago wastewater-treatment Plant	5.4	West
HWTP	Hammond wastewater-treatment Plant	4.5	West

Measurement of Streamflow

Streamflow measurements on the Grand Calumet River were made from bridges or boats. Velocity was measured with Price AA current meters and stopwatches, depth with sounding weights and cable or wading rods, and width with taglines.

At sampling stations on the West Branch where the water was less than 3 ft deep but was unwadable because of thick bottom sediments, flow was measured from a small boat with a Price AA meter, stopwatch, tagline, and wading rod. The wading rod was equipped with an oversized base plate to prevent the rod from sinking into the stream bottom.

Effluent outfalls at the U.S. Steel Corporation Gary Works are not equipped with instream flow measurement equipment. Discharge from these outfalls was calculated from a current meter measurement of velocity and the cross-sectional area of each culvert. An average velocity was determined from point velocities measured in the culvert barrel. All other outfalls were equipped with instream flow measurement devices operated by the discharger, and flows were reported for each sample at the time of collection or as a 24-hour total.

Measurement cross sections were selected on the basis of as many of the following criteria as possible:

1. The cross section was within a straight reach and streamlines were parallel.
2. Velocities were greater than 0.5 ft/s and depths were greater than 0.5 ft.
3. Streambed was uniform and free of numerous boulders or heavy aquatic growth.
4. Flow was uniform and free of eddies, slack water, and excessive turbulence.

After the cross section was selected, a tagline was strung across the measurement section perpendicular to the flow lines. Measurement points (verticals) were selected on the cross section so that no more than 15 percent of the total discharge was in one subsection.

The method of velocity measurement used was based on the depth of the stream. Velocity measurements were made at two- and eight-tenths of the depth if the depth was greater than 2.5 ft below the water surface or six-tenths of the depth if the depth was less than 2.5 ft. After the meter was placed at the proper depth and was pointed into the current, rotation of the measurement cups was permitted to adjust to the speed of the current. After the meter had become adjusted, the number of revolutions made by the rotor was counted for 40 to 70 seconds (with a stopwatch). The number of revolutions and the number of seconds were then recorded. Velocity was obtained from a standard meter-rating table. If the velocity was to be measured at more than one point in the vertical, the meter was reset for each depth, and the procedure was repeated. The two velocities were then averaged to obtain a mean velocity. The procedure was repeated at each measurement point on the cross section until the entire cross section had been traversed.

For each subsection, area (depth times width), mean velocity, and streamflow (area times mean velocity) were determined. Summation of discharges from individual subsections yielded the total flow for the stream at that cross section.

Additional information about the current meter method of determining streamflow is given by Rantz and others (1982).

The individual flow measurements at each station were averaged to obtain an estimate of 24-hour average flow for that station. Because streamflow was measured at approximately uniform intervals of time, the estimate thus obtained is virtually a time-weighted average.

Sample-Collection Procedures

Water samples were collected with a Federal Inter-Agency Sedimentation Project Model USDH-48 handheld sampler, a USDH-S-48 handline sampler, or a USD-76 TM cable-and-reel sampler, depending on the velocity and depth at the sampling stations. Each sampler was equipped with a Teflon nozzle and gasket and was coated with epoxy to prevent contamination of samples.

Field measurements of dissolved oxygen (DO), specific conductance (SC), pH, and water temperature were made with a Hydrolab multiparameter meter (model 4041 or 6000), Yellow Springs Instrument DO meter, Leeds and Northrop or Orion pH meters, Beckman or Lab-Line SC meters, and thermometers. All crews were supplied with pH standards and SC standards.

The instruments were calibrated at the beginning of the survey and checked at least four times during the survey. More frequent calibrations were done if the operator felt it necessary. Dissolved-oxygen meters were calibrated to saturated air on the basis of atmospheric pressure and water temperature. Dissolved-oxygen concentrations also were determined by the Winkler method as a check against meter calibration. pH meters were calibrated to a buffer solution of pH 7.0 and were checked against buffer solutions of pH 4.0 and 10.0. Specific conductance meters used in the East Branch and ship canal were calibrated against solutions of 222, 394, and 606 µS/cm (microsiemens per centimeter at 25 °Celsius). Specific conductance meters used in the West Branch were calibrated against solutions of 606, 1,002, and 1,941 µS/cm.

Samples to be analyzed for DO by the Winkler method were collected from the center of flow with a DO sampler. Sampling crews that used the Hydrolab multiparameter instruments measured DO concentration, SC, pH, and water temperature at 10 equally spaced points in the same river cross section where streamflow was measured. The average of the 10 readings was recorded as the value for the station. Sample crews that used Yellow Springs Instruments DO and temperature meters and separate SC and pH meters averaged dissolved-oxygen readings from 10 points in the river as previously described. Specific conductance and pH readings were measured from a composite sample collected in a sampling churn because cables on the probes were too short to allow representative instream readings. A single measurement of DO concentration and temperature of the effluents was taken near the center of flow. Readings were taken at mid-depth except for channel sections whose depths were greater than 5 ft where readings were taken at depths of approximately 25 and 75 percent of the total depth.

Water-quality samples were collected by use of the equal-width-increment/equal-transit-rate (EWI/ETR) method. Ten equally spaced points on the cross section were sampled at each river station. The water sampler was lowered at a uniform rate from the surface to the bottom of the river and was raised to the surface again. The sampler was raised and was lowered the same number of times at each point. A sampling churn was used to composite the 10 water samples. After a thorough mixing of the water in the churn, a one-liter subsample for chemical analysis was drawn off and kept chilled in an ice chest. The sampling churn was rinsed with sample water before each use and with distilled water after each use.

Sample Handling and Preservation

A field laboratory was established at ECWTP. Water samples and field data were brought to this laboratory following completion of the water-quality survey. Individual samples collected at each station over the 24-hour period were composited; subsamples were drawn off, preserved, and prepared for shipment to laboratories at the U.S. Geological Survey in Doraville, Ga., or Purdue University in West Lafayette, Ind. From 10 to 13 L of sample water were collected and composited from each of the 35 sampling stations. Water from each station was handled as follows:

1. If streamflow varied more than 10 percent at a station during the survey, the individual water samples were composited by flow weighting. Otherwise, samples were composited on the basis of time. Water was composited in a churn, thoroughly mixed, and the following subsamples were drawn off and preserved:

Constituent	Sample volume	Method of preservation
Biochemical-oxygen demand	2 L	Chilled to 4 °C.
Chloride, total dissolved solids, and sulfate	500 mL	Filtered, untreated.
Chromium, hexavalent	250 mL	Nitric acid in acid rinsed bottle.
Cyanide	250 mL	Sodium hydroxide added until pH greater than 12.

Constituent	Sample volume	Method of preservation--Cont.
Metals, except hexavalent chromium and mercury	1 L	Nitric acid in acid rinsed bottle.
Mercury	250 mL	Nitric acid in acid rinsed bottle.
Nutrients	250 mL	Mercuric chloride in amber bottle, chilled to 4 °C.
Phenol	1 L	Phosphoric acid and copper sulfate in glass bottle.
Suspended solids and fluoride	1 L	Untreated.

The churn and the filtering equipment were washed and thoroughly rinsed with distilled water after each set of samples was processed. Samples for chloride, sulfate, total dissolved solids, and hexavalent chromium were filtered through plate-type 0.45-micrometer porosity membrane filters. A peristaltic pump equipped with silicone tubing was used to pass sample water through the filtering apparatus.

2. Samples for determination of BOD were transported by U.S. Geological Survey personnel to a laboratory at Purdue University as soon as the last sample had been drawn off. Samples were kept on ice until BOD analysis was begun within 12 hours of the end of the diel survey.

3. Samples for all other analyses were packed in ice in sealed coolers and were air mailed to the U.S. Geological Survey laboratory in Georgia.

Analytical Laboratory Procedures

Biochemical-Oxygen Demand

Total, uninhibited, ultimate BOD's were run for each sample. Filtered, uninhibited, ultimate BOD's were run on three stations on the West Branch downstream from the WTP's to define the effect of high suspended-solids concentrations observed at those stations. Samples to be analyzed for BOD were dechlorinated and placed into four 300-mL glass bottles (3 replicates and 1 fill bottle) as soon as they were received by the laboratory. The samples were allowed to reach 20 °C before the initial DO concentration was measured. A Yellow Springs Instrument DO meter and probe equipped with a stirring arm was used to measure the DO concentration in the bottles. The meter was calibrated daily by the Winkler method. The sample bottles were sealed, making sure no air bubbles were trapped and were stored in an incubator at 20 °C for the duration of the analysis. The DO concentration of each sample was measured at days 0, 2, 5, 7, 10, 12, 15, 20, 30, 40, 50, 60, 70, and 80. When there was no longer any change in the DO concentration from measurement to measurement (approximately 80 days), the ultimate BOD was calculated as the cumulative DO consumption. Carbonaceous biochemical-oxygen demand (CBOD) was estimated by subtracting the nitrogenous biochemical-oxygen demand (calculated as 4.33 times the ammonia concentration in milligrams per liter). The conversion factor used, 4.33, was determined experimentally by Wezernak and Gannon (1967).

Nitrification inhibitors were not used because of problems reported by other investigators (John Bell, Purdue University, oral commun., 1984; McCutcheon and others, 1985) and experienced by the authors in previous work (U.S. Geological Survey, Indianapolis, Ind., written commun., 1984). The inhibitors have been observed to be completely or partially ineffective in some circumstances. It was also difficult to determine when the inhibitor would fail to inhibit nitrification or to determine the effectiveness of the inhibitor after use.

Constituents and Properties other than Biochemical-Oxygen Demand

Laboratory procedures used to determine constituents other than BOD were methods described by Goerlitz and Brown (1972) or Skougstad and others (1979). Analyses were done by the U.S. Geological Survey laboratory in Doraville, Ga. Quality-assurance practices used by this laboratory are given in a report by Friedman and Erdmann (1982). A list of constituents and properties determined and the detection limit of the methods used is given in table 2.

STREAMFLOW

The water-quality survey was done during a period of dry-weather flow. Two National Weather Service stations (Hobart and Ogden Dunes, Ind.) near the study area, reported rainfall of less than 0.05 in. in the 7 days prior to the study. Flow data collected during the survey are presented in tables 3 and 4.

Table 2.--Constituents and properties determined and detection limits of the methods used

[n.a., not applicable; µg/L, microgram per liter; mg/L, milligram per liter]

Constituents and Properties	Detection limits	
Oxygen and related properties		
Dissolved oxygen	n.a.	
Five-day biochemical-oxygen demand	n.a.	
Time series ultimate biochemical-oxygen demand	n.a.	
Temperature	n.a.	
Nutrients		
Ammonia	10	µg/L
Total Kjeldahl nitrogen	.1	mg/L
Nitrite plus nitrate	10	µg/L
Total and ortho-phosphorus	10	µg/L
Metals		
Copper	1	µg/L
Chromium (total)	1	µg/L
Chromium (hexavalent)	1	µg/L
Iron (total)	10	µg/L
Lead (total)	1	µg/L
Mercury	.1	µg/L
Nickel (total)	1	µg/L
Zinc (total)	10	µg/L
Solids		
Dissolved (total)	1	mg/L
Suspended	1	mg/L
Other		
pH	n.a.	
Chloride	.1	mg/L
Fluoride	.1	mg/L
Hardness	n.a.	
Sulfate	.2	mg/L
Cyanide (total)	.01	mg/L
Phenol	1	µg/L

Table 3.--Flow measurements at river-sampling stations, Grand Calumet River basin, October 3-4, 1984

[All measurements by U.S. Geological Survey; measurements at site C9 were made in the culverts beneath Hohman Avenue, measurements at all other sites were made in the stream channel; ft^3/s, cubic foot per second; ft, foot; ft^2, square foot]

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)	Average velocity (ft/s)	Average depth (ft)	Width (ft)	Area (ft^2)
C1A	1	0900	1015	127	0.8	3.2	49	155
C1A	2	1100	1215	127	.8	3.1	49	154
C1A	3	1300	1430	118	.8	3.1	49	153
C1A	4	1500	1620	128	.9	2.9	49	140
C1A	5	1700	1810	124	.8	3.1	49	154
C1A	6	1900	2015	129	.8	3.3	49	161
C1A	7	2100	2210	128	.8	3.3	49	162
C1A	8	2300	0025	129	.8	3.2	49	159
C1A	9	0100	0230	134	.9	3.2	49	156
C1A	10	0330	0435	128	.8	3.4	49	167
C1A	11	0500	0650	142	.8	3.6	49	175
C1A	12	0700	0830	118	.7	3.4	49	165
C1A	13	0900	1000	121	.7	3.5	49	171
			Average	127	.8	3.3	49	159
C3	1	0900	1020	328	.8	4.5	86	386
C3	2	1120	1240	292	.8	4.5	86	386
C3	3	1315	1420	308	.8	4.6	85	388
C3	4	1500	1615	311	.8	4.6	85	389
C3	5	1710	1815	352	.9	4.6	85	391
C3	6	1910	2015	371	.9	4.6	85	394
C3	7	2110	2220	394	1.0	4.6	86	399
C3	8	2310	0015	381	.9	4.7	86	402
C3	9	0115	0220	405	1.0	4.6	88	409
C3	10	0310	0420	416	1.0	4.6	88	408
C3	11	0515	0630	411	1.0	4.8	87	414
C3	12	0715	0820	411	1.0	4.7	87	410
C3	13	0905	1020	424	1.0	4.7	88	411
			Average	370	.9	4.6	86	399

Table 3.--Flow measurements at river-sampling stations, Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)	Average velocity (ft/s)	Average depth (ft)	Width (ft)	Area (ft^2)
C4	1	0900	1005	406	1.2	4.3	77	328
C4	2	1055	1145	377	1.1	4.3	77	330
C4	3	1300	1342	440	1.3	4.5	77	347
C4	4	1500	1548	460	1.4	4.3	77	332
C4	5	1650	1735	480	1.5	4.3	77	331
C4	6	1900	1950	475	1.4	4.5	77	350
C4	7	2057	2142	490	1.5	4.3	77	333
C4	8	2300	2342	526	1.6	4.4	77	337
C4	9	0102	0148	542	1.6	4.4	77	336
C4	10	0303	0352	518	1.5	4.5	77	343
C4	11	0503	0547	571	1.7	4.5	77	345
C4	12	0655	0741	535	1.6	4.4	77	339
C4	13	0850	0935	559	1.5	4.9	77	374
			Average	491	1.5	4.4	77	340
C5	1	0903	1045	363	.4	5.6	168	940
C5	2	1116	1230	435	.5	5.2	168	881
C5	3	1306	1415	402	.4	5.7	168	958
C5	4	1500	1620	485	.5	5.6	168	934
C5	5	1700	1830	466	.5	5.5	168	922
C5	6	1915	2015	426	.4	5.7	168	953
C5	7	2100	2215	489	.5	5.7	168	956
C5	8	2300	0026	502	.5	5.8	168	975
C5	9	0106	0220	545	.6	5.8	168	979
C5	10	0309	0427	527	.5	6.0	168	1002
C5	11	0502	0625	526	.5	5.8	168	974
C5	12	0700	0823	514	.5	5.6	168	948
C5	13	0900	1000	553	.6	5.9	168	986
			Average	479	.5	5.7	168	954

Table 3.--Flow measurements at river-sampling stations, Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)	Average velocity (ft/s)	Average depth (ft)	Width (ft)	Area (ft^2)
C6	1	0925	1050	304	0.4	6.2	110	687
C6	2	1100	1150	484	.7	6.2	110	680
C6	3	1300	1355	333	.5	6.1	110	669
C6	4	1500	1550	383	.6	6.0	110	664
C6	5	1700	1750	393	.6	6.1	110	667
C6	6	1900	1950	386	.6	6.1	110	674
C6	7	2100	2150	486	.7	6.1	110	671
C6	8	2300	2355	417	.6	6.1	110	669
C6	9	0100	0150	458	.7	6.0	110	664
C6	10	0300	0355	454	.7	6.0	110	662
C6	11	0500	0600	497	.7	6.1	110	666
C6	12	0700	0750	512	.8	6.1	110	668
C6	13	0900	0950	422	.6	6.1	110	669
			Average	425	.6	6.1	110	670
C12	1	0900	1022	275	.5	5.5	110	608
C12	2	1104	1218	574	1.0	5.4	109	586
C12	3	1308	1421	463	.8	5.4	110	590
C12	4	1511	1627	442	.7	5.4	110	594
C12	5	1716	1827	473	.8	5.2	109	572
C12	6	1905	2030	507	.9	5.3	110	588
C12	7	2105	2035	570	1.0	5.2	110	571
C12	8	2305	0024	537	.9	5.3	110	583
C12	9	0105	0218	593	1.0	5.2	110	577
C12	10	0256	0410	513	.9	5.2	110	577
C12	11	0500	0627	554	1.0	5.2	110	573
C12	12	0705	0815	484	.8	5.3	110	584
C12	13	0905	1018	556	.9	5.4	110	591
			Average	503	.9	5.3	110	584

Table 3.--Flow measurements at river-sampling stations, Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)	Average velocity (ft/s)	Average depth (ft)	Width (ft)	Area (ft^2)
C7	1	0923	1029	41.7	0.3	2.0	62	126
C7	2	1130	1200	-34.1	-.3	2.0	62	125
C7	3	1315	1337	3.5	< .1	2.0	62	124
C7	4	1505	1527	-25.9	-.2	2.0	62	121
C7	5	1705	1730	-3.1	< -.1	2.0	62	123
C7	6	1905	1925	24.6	.2	2.1	62	129
C7	7	2100	2128	-13.8	-.1	2.0	62	124
C7	8	2305	2325	-18.9	-.1	2.1	62	128
C7	9	0100	0125	-11.3	-.1	2.0	62	127
C7	10	0300	0320	-1.3	< -.1	2.0	62	122
C7	11	0455	0515	-9.5	-.1	2.0	62	121
C7	12	0655	0715	-29.5	-.2	1.9	62	120
C7	13	0900	0915	44.1	.4	2.0	62	123
			Average	-2.6	.0	2.0	62	124
C7A	1	1050	1221	8.1	.1	2.4	50	118
C7A	2	1310	1345	23.6	.2	2.2	50	110
C7A	3	1503	1540	-.2	< -.1	2.2	50	110
C7A	4	1708	1745	11.2	.1	2.2	50	110
C7A	5	1901	1938	31.7	.3	2.2	50	112
C7A	6	2105	2155	-.9	< -.1	2.4	50	118
C7A	7	2305	2340	8.2	.1	2.3	50	115
C7A	8	0114	0152	8.5	.1	2.3	50	113
C7A	9	0311	0344	22.6	.2	2.2	50	112
C7A	10	0516	0550	23.7	.2	2.2	50	111
C7A	11	0707	0750	6.7	.1	2.2	50	110
C7A	12	0902	0940	30.8	.3	2.2	50	111
			Average	14.5	.1	2.3	50	113

Table 3.--Flow measurements at river sampling stations, Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)	Average velocity (ft/s)	Average depth (ft)	Width (ft)	Area (ft^2)
C8	1	0920	1020	53.3	0.8	2.1	30	64
C8	2	1100	1154	62.2	.9	2.3	30	69
C8	3	1300	1400	54.8	.8	2.3	30	68
C8	4	1500	1540	52.1	.8	2.3	30	68
C8	5	1657	1735	51.4	.8	2.3	30	68
C8	6	1900	1940	53.1	.8	2.2	30	67
C8	7	2100	2143	59.0	.9	2.3	30	68
C8	8	2300	2345	55.8	.8	2.3	30	70
C8	9	0100	0140	52.6	.8	2.3	30	68
C8	10	0300	0345	48.0	.7	2.2	30	67
C8	11	0500	0540	52.2	.8	2.3	30	68
C8	12	0700	0740	51.9	.8	2.2	30	67
C8	13	0900	0950	47.5	.7	2.2	30	66
			Average	53.4	.8	2.3	30	68
C9	1	0900	0950	38.3	Not applicable			
C9	2	1100	1150	50.7	Not applicable			
C9	3	1300	1350	49.7	Not applicable			
C9	4	1500	1550	48.1	Not applicable			
C9	5	1700	1750	49.8	Not applicable			
C9	6	1900	1940	48.9	Not applicable			
C9	7	2100	2140	50.2	Not applicable			
C9	8	2300	2340	51.3	Not applicable			
C9	9	0100	0140	49.9	Not applicable			
C9	10	0300	0340	46.6	Not applicable			
C9	11	0500	0535	45.1	Not applicable			
C9	12	0700	0735	44.2	Not applicable			
C9	13	0900	0935	42.2	Not applicable			
			Average	47.3	Not applicable			

Table 3.--Flow measurements at river-sampling stations, Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)	Average velocity (ft/s)	Average depth (ft)	Width (ft)	Area (ft^2)
C10	1	0915	1020	37.4	0.5	2.2	36	79
C10	2	1115	1230	51.0	.6	2.3	36	84
C10	3	1315	1421	55.8	.6	2.5	36	92
C10	4	1525	1628	54.7	.6	2.5	36	89
C10	5	1705	1814	53.4	.6	2.5	36	89
C10	6	1850	2000	53.8	.6	2.5	36	90
C10	7	2120	2230	55.8	.6	2.5	36	89
C10	8	2306	0013	56.6	.6	2.5	36	89
C10	9	0110	0222	55.8	.6	2.5	36	89
C10	10	0310	0420	53.1	.6	2.5	36	89
C10	11	0505	0620	50.4	.6	2.4	36	87
C10	12	0700	0810	50.4	.6	2.4	36	86
C10	13	0900	1008	49.0	6	2.4	36	85
			Average	52.	.6	2.4	36	87
C11	1	0949	1019	22.7	.4	1.0	50	52
C11	2	1130	1201	48.0	.9	1.1	50	53
C11	3	1246	1301	45.2	.9	1.0	50	52
C11	4	1344	1356	56.2	1.1	1.1	50	54
C11	5	1445	1500	49.7	.9	1.1	50	56
C11	6	1527	1541	61.0	1.2	1.0	50	53
C11	7	1648	1658	45.8	.8	1.1	50	57
C11	8	1730	1743	68.0	1.3	1.1	50	54
C11	9	1845	1858	43.1	.8	1.1	50	56
C11	10	1931	1946	70.2	1.4	1.0	50	50
C11	11	2154	2108	37.1	.7	1.1	50	54
C11	12	2140	2156	63.7	1.3	1.0	50	51
C11	13	2244	2257	49.8	1.0	1.0	50	52
C11	14	2325	2338	55.2	1.1	1.0	50	53
C11	15	0050	0100	46.2	.8	1.1	52	57
C11	16	0143	0155	62.9	1.2	1.0	50	52
C11	17	0250	0308	42.6	.7	1.1	50	57
C11	18	0334	0345	58.7	1.2	1.0	50	50
C11	19	0445	0502	42.5	.8	1.0	50	52
C11	20	0535	0549	51.0	1.1	.9	50	48
C11	21	0640	0651	42.6	.9	1.0	50	49
C11	22	0718	0730	57.8	1.2	.9	50	47
C11	23	0828	0841	32.3	.7	1.0	50	48
C11	24	0908	0919	59.8	1.4	.9	50	43
			Average	50.5	1.0	1.0	50	52

Table 4.--Effluent discharge measurements at industrial and municipal outfalls, in the Grand Calumet River basin, October 3-4, 1984

[Measurements at U.S. Steel Corporation outfalls by U.S. Geological Survey; all other measurements by plant operators; all measurements taken at discharge point except at Hammond Wastewater-Treatment Plant where flow was metered at inflow; ft^3/s, cubic foot per second]

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)
GW1	1	0900	0920	44.9
GW1	2	1540	1600	46.1
GW1	3	2010	2010	43.0
GW1	4	0315	0315	42.0
GW1	5	0715	0715	42.0
			Average	43.6
GW1A	1	0905	0905	1.3
GW1A	2	1020	1030	2.6
GW1A	3	1545	1545	2.6
GW1A	4	0345	0345	.0
GW1A	5	0730	0730	.0
			Average	1.3
GW2	1	0920	0930	13.0
GW2	2	1050	1100	10.7
GW2	3	1615	1625	13.0
GW2	4	0410	0420	12.6
GW2	5	0745	0745	12.6
			Average	12.4
GW3	1	1010	1025	6.5
GW3	2	1135	1135	6.5
GW3	3	1640	1640	6.6
GW3	4	0445	0445	6.5
GW3	5	0800	0810	5.9
			Average	6.4
GW4	1	1055	1055	2.8
GW4	2	1435	1445	3.1
GW4	3	1825	1825	2.8
GW4	4	0500	0500	2.8
GW4	5	0835	0850	2.8
			Average	2.9

Table 4.--Effluent discharge measurements at industrial and municipal outfalls, Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)
GW6	1	1230	1250	46.8
GW6	2	1655	1710	57.0
GW6	3	2335	2350	57.8
GW6	4	0530	0530	56.5
GW6	5	0910	0930	60.9
			Average	55.8
GW7	1	1310	1325	42.0
GW7	2	1725	1740	68.0
GW7	3	0020	0035	62.4
GW7	4	0600	0615	66.4
GW7	5	0935	0950	49.5
			Average	57.7
GW7A	1	1345	1405	64.6
GW7A	2	1800	1815	107
GW7A	3	0115	0140	136
GW7A	4	0630	0650	138
GW7A	5	1010	1030	141
			Average	117
GW10A	1	0920	0950	8.2
GW10A	2	1350	1410	8.0
GW10A	3	1750	1805	6.3
GW10A	4	2205	2220	6.4
GW10A	5	0130	0150	7.0
GW10A	6	0505	0520	7.4
GW10A	7	0855	0910	10.5
			Average	7.7
GW11A	1	1000	1041	47.7
GW11A	2	1420	1435	52.9
GW11A	3	1815	1830	37.6
GW11A	4	2235	2250	36.5
GW11A	5	0200	0215	36.8
GW11A	6	0530	0545	47.3
GW11A	7	0930	0940	68.2
			Average	46.7

Table 4.--Effluent discharge measurements at industrial and municipal outfalls, Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)
GW12	1	1205	1230	11.7
GW12	2	1530	1545	9.9
GW12	3	1950	2005	10.4
GW12	4	2350	0005	11.2
GW12	5	0315	0330	11.0
GW12	6	0655	0710	10.9
GW12	7	1105	1120	11.3
			Average	10.9
GW13	1	1138	1200	2.5
GW13	2	1500	1515	2.1
GW13	3	1920	1935	4.2
GW13	4	2325	2340	4.9
GW13	5	0250	0305	6.0
GW13	6	0625	0640	5.4
GW13	7	1035	1050	2.5
			Average	3.9
ST14	1	1115	1130	2.2
ST14	2	1450	1500	2.4
ST14	3	1855	1910	2.9
ST14	4	2300	2315	3.1
ST14	5	0225	0240	2.6
ST14	6	0605	0620	2.4
ST14	7	1005	1020	2.8
			Average	2.6
ST17	1	1300	1310	35.5
ST17	2	1605	1620	32.1
ST17	3	2020	2030	39.9
ST17	4	0015	0030	28.0
ST17	5	0350	0400	42.0
ST17	6	0725	0740	28.4
ST17	7	1130	1145	30.5
			Average	33.8

Table 4.--Effluent discharge measurements at industrial and municipal outfalls, Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)
GWTP	1	0900	0900	15.4
GWTP	2	1100	1100	15.4
GWTP	3	1300	1300	86.5
GWTP	4	1500	1500	92.6
GWTP	5	1700	1700	80.3
GWTP	6	1900	1900	30.9
GWTP	7	2100	2100	30.9
GWTP	8	2300	2300	77.2
GWTP	9	0100	0100	18.5
GWTP	10	0300	0300	20.1
GWTP	11	0500	0500	77.2
GWTP	12	0700	0700	61.8
GWTP	13	0900	0900	61.8
			Average	51.4
VM1	1	1100	1100	.15
DP1	1	0900	0900	6.5
DP1	2	1100	1100	6.5
DP1	3	1300	1300	6.7
DP1	4	1500	1500	7.1
DP1	5	1700	1700	7.1
DP1	6	1900	1900	7.6
DP1	7	2100	2100	7.3
DP1	8	2300	2300	7.3
DP1	9	0100	0100	7.6
DP1	10	0300	0300	7.1
DP1	11	0500	0500	6.7
DP1	12	0700	0700	6.7
DP1	13	0900	0900	6.7
			Average	7.0

Table 4.--Effluent discharge measurements at industrial and municipal outfalls, Grand Calumet River Basin, October 3-4, 1984--Continued

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)
DP2	1	0900	0900	1.6
DP2	2	1100	1100	1.4
DP2	3	1300	1300	1.7
DP2	4	1500	1500	1.6
DP2	5	1700	1700	1.7
DP2	6	1900	1900	1.7
DP2	7	2100	2100	2.1
DP2	8	2300	2300	1.9
DP2	9	0100	0100	1.8
DP2	10	0300	0300	1.9
DP2	11	0500	0500	1.9
DP2	12	0700	0700	1.9
DP2	13	0900	0900	1.8
			Average	1.8
DP3	1	0900	0900	1.2
DP3	2	1100	1100	1.1
DP3	3	1300	1300	1.0
DP3	4	1500	1500	1.0
DP3	5	1700	1700	1.0
DP3	6	1900	1900	1.0
DP3	7	2100	2100	1.1
DP3	8	2300	2300	1.1
DP3	9	0100	0100	1.1
DP3	10	0300	0300	1.1
DP3	11	0500	0500	1.1
DP3	12	0700	0700	1.2
DP3	13	0900	0900	1.2
			Average	1.1
HW1	1	0900	0900	.06
USSL1	1	0900	0900	.01

Table 4.--Effluent discharge measurements at industrial and municipal outfalls, Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)
ECWTP	1	0900	0900	20.1
ECWTP	2	1100	1100	21.6
ECWTP	3	1300	1300	20.1
ECWTP	4	1500	1500	26.2
ECWTP	5	1700	1700	20.1
ECWTP	6	1900	1900	26.2
ECWTP	7	2100	2100	20.1
ECWTP	8	2300	2300	20.1
ECWTP	9	0100	0100	17.8
ECWTP	10	0300	0300	14.7
ECWTP	11	0500	0500	17.0
ECWTP	12	0700	0700	14.7
ECWTP	13	0900	0900	20.1
			Average	19.9
HWTP	1	0900	0900	46.3
HWTP	2	1100	1100	57.1
HWTP	3	1300	1300	57.1
HWTP	4	1500	1500	57.1
HWTP	5	1700	1700	57.1
HWTP	6	1900	1900	55.6
HWTP	7	2100	2100	55.6
HWTP	8	2300	2300	60.2
HWTP	9	0100	0100	57.1
HWTP	10	0300	0300	47.9
HWTP	11	0500	0500	43.2
HWTP	12	0700	0700	43.2
HWTP	13	0900	0900	47.9
			Average	52.7

Diel Variations in Flow

Flow at all stations in the East Branch except Virginia Street (C1A) gradually increased throughout the period of the survey. Streamflow measured near the end of the survey was generally 100 to 150 ft^3/s greater than that measured near the beginning of the 24-hour period. These increases reflect changes observed in the effluent flow from several of the U.S. Steel Corporation outfalls. For example, flow from outfall GW6 increased from 47 to 60 ft^3/s and flow from outfall GW7A increased from 65 to 140 ft^3/s. Smaller increases in flow were observed at several other U.S. Steel Corporation outfalls.

Extreme diel fluctuations in streamflow were observed at several of the sampling stations in the Grand Calumet River (figs. 2 and 3). The fluctuations in the East and West Branches were greatest at stations nearest the ship canal. At the station on the ship canal (C12), a change in streamflow of about 300 ft^3/s was observed in one 2-hour period. Fluctuations of 50 ft^3/s between measurements were common. A similar pattern was observed in the East Branch at Kennedy Avenue (station C6) and to a lesser degree at Cline Avenue (station C5). Little diel variation was observed at stations further upstream from Cline Avenue (Industrial Highway, station C4; Bridge Street, station C3; and Virginia Street, station C1A).

The most drastic diel fluctuations in streamflow were observed at the two sampling stations in the West Branch nearest the ship canal (near Indianapolis Boulevard, C7; and near the Indiana East-West Toll Road, C7A). Complete reversals of streamflow were observed at station C7 near Indianapolis Boulevard. Streamflow at station C7 ranged from -34 ft^3/s (easterly flow) to 42 ft^3/s (westerly flow). Average streamflow at this station for the period of study was -2.6 ft^3/s. Thus, a small net amount of water flowed from this station into the ship canal during the survey. The same debris was observed to float past the station several times during the reversals in flow, indicating that the same parcel of water virtually flowed back and forth in this reach of the river a number of times before finally discharging into the ship canal. Only two small reversals in flow were observed near the Indiana East-West Toll Road (station C7A). Streamflow at station C7A ranged from zero flow to as high as 32 ft^3/s toward the west. Virtually no fluctuation was observed at the first three sampling stations downstream of the Indiana East-West Toll Road (Columbia Avenue, C8; Hohman Avenue, C9; and Burnham Road, C10) during the 24-hour period, presumably because the fluctuations seen near Indianapolis Boulevard and the Indiana East-West Toll Road were dampened by culverts through which the West Branch flows underneath Columbia Avenue. Significant diel variation was observed at Burnham Park (station C11) and was probably due to the operation of the Thomas J. O'Brien Lock and Dam on the Little Calumet River 0.6 mi downstream from its confluence with the West Branch of the Grand Calumet River.

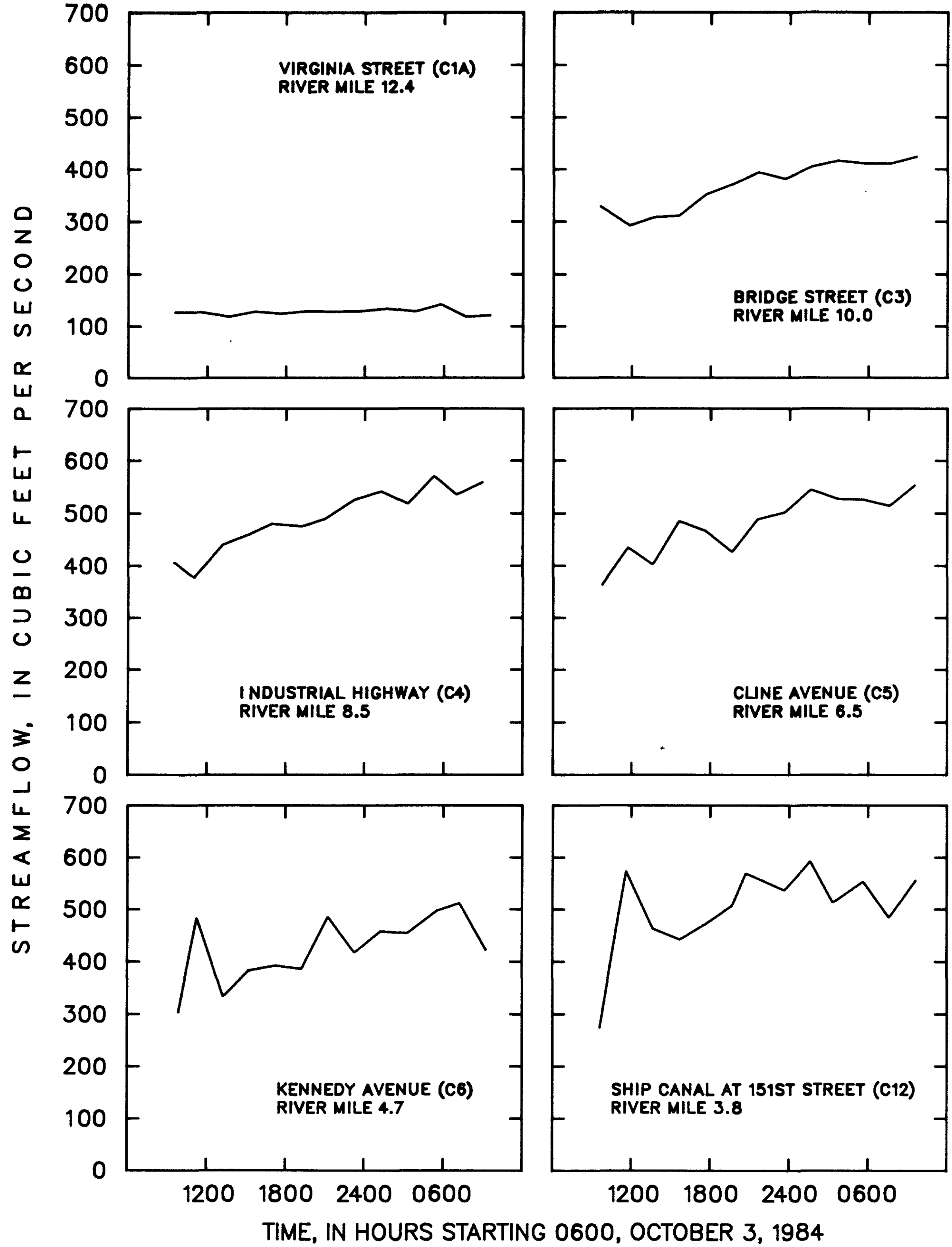


Figure 2.--Relation of streamflow to time, East Branch Grand Calumet River, October 3-4, 1984. (Station identifiers given in parentheses refer to locations shown in figure 1).

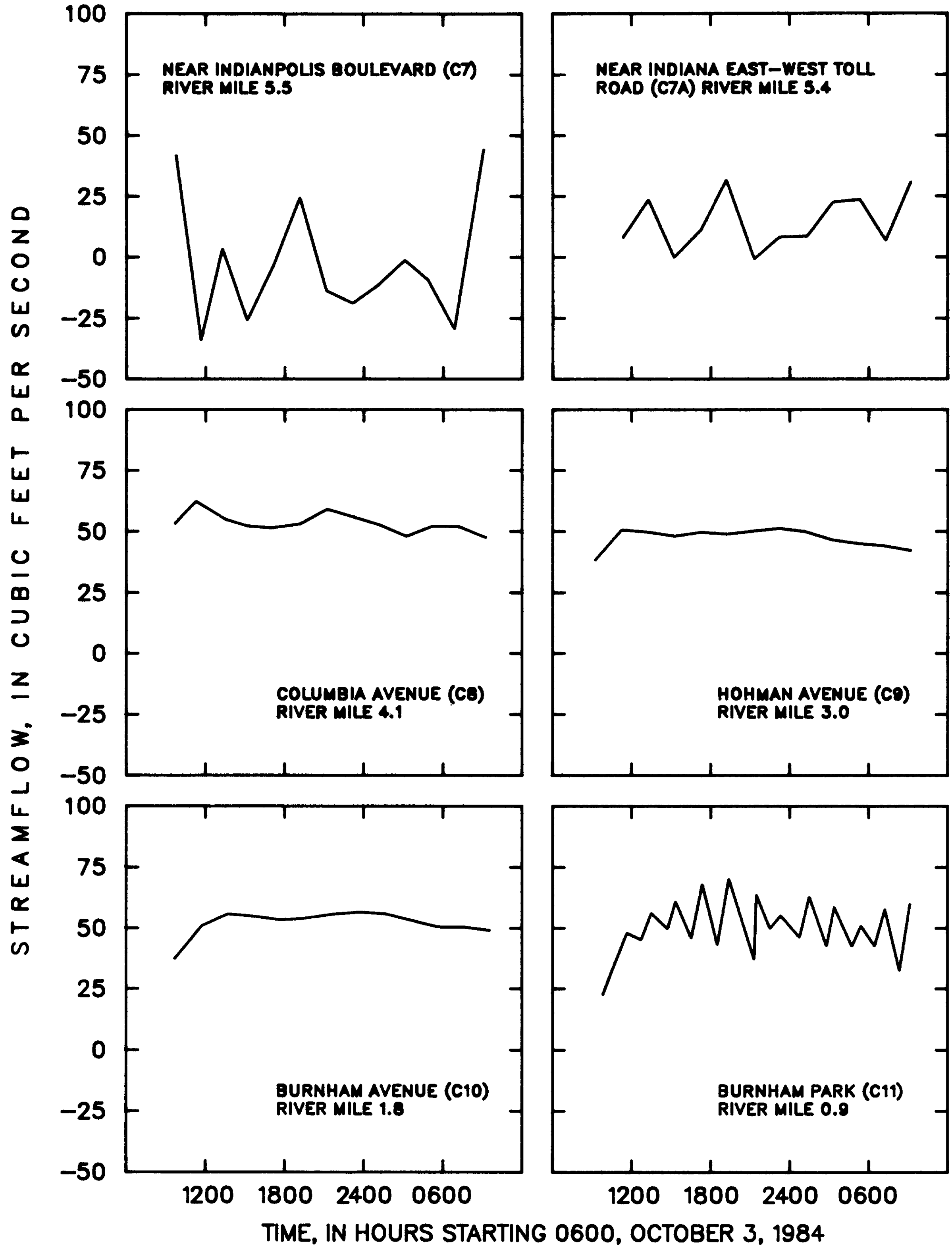


Figure 3.--Relation of streamflow to time, West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers given in parentheses refer to locations shown in figure 1).

The reason for the large diel fluctuations in streamflow at sampling stations near the ship canal is not known. They may be due to changes in the water level in Lake Michigan. Water levels in Lake Michigan at Calumet Harbor, Illinois (approximately 6.5 mi northwest of the Indiana Harbor), for the period October 2-4, 1984, are shown in figure 4. Water levels in the lake during the survey fluctuated between 579.7 and 580.1 ft above the IGLD of 1955, changing about 0.2 ft every 4 hours. Prior to the start of the water-quality survey on October 3, the lake water level rose about 0.6 ft in 6 hours. The U.S. Army Corps of Engineers (1985) attribute such short-term fluctuations in Great Lakes water levels to wind and changes in barometric pressure. Lunar tides are negligible in the Great Lakes (Heyford, 1922, p. 113). The true tide at Chicago, Ill., has been estimated to produce a range in oscillations of less than 0.14 ft (Harris, 1907, p. 483-486). Whether the variations in streamflow observed in the East and West Branches of the Grand Calumet River are attributable to water-level changes in Lake Michigan is uncertain; given the volume of water in the Indiana Harbor and ship canal and the small hourly water-level changes recorded during the survey, it would seem unlikely, however.

On the basis of visual observations made during a reconnaissance of the river and ship canal in September 1984, the authors doubt the importance of Lake Michigan water levels as a cause of the fluctuations in streamflow. Reversals of surface flow during this reconnaissance were noted in the ship canal at the Indiana Harbor Belt Railroad crossing (RM 1.9, 0.2 mi downstream from the Lake George Canal) but not at the Elgin, Joliet, and Eastern Railroad crossing (RM 0.7, 0.5 mi downstream from Dickey Road). Downstream flow was significant at the Elgin, Joliet, and Eastern Railroad crossing during the flow reversal noted at the Indiana Harbor Railroad crossing. When downstream flow was observed at the Indiana Harbor Railroad crossing, less flow was observed at the Elgin, Joliet, and Eastern Railroad crossing than during the reversal. Both of these railroad crossings constrict the ship canal channel to about 40 percent of its normal width. Flow reversals may be a function of these constrictions and changes in water volume in the canal between and downstream from them. There are a total of 16 effluent outfalls downstream from the Indiana Harbor Railroad crossing. Although flow from these outfalls was not measured during the survey, previous studies have reported average 24-hour flow for these outfalls totaling about 1,350 ft^3/s (HydroQual, 1984). This flow is nearly three times the average flow measured at 151st Street (C12). The flow reversals observed in the ship canal and the river may be due to backwater caused by the interaction of the volume and diel variation of the effluent discharges and the locations of their outfalls in the ship canal with respect to the channel constrictions.

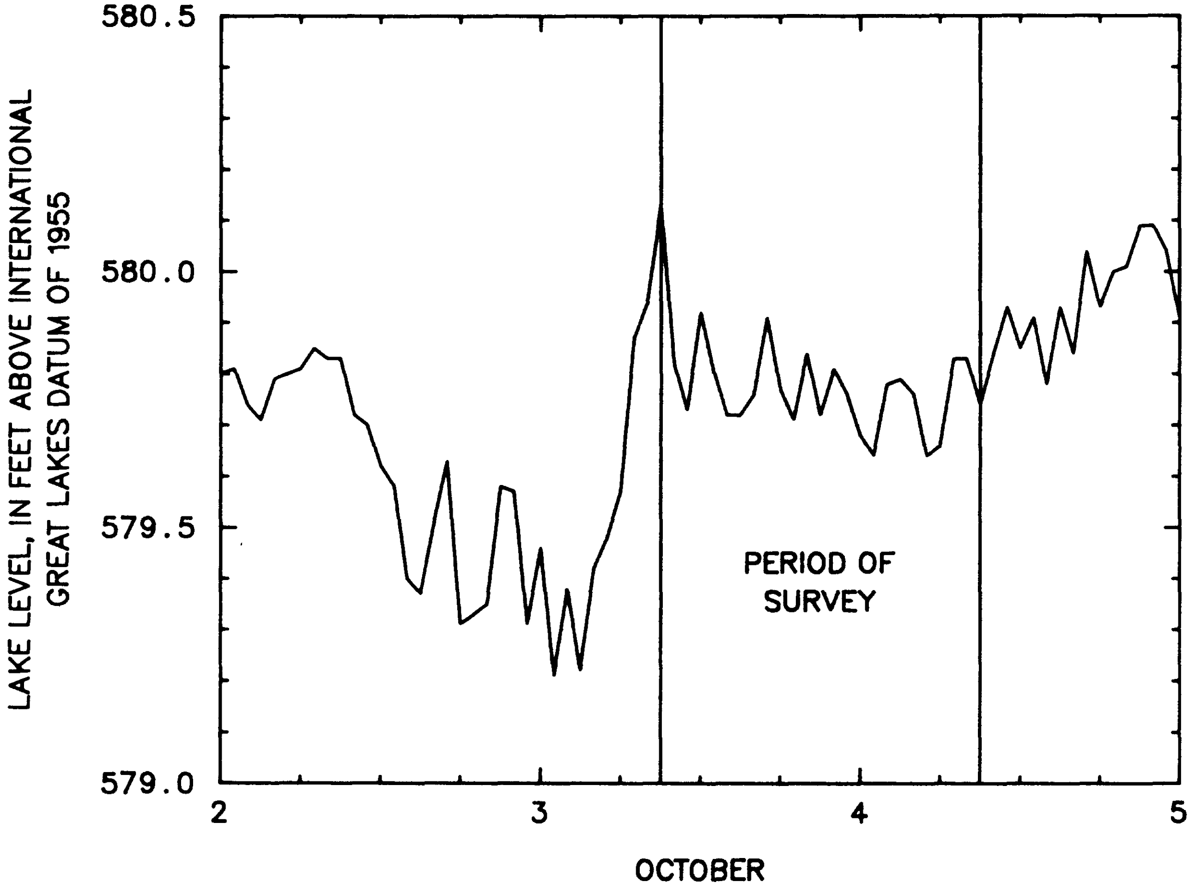


Figure 4.--Water levels in Lake Michigan, Calumet Harbor, Illinois, October 2-4, 1984.

Flow Balance

East Branch Grand Calumet River

Dry-weather flow in the Grand Calumet River is composed almost exclusively of industrial and municipal effluents (fig. 5). Flow upstream from the first effluent discharge in the East Branch was estimated to be less than 0.1 ft^3/s. Effluents accounted for about 93 percent of the 500 ft^3/s average streamflow at the farthest downstream site (151st Street, station C12) in the East Branch. The largest single discharger is U.S. Steel Corporation, which discharged an average of 400 ft^3/s from 14 outfalls (GW1 to GW13, ST14, ST17). Other major dischargers in the East Branch include the GWTP (51 ft^3/s) and DuPont, E. I. DeNemours and Company (9.9 ft^3/s from outfalls DP1 to DP3). About 67 percent of the industrial effluent is noncontact cooling water from Lake Michigan. The remainder is process water from the U.S. Steel Corporation Gary Works mill operations and DuPont, E. I. DeNemours and Company chemical production.

The approximately 36 ft^3/s increase in streamflow in the East Branch not attributable to effluent was assumed to be ground-water inflow or seepage from adjacent wetlands. None of the small tributary streams were observed to be flowing during the survey. For purposes of estimating chemical-mass discharges in the East Branch of the river, this additional flow was added uniformly to the reaches where inflow was indicated by streamflow measurements (4.6 ft^3/s between RM 13.8 and 12.4, 25.9 ft^3/s between RM 11.3 and 6.8, and 5.5 ft^3/s between RM 4.8 and 3.8). These rates of inflow are rather high and may be unrealistic. However, data concerning ground-water flow in the study area are presently insufficient to obtain an independent estimate of rates of ground-water inflow. Average streamflow at Kennedy Avenue (station C6) was approximately 50 ft^3/s less than that upstream at Cline Avenue (station C5). This decrease is probably not indicative of an actual loss of water from the river. Rather, the river near Kennedy Avenue has extensive marshy areas along its banks that have thick growths of macrophytes. Streamflow measurements made at Kennedy Avenue reflect only flow in the open channel, not flow through this marshy area. It is likely that the balance of the flow not measured at this site moved through this area, especially since no decrease in flow was observed between Cline Avenue (station C5) and 151st Street (station C12).

The estimate of streamflow adjusted for gains or losses used for calculating instream chemical-mass discharges of the East Branch Grand Calumet River is shown in figure 6.

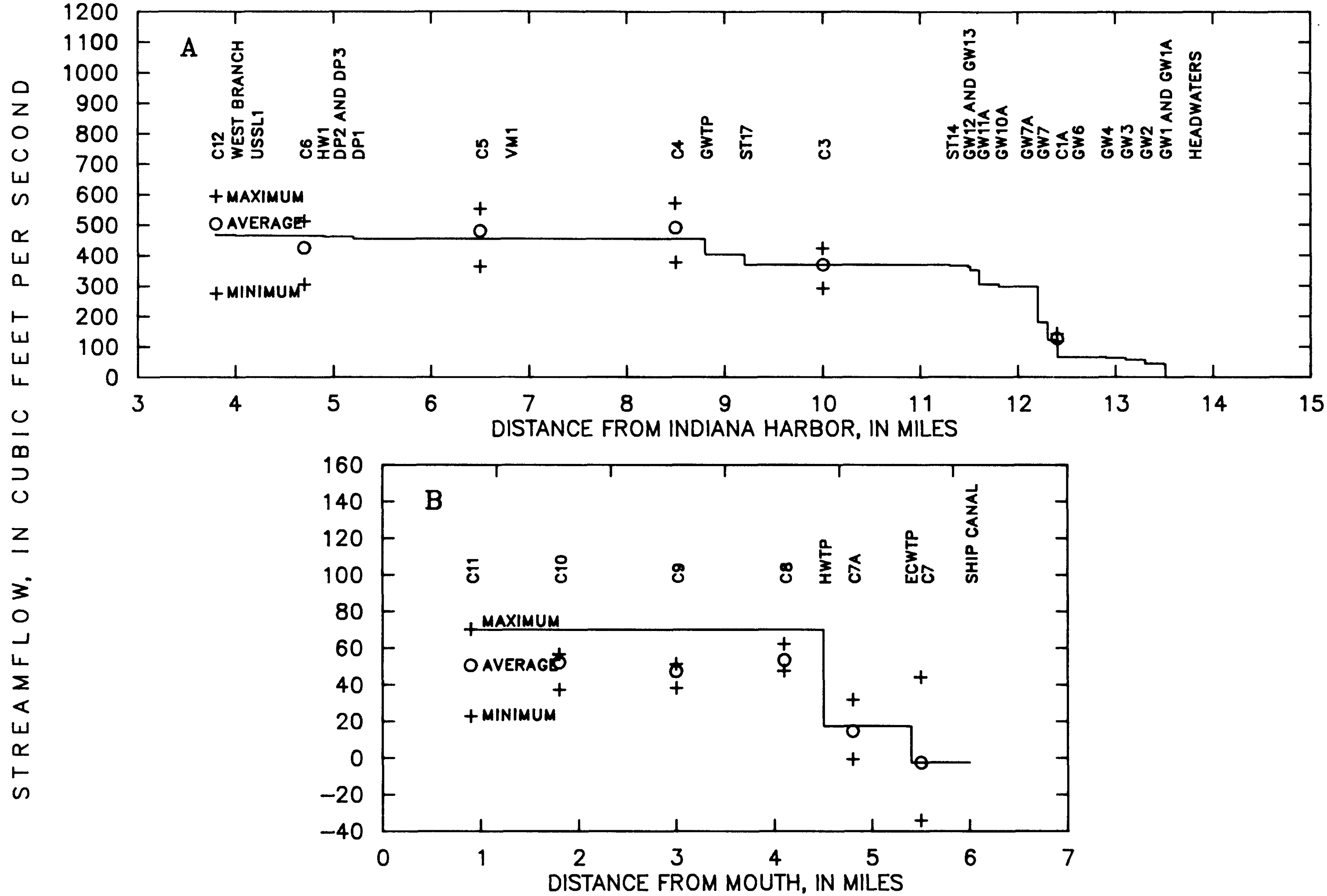


Figure 5.--Relation of cumulative effluent discharge to streamflow, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

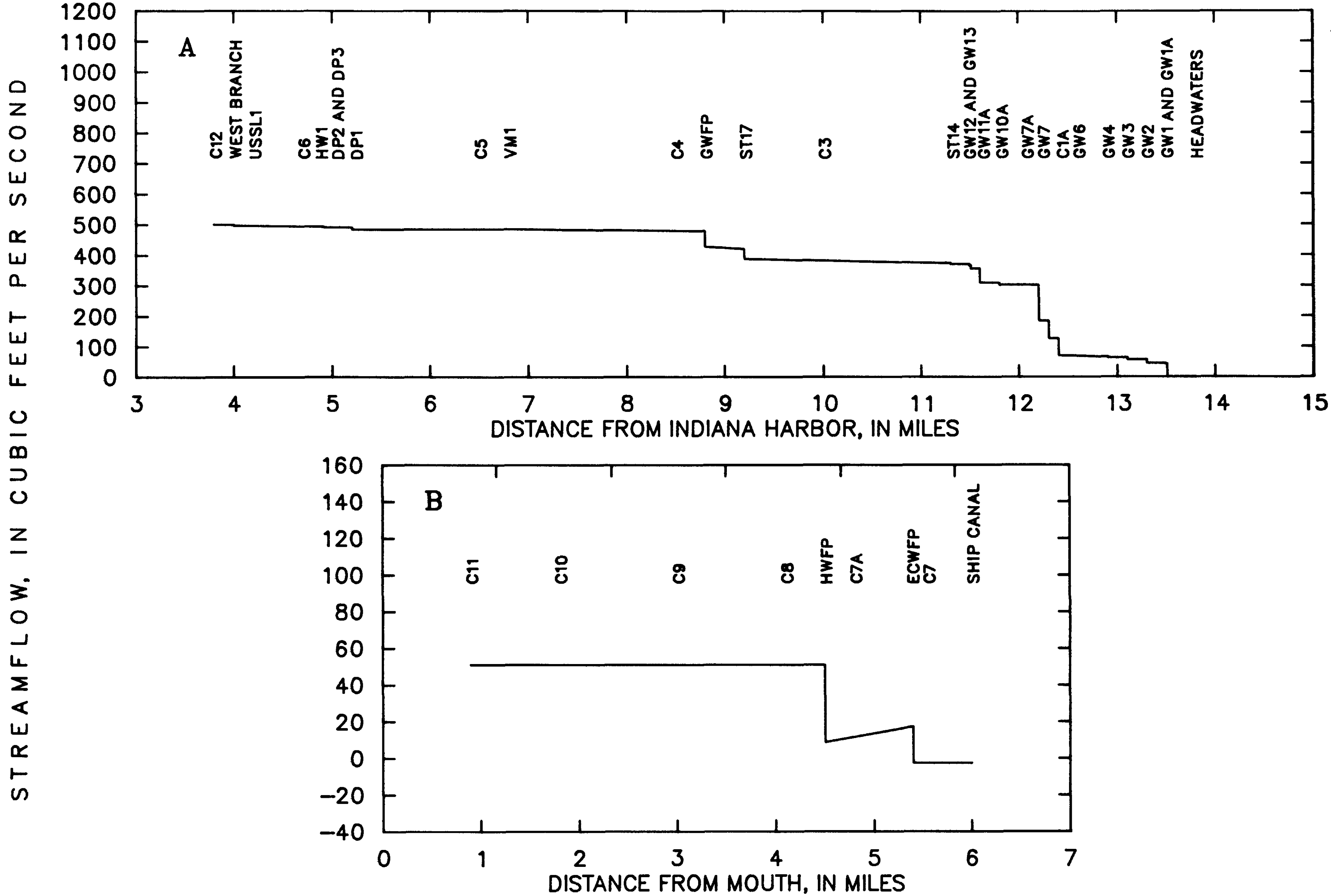


Figure 6.--Estimates of streamflow adjusted for gains or losses used for calculating instream chemical-mass discharge, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

West Branch Grand Calumet River

The HWTP and ECWTP were the only active permitted dischargers in the West Branch during the survey and accounted for all of the streamflow in the West Branch (fig. 5). The ECWTP reported an average effluent flow of 19.9 ft^3/s during the study. An average streamflow of 2.6 ft^3/s was measured near Indianapolis Boulevard (station C7) flowing east into the ship canal. An average streamflow of 14.5 ft^3/s was measured near the Indiana East-West Toll Road (station C7A) flowing west. These flows total 17.1 ft^3/s or 2.8 ft^3/s less than the flow reported by the ECWTP (19.9 ft^3/s). Thirteen percent of flow from the ECWTP (2.6 ft^3/s) was assumed to flow toward the east (into the ship canal) and 87 percent of the flow (17.3 ft^3/s) was assumed to flow toward the west. These assumptions are based on the observation that some water flowing west was apparently lost from the West Branch between the Indiana East-West Toll Road (station C7A) and Columbia Avenue (station C8). Thus it was assumed that some loss would also occur between Indianapolis Boulevard and the Indiana East-West Toll Road since these two reaches are geomorphically similar. Therefore, the 2.8 ft^3/s difference was attributed to losses in the channel between the ECWTP and the Indiana East-West Toll Road (station C7A).

Flow in the West Branch downstream from the HWTP was substantially less than the sum of the westerly flowing portion of the effluents. The average streamflow at the four sampling stations downstream from the HWTP (C8, C9, C10, and C11) was 51 ft^3/s and ranged from 47.3 to 53.4 ft^3/s. This flow is approximately 19 ft^3/s less than the sum of the effluent flow measured by the HWTP (52.6 ft^3/s) and the westerly flowing portion of the ECWTP effluent (about 17 ft^3/s). It is unlikely this difference can be attributed to measurement error alone.

Some of the difference can be attributed to the fact that the HWTP only measures flow as it enters the plant (unlike the ECWTP and the GWTP which measure effluent flow as it enters the river). Thus, the flow that the HWTP reported may have been greater than the actual effluent flow because: (1) return flow used by the HWTP is added to the incoming wastewater upstream from the plant's flowmeter, (2) evaporation losses from the settling tanks and clarifiers are not taken into account, (3) some water is removed from the system when sludge is pumped from settling tanks to sludge lagoons, and (4) differences that result from the lag between changes in inflow and outflow owing to travel time through the plant. Measurement bias may also account for some of the difference.

Use of the effluent flow reported by the HWTP for estimating chemical-mass discharges results in substantially larger chemical-mass discharges than observed at the four downstream sampling stations. Thus, for purposes of calculating effluent and instream chemical-mass discharges, the effluent flow from the HWTP and the streamflow immediately upstream from the plant (0.3 mi downstream from C7A) were estimated from a mass balance of chloride, sulfate, and dissolved solids. This technique was feasible because the effluents from the two WTP's were considerably different chemically with respect to concentrations of chloride, sulfate and dissolved solids. Least-squares optimization was used to obtain the best fit solution to the following set of equations:

$$CLds \times Qds = CLWTP \times QWTP + CLus \times Qus$$
$$SO_4ds \times Qds = SO_4WTP \times QWTP + SO_4us \times Qus$$
$$DSds \times Qds = DSWTP \times QWTP + DSus \times Qus$$
$$Qds = QWTP + Qus$$

where CL is the chloride concentration, in milligrams per liter;
SO_4 is the sulfate concentration, in milligrams per liter;
DS is the dissolved solids concentration, in milligrams per liter;
Q is the flow, in cubic feet per second;

and ds, WTP, and us are subscripts indicating the downstream, wastewater-treatment plant, or upstream location.

The unknowns in the equations are QWTP and Qus. The concentrations of chloride, sulfate, and DS observed near the Indiana East-West Toll Road (station C7A) were used as the upstream concentrations; the concentrations measured in the HWTP effluent were used as the WTP concentrations; and the average flow and concentrations of the four sampling stations downstream from the HWTP were used as the downstream flow and concentrations.

Estimates of 42.3 ft^3/s as the average effluent flow from the HWTP and 8.7 ft^3/s as the average streamflow immediately upstream of the plant were obtained using this procedure. The estimated effluent flow for the HWTP is approximately 81 percent of the 52.6 ft^3/s influent flow. This difference indicates a sizable measurement error or loss of water through the plant. Similar percentages have been noted by the authors in previous studies of other wastewater-treatment plants (U.S. Geological Survey, Indianapolis, Ind., written commun., 1984). This estimate of effluent flow is supported by the findings of the follow-up study done in September 1985 (see appendix) during which effluent flow was found to be 77 percent of the influent flow.

The estimate of upstream flow indicates a substantial loss of water (as much as 8.6 ft^3/s) between the ECWTP and HWTP--a distance of slightly less than 1 mi. This loss is roughly 44 percent of the total effluent flow from the ECWTP.

Insufficient data are available to explain this loss. Between the ECWTP and HWTP, a part of the stream is diverted southward through a small lake that is surrounded by a marshy area with dense macrophyte growth. The surface area of this lake is about 10 acres; the marshy area around the lake totals about 15 acres. Even though there is an outlet from the lake that drains back into the West Branch near the Indiana East-West Toll Road Bridge, some of the water loss in this area may be due to evaporation or seepage or retention of the water as surface storage. The inlet to the lake is upstream from the sampling station located at the Indiana East-West Toll Road (station C7A). Average streamflow measured at the Indiana East-West Toll Road, 14.5 ft^3/s, is 2.8 ft^3/s less than the 17.3 ft^3/s that would have been expected at this station from the ECWTP (19.9 ft^3/s effluent flow minus 2.6 ft^3/s average flow measured flowing easterly into the ship canal). This 2.8 ft^3/s amount is equivalent to 0.2 ft/d over the 25-acre lake and marsh. Evaporation, seepage, or change in storage could reasonably account for this difference.

The loss of an additional 5.8 ft^3/s between the Indiana East-West Toll Road and the HWTP is not so easily explained. Beneath the Indiana East-West Toll Road, the river channel becomes very broad and shallow, probably as a consequence of highway construction. The channel in this reach is several hundred feet wide and only about 0.5 ft deep, instead of the typical 60 to 90-ft width and 2-ft depth. The area of this channel section is about 2.2 acres. On the north side of the channel is another marshy area of approximately 11 acres. Possibly owing to the reduced stream velocity and large surface area to volume ratio for this section of the channel, the marsh acts as an area of substantial ground-water recharge. Such seepage would be equivalent to about 0.9 ft/d over this 13.2-acre area, a seemingly high rate of seepage. However, tracer data obtained during the September 1985 follow-up study support the loss of water in this section of the West Branch.

There are several additional explanations for the imbalance between the effluent flows and the flow measured in the West Branch. If one assumes an effluent flow of 50 ft^3/s from the HWTP (95 percent of the reported flow to account for return flow and to allow for some evaporative losses) and an upstream flow of 14.5 ft^3/s (the flow measured near the Indiana East-West Toll Road, station C7A), mass balances on the concentrations of chloride, sulfate, and dissolved solids result in concentrations in the mixed water similar to those observed at Columbia Avenue (station C8). Without an adjustment for the loss of flow, however, the mass discharges of chloride, sulfate, and dissolved solids would not agree with those observed at Columbia Avenue. For a balance in flows to occur, 13.5 ft^3/s would have to be lost from the river in the 0.4-mi between the HWTP and Columbia Avenue. After field reconnaissance of this section of the channel, the authors concluded that flow losses of this magnitude were improbable.

Another possible explanation is measurement errors in streamflow, especially at the two stations on the West Branch nearest the ship canal (C7 and C7A). Flow at these stations was quite unsteady with reversals of flow observed at station C7. The unsteady flow at these sites could have resulted in considerable error in individual streamflow measurements. However, error in the 24-hour average flow is a function of error in individual measurements and the assumption that flow varied linearly between measurements. The error in the 24-hour average is not a function of the total range in flow of the individual measurements because this includes systematic variability attributable to changes in lake levels, industrial withdrawal and discharge, or other causes as well as measurement error. It is unlikely that measurement error alone could account for the difference. For example, the sum of the 24-hour average flow estimated at stations C7 and C7A (17.1 ft^3/s) agrees reasonably well with the flow reported by the ECWTP (within 85 percent). If the flow reported by the HWTP and that measured at the four downstream stations (C8, C9, C10, and C11) are assumed to be equal and the difference is due primarily to measurement errors at stations C7 and C7A, a 24-hour average flow of 19.8 ft^3/s at station C7 would be needed to account for the difference in flow observed in the West Branch. This corresponds to an error of nearly 1,000 percent in the 24-hour average flow at station C7 and zero flow at station C7A. If flow from the HWTP is assumed to be equal to that estimated by the mass-balance technique (42.3 ft^3/s), then a flow of 11.1 ft^3/s, corresponding to an error of over 400 percent in the 24-hour average flow, would be needed at station C7 to account for the difference. Errors of this magnitude are unlikely, even for highly unsteady flow.

These alternative explanations were deemed less likely than the first one presented. However, conclusions drawn should be interpreted within the uncertainty of the flow system in the West Branch. The only conclusions concerning the flow imbalance known with reasonable certainty are (1) that only part of the effluent discharged by the two municipal WTP's into the West Branch during the survey left the watershed by means of the river channel during the survey, and (2) available data are insufficient to resolve the imbalance.

The estimate of streamflow adjusted for gains or losses used for calculating instream chemical-mass discharges of the West Branch Grand Calumet River is shown in figure 6.

WATER QUALITY

The Indiana Stream Pollution Control Board has designated waters of the Grand Calumet River for recreation on or near the body, limited aquatic life and industrial-water supply (330 IAC 2-2-3). A summary of selected water-quality standards for the Grand Calumet River is presented in table 5. The complete standards may be found in 330 IAC 2-2.

Water-quality data collected during the October 1984 diel survey are summarized in table 6. A discussion of each of the properties and constituents measured follows.

Table 5.--Water-quality standards for the Grand Calumet River
[Source, 330 IAC 2-2]

Constituent or property	Standards in effect before October 1985 East and West Branches	Standards in effect since October 1985	
		East Branch	West Branch
pH	not to be less than 6.0 or exceed 9.0 standard units	not to be less than 6.0 or exceed 9.0 standard units	not to be less than 6.0 or exceed 9.0 standard units
Dissolved oxygen	not to be less than 4.0 mg/L	not to be less than 4.0 mg/L	not to be less than 4.0 mg/L
Temperature			
January - March	not to exceed 15.6 °C	not to exceed 15.6 °C	not to exceed 15.6 °C
April	not to exceed 18.3 °C	not to exceed 18.3 °C	not to exceed 18.3 °C
May	not to exceed 23.9 °C	not to exceed 23.9 °C	not to exceed 23.9 °C
June	not to exceed 29.4 °C	not to exceed 29.4 °C	not to exceed 29.4 °C
July - August	not to exceed 30.6 °C	not to exceed 30.6 °C	not to exceed 30.6 °C
September	not to exceed 29.4 °C	not to exceed 29.4 °C	not to exceed 29.4 °C
October	not to exceed 23.9 °C	not to exceed 23.9 °C	not to exceed 23.9 °C
November	not to exceed 21.1 °C	not to exceed 21.1 °C	not to exceed 21.1 °C
December	not to exceed 15.6 °C	not to exceed 15.6 °C	not to exceed 15.6 °C
Ammonia			
Total	not to exceed 1.5 mg/L as N	no standard	no standard
Unionized	no standard	not to exceed 0.02 mg/L as N	not to exceed 0.05 mg/L as N
Chloride	not to exceed 125 mg/L	not to exceed 125 mg/L	not to exceed 125 mg/L
Cyanide	not to exceed 0.1 mg/L	not to exceed 0.05 mg/L	not to exceed 0.1 mg/L
Dissolved solids	not to exceed 500 mg/L	not to exceed 350 mg/L	not to exceed 500 mg/L
Fluoride	not to exceed 1.3 mg/L	not to exceed 1.3 mg/L	not to exceed 1.3 mg/L
Phosphorus (total)	not to exceed 0.1 mg/L	not to exceed 0.1 mg/L	no standard
Sulfate	not to exceed 225 mg/L	not to exceed 100 mg/L	not to exceed 225 mg/L
Chromium (total)	not to exceed 50 µg/L	not to exceed 25 µg/L	not to exceed 25 µg/L
Iron (dissolved)	not to exceed 300 µg/L	not to exceed 300 µg/L	not to exceed 300 µg/L
Lead (total)	not to exceed 50 µg/L	not to exceed 25 µg/L	not to exceed 25 µg/L
Mercury (total)	not to exceed 0.5 µg/L	not to exceed 0.5 µg/L	not to exceed 0.5 µg/L
PCB's (total)	not to exceed 0.001 µg/L	not to exceed 0.001 µg/L	not to exceed 0.001 µg/L
Phenol	not to exceed 10 µg/L	not to exceed 10 µg/L	not to exceed 10 µg/L

Table 6.--Water-quality analyses for sampling stations in the Grand Calumet River basin, October 3-4, 1984

[mg/L, milligram per liter; n.d., no data; °C, degree Celsius; µS/cm, microsiemens per centimeter at 25 °Celsius; µg/L, microgram per liter]

Station ID	Determined by meter: Average dissolved-oxygen concentration (mg/L)	Determined by meter: Minimum dissolved-oxygen concentration (mg/L)	Determined by meter: Maximum dissolved-oxygen concentration (mg/L)	Determined by Winkler method: Average dissolved-oxygen concentration (mg/L)	Determined by Winkler method: Minimum dissolved-oxygen concentration (mg/L)	Determined by Winkler method: Maximum dissolved-oxygen concentration (mg/L)
C1A	8.2	7.7	9.5	7.8	7.4	8.2
C3	7.4	6.2	8.3	8.0	7.8	8.6
C4	7.4	6.4	8.4	7.3	6.8	7.8
C5	6.7	6.4	7.4	6.0	4.0	7.0
C6	6.1	5.3	6.6	5.9	5.0	6.6
C12	5.7	4.8	6.2	5.7	5.0	6.4
GW1	6.5	6.3	7.2	8.1	8.0	8.4
GW1A	5.5	4.3	6.1	6.4	6.2	6.6
GW2	5.3	4.9	5.7	7.0	6.6	7.4
GW3	5.0	4.5	5.7	6.4	5.8	7.0
GW4	6.4	5.7	6.9	8.0	7.8	8.4
GW6	6.9	6.4	7.4	8.6	8.2	8.8
GW7	6.1	5.4	6.8	8.9	8.4	9.2
GW7A	6.8	6.3	7.1	8.3	7.8	8.6
GW10A	8.0	7.4	9.2	7.3	7.2	7.4
GW11A	9.4	8.4	11.9	8.4	8.0	8.8
GW12	10.3	9.7	11.8	9.1	9.0	9.2
GW13	9.3	8.7	10.0	9.0	8.8	9.2
ST14	4.7	3.8	5.2	4.4	4.2	4.6
ST17	7.5	5.2	11.5	6.1	6.0	6.2
GWTP	5.9	4.4	7.7	n.d.	n.d.	n.d.
VM1	n.d.	n.d.	n.d.	8.0	7.8	8.2
DP1	n.d.	n.d.	n.d.	7.4	7.2	7.6
DP2	n.d.	n.d.	n.d.	8.5	8.3	9.0
DP3	n.d.	n.d.	n.d.	7.6	7.4	8.0
HW1	n.d.	n.d.	n.d.	3.3	< .1	6.6
USSL1	n.d.	n.d.	n.d.	5.5	5.4	5.6
C7	6.6	4.4	7.6	6.3	4.4	7.6
C7A	5.8	4.8	7.0	5.7	4.6	6.6
C8	5.0	4.0	6.0	4.8	4.2	6.0
C9	1.5	.9	3.0	1.3	.8	1.8
C10	.9	.6	1.4	.6	.2	1.2
C11	.8	.6	1.0	.9	.8	1.2
ECWTP	5.7	4.7	7.1	n.d.	n.d.	n.d.
HWTP	7.2	n.d.	n.d.	n.d.	n.d.	n.d.

Table 6.--Water-quality analyses for sampling stations in the Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Average temper- ature (°C)	Minimum temper- ature (°C)	Maximum temper- ature (°C)	Average specific conductance (µS/cm	Minimum specific conductance (µS/cm)	Maximum specific conductance (µS/cm)
C1A	19.1	17.7	19.7	367	349	420
C3	18.3	16.4	19.5	359	343	380
C4	19.5	18.0	20.7	421	385	480
C5	19.2	17.9	20.7	429	384	478
C6	19.8	18.0	21.5	n.d.	n.d.	n.d.
C12	18.9	17.3	20.2	498	465	579
GW1	21.0	20.0	23.0	356	350	360
GW1A	32.0	28.0	35.0	363	330	420
GW2	27.6	25.0	30.0	420	340	550
GW3	22.0	21.0	23.0	372	340	420
GW4	17.8	17.0	18.0	358	340	380
GW6	17.2	16.0	19.0	359	340	390
GW7	23.2	16.0	28.0	335	320	360
GW7A	16.6	15.0	20.0	345	340	350
GW10A	20.7	20.0	22.0	341	300	380
GW11A	19.8	19.0	21.0	336	320	390
GW12	15.8	15.0	17.0	323	300	400
GW13	16.4	16.0	17.0	285	240	350
ST14	27.8	27.0	28.0	656	530	740
ST17	24.0	23.0	25.0	735	600	800
GWTP	18.8	17.0	20.0	n.d.	n.d.	n.d.
VM1	17.8	16.0	20.0	n.d.	n.d.	n.d.
DP1	26.3	25.0	28.0	n.d.	n.d.	n.d.
DP2	24.3	23.5	25.0	n.d.	n.d.	n.d.
DP3	29.6	23.5	31.0	n.d.	n.d.	n.d.
HW1	23.7	23.3	24.4	n.d.	n.d.	n.d.
USSL1	23.0	23.0	24.0	n.d.	n.d.	n.d.
C7	17.2	15.0	19.0	1,630	480	2,100
C7A	18.0	15.0	20.0	1,610	1,295	1,950
C8	20.1	18.2	21.0	1,180	1,000	1,320
C9	19.8	18.0	21.0	n.d.	650	n.d.
C10	19.0	17.0	20.3	n.d.	n.d.	n.d.
C11	18.6	16.8	21.1	1,150	1,010	1,290
ECWTP	18.2	17.5	19.0	n.d.	n.d.	n.d.
HWTP	17.8	16.0	21.0	n.d.	n.d.	n.d.

Table 6.--Water-quality analyses for sampling stations in the Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Average pH (standard units)	Minimum pH (standard units)	Maximum pH (standard units)	Suspended solids (mg/L)	Dissolved solids (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)	Hardness as $CaCo_3$ (mg/L)
C1A	7.6	7.3	7.8	10	203	25	0.2	33	110
C3	7.9	7.6	8.1	4	186	18	.3	31	110
C4	6.6	6.1	6.9	6	246	43	.3	38	140
C5	7.2	6.8	7.4	< 1	326	44	.4	40	140
C6	n.d.	n.d.	n.d.	3	306	44	.4	49	140
C12	7.3	7.3	7.5	4	288	52	.5	52	150
GW1A	7.9	7.7	8.2	3	173	13	.2	26	110
GW2	8.1	7.8	8.2	5	254	63	.1	29	130
GW3	7.7	7.4	8.0	4	162	17	.3	26	110
GW4	7.6	7.3	8.1	5	174	15	.2	26	110
GW6	7.7	7.4	8.0	2	168	12	.2	26	130
GW7	7.4	7.1	8.0	2	144	11	.2	22	120
GW7A	7.7	7.4	8.0	2	197	24	1.3	40	130
GW10A	8.1	7.9	8.3	4	167	11	.1	24	94
GW11A	8.3	8.1	8.6	2	193	21	.9	36	120
GW12	7.3	7.1	7.8	3	235	13	.1	36	140
GW13	7.4	7.0	7.6	2	162	11	.1	24	130
ST14	6.8	6.6	7.9	12	399	65	.3	120	250
ST17	6.6	6.4	6.8	2	523	190	.2	47	280
GWTP	7.1	7.0	7.5	4	480	84	.8	28	190
VM1	8.6	8.4	8.9	2	378	124	1.1	32	120
DP1	n.d.	n.d.	n.d.	6	284	44	.4	63	180
DP2	7.6	7.4	8.0	4	1,240	220	1.1	190	120
DP3	7.5	7.5	7.6	4	9,100	32	.7	5,900	320
HW1	n.d.	n.d.	n.d.	3	166	11	.9	26	110
USSL1	6.7	6.7	7.2	12	712	63	4.7	320	360
C7	7.6	7.5	8.2	12	938	329	2.3	154	200
C7A	n.d.	n.d.	n.d.	11	1,000	335	2.3	162	220
C8	7.1	6.8	7.2	14	684	160	1.3	116	200
C9	7.5	7.4	7.7	16	660	153	1.2	114	220
C10	n.d.	n.d.	n.d.	16	661	155	1.3	120	190
C11	7.1	6.9	7.2	16	674	160	1.2	120	140
GW1	7.8	7.7	7.9	4	184	17	.1	28	30
ECWTP	7.1	6.9	7.2	7	1,080	438	3.1	190	220
HWTP	n.d.	n.d.	n.d.	3	593	120	1.1	104	210

Table 6.--Water-quality analyses for sampling stations in the Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Five day biochemical-oxygen demand (mg/L)	Total biochemical-oxygen demand (mg/L)	Carbonaceous biochemical-oxygen demand (mg/L)	Filtered biochemical-oxygen demand (mg/L)	Total phenols (µg/L)	Total cyanide (mg/L)
C1A	3.8	12.0	5.5	n.d.	17	0.05
C3	1.8	6.5	3.0	n.d.	2	.02
C4	2.6	10.0	6.9	n.d.	34	.01
C5	3.7	11.0	7.7	n.d.	20	.01
C6	2.8	10.0	6.3	n.d.	2	< .01
C12	3.2	11.0	7.4	n.d.	27	< .01
GW1	2.0	6.5	4.0	n.d.	< 1	.04
GW1A	1.2	4.5	.5	n.d.	14	.02
GW2	2.4	13.0	5.6	n.d.	64	< .01
GW3	3.3	7.0	4.3	n.d.	13	.05
GW4	1.0	3.0	2.6	n.d.	< 1	< .01
GW6	1.5	5.0	2.7	n.d.	17	< .01
GW7	1.8	4.0	3.6	n.d.	< 1	< .01
GW7A	1.4	3.0	2.3	n.d.	52	.06
GW10A	2.1	13.0	7.4	n.d.	1	< .01
GW11A	3.0	12.0	7.8	n.d.	< 1	.05
GW12	1.0	3.0	2.5	n.d.	< 1	< .01
GW13	1.0	3.0	2.8	n.d.	< 1	< .01
ST14	1.5	7.0	4.5	n.d.	< 1	< .01
ST17	12.0	31	30	n.d.	67	< .01
GWTP	4.0	14.0	11.4	n.d.	2	< .01
VM1	1.0	4.0	3.7	n.d.	< 1	< .01
DP1	2.1	12.0	5.9	n.d.	16	.01
DP2	1.0	25.0	19.0	n.d.	< 1	< .01
DP3	1.2	4.0	3.4	n.d.	5	< .01
HW1	1.0	4.0	3.1	n.d.	n.d.	< .01
USSL1	1.0	7.0	3.1	n.d.	< 1	< .01
C7	2.5	27	16.	n.d.	8	.17
C7A	4.2	31	17.	n.d.	11	.04
C8	15.0	48	30	36	7	.02
C9	13.0	50	30	41	2	.02
C10	12.0	49	28	39	4	.02
C11	11.5	49	27	n.d.	3	.01
ECWTP	13.0	24	14.0	n.d.	2	.26
HWTP	4.5	36	21	n.d.	1	< .01

Table 6.--Water-quality analyses for sampling stations in the Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Total organic nitrogen (mg/L as N)	Total ammonia (mg/L as N)	Total nitrite (mg/L as N)	Total nitrate (mg/L as N)	Total ortho-phosphorus (mg/L as P)	Total phosphorus (mg/L)
C1A	0.5	1.50	0.05	0.21	0.02	0.02
C3	.1	.80	.06	.21	.02	.03
C4	.3	.71	.08	1.32	.02	.05
C5	.2	.77	.09	1.51	.04	.13
C6	.5	.85	.10	1.40	.03	.04
C12	.6	.82	.13	1.57	.04	.06
GW1	.1	.58	.02	.21	.03	.04
GW1A	< .1	.93	.03	.26	< .01	< .01
GW2	.2	1.70	.03	.26	.01	< .01
GW3	.4	.63	.03	.21	.02	< .01
GW4	.2	.09	.03	.26	< .01	< .01
GW6	.1	.53	.03	.17	< .01	< .01
GW7	.2	.09	.01	.18	.02	.01
GW7A	.2	.17	.01	.14	.01	.02
GW10A	.1	1.30	.06	.21	< .01	.01
GW11A	< .1	.96	.05	.20	< .01	< .01
GW12	.1	.12	.01	.23	.02	< .01
GW13	.1	.05	.02	.26	< .01	< .01
ST14	< .1	.57	.02	.38	.01	< .01
ST17	.4	.22	.18	.11	.02	.03
GWTP	1.5	.61	.07	9.03	.20	.35
VM1	.2	.06	.36	.21	.09	.09
DP1	.2	1.40	.12	1.48	.03	.06
DP2	81.7	1.30	.01	.17	< .01	< .01
DP3	.6	.13	.01	.09	< .01	< .01
HW1	.1	.21	.02	.48	< .01	< .01
USSL1	.4	.91	.08	1.12	< .01	.04
C7	1.6	2.60	1.00	8.10	.05	.18
C7A	1.7	3.20	.98	8.12	.07	.23
C8	2.5	4.10	.43	3.07	.25	.54
C9	2.4	4.70	.37	2.13	.30	.62
C10	2.6	4.90	.34	1.96	.29	.58
C11	2.5	5.00	.37	2.13	.29	.44
ECWTP	1.9	2.40	1.80	10.20	.28	.57
HWTP	1.7	3.50	.18	1.52	.28	.35

Table 6.--Water-quality analyses for sampling stations in the Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Total chromium (µg/L)	Total hexavalent chromium (µg/L)	Total copper (µg/L)	Total iron (µg/L)	Total lead (µg/L)	Total mercury (µg/L)	Total nickel (µg/L)	Total zinc (µg/L)
C1A	3	< 1	2	1,500	7	0.2	4	30
C3	2	< 1	4	810	6	.2	8	40
C4	2	< 1	1	1,000	4	.2	6	30
C5	2	< 1	8	3,600	42	.2	9	100
C6	2	< 1	3	740	5	.3	7	40
C12	< 1	< 1	3	1,200	6	.2	8	50
GW1	< 1	< 1	< 1	380	1	.5	5	20
GW1A	< 1	< 1	4	310	< 1	.7	4	30
GW2	< 1	< 1	1	360	< 1	2.5	10	20
GW3	2	< 1	< 1	410	< 1	.3	7	20
GW4	< 1	< 1	< 1	540	20	.3	5	20
GW6	1	< 1	< 1	250	< 1	.5	5	30
GW7	< 1	< 1	< 1	350	< 1	.3	7	40
GW7A	< 1	< 1	3	860	4	1.0	5	20
GW10A	2	< 1	1	470	< 1	.2	6	20
GW11A	1	< 1	< 1	760	3	1.0	7	30
GW12	1	< 1	< 1	490	1	.7	4	20
GW13	2	< 1	< 1	210	1	.4	5	20
ST14	1	< 1	1	6,000	3	1.1	7	30
ST17	1	< 1	< 1	1,100	< 1	.9	8	30
GWTP	n.d.	n.d.	9	450	1	.4	11	40
VM1	3	< 1	4	190	5	.6	5	20
DP1	1	< 1	1	1,700	15	.3	6	410
DP2	8	< 1	5	1,200	10	.2	12	40
DP3	7	< 1	7	1,000	28	< .1	8	90
HW1	5	< 1	2	290	2	.2	8	20
USSL1	< 1	< 1	61	2,600	n.d.	.3	24	380
C7	8	< 1	12	1,900	16	.3	13	100
C7A	4	< 1	6	1,200	14	.6	14	80
C8	4	< 1	7	1,200	12	.6	13	50
C9	3	< 1	2	1,100	15	.6	13	50
C10	< 1	< 1	7	1,200	14	.6	14	50
C11	< 1	< 1	8	1,400	18	.5	13	50
ECWTP	1	< 1	3	700	8	1.3	12	60
HWTP	1	< 1	< 1	330	< 1	.5	11	20

Water-Quality Characteristics

Dissolved Oxygen

Average DO concentrations measured in the East Branch ranged from about 6 mg/L near the confluence of the East Branch with the ship canal to about 8 mg/L at Virginia Avenue (fig. 7). Diel fluctuations in DO concentration were only about 1 to 2 mg/L. The fluctuation during the survey seemed to be random and untypical of fluctuations attributable to aquatic plants (fig. 8). Dissolved-oxygen concentrations were greater than the daily minimum (4.0 mg/L) and the daily average (5.0 mg/L) DO standards in the East Branch.

Dissolved-oxygen concentrations were substantially lower in the West Branch than in the East Branch. Average concentrations ranged from about 1 mg/L near the confluence of the West Branch with the Little Calumet River to about 7 mg/L near the confluence with the ship canal (fig. 7). Diel fluctuations in concentration ranged from about 0.5 mg/L near the confluence with the Little Calumet River to about 3 mg/L near the ship canal (fig. 9). The large fluctuation in the West Branch near the ship canal is probably more a function of the interaction between waters from the ship canal and West Branch during the reversals of flow than photosynthetic activity. Concentrations at four of the sampling stations west of Columbia Avenue in Hammond (C8, C9, C10, and C11) were less than both the daily average and the minimum DO standards.

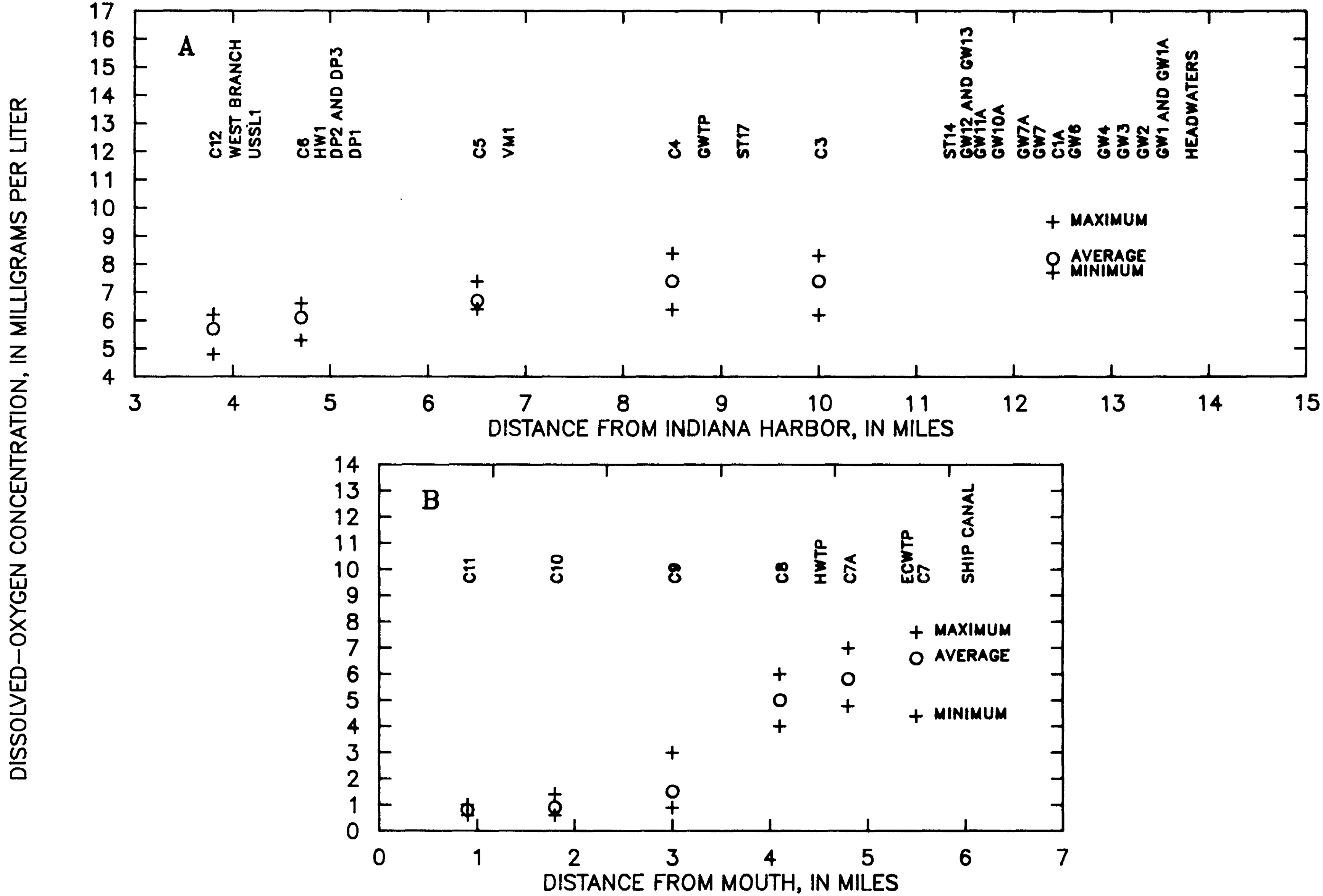


Figure 7.--Longitudinal variation in dissolved-oxygen concentration, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

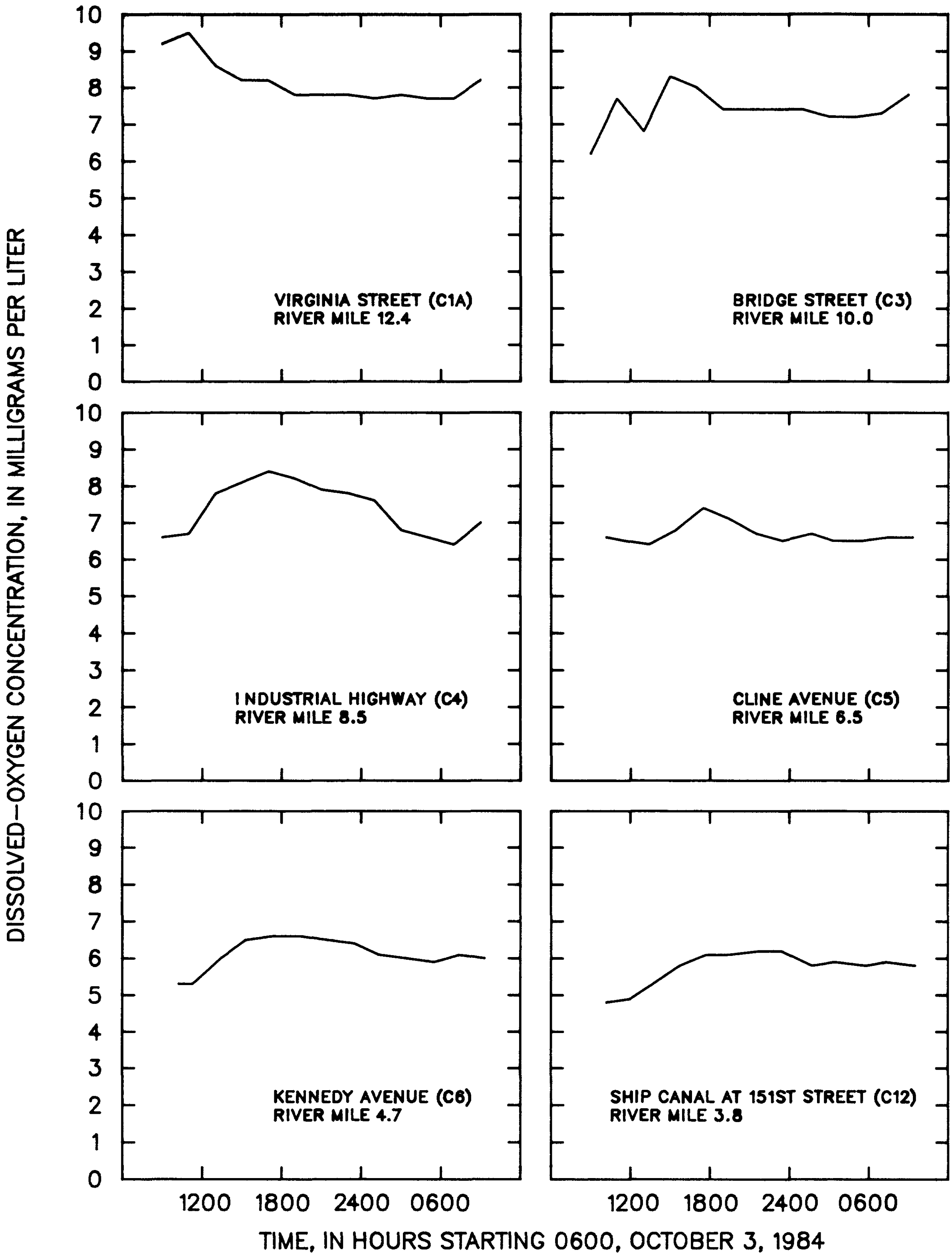


Figure 8.—Relation of dissolved-oxygen concentration to time, East Branch Grand Calumet River, October 3–4, 1984. (Station identifiers given in parentheses refer to locations shown in figure 1).

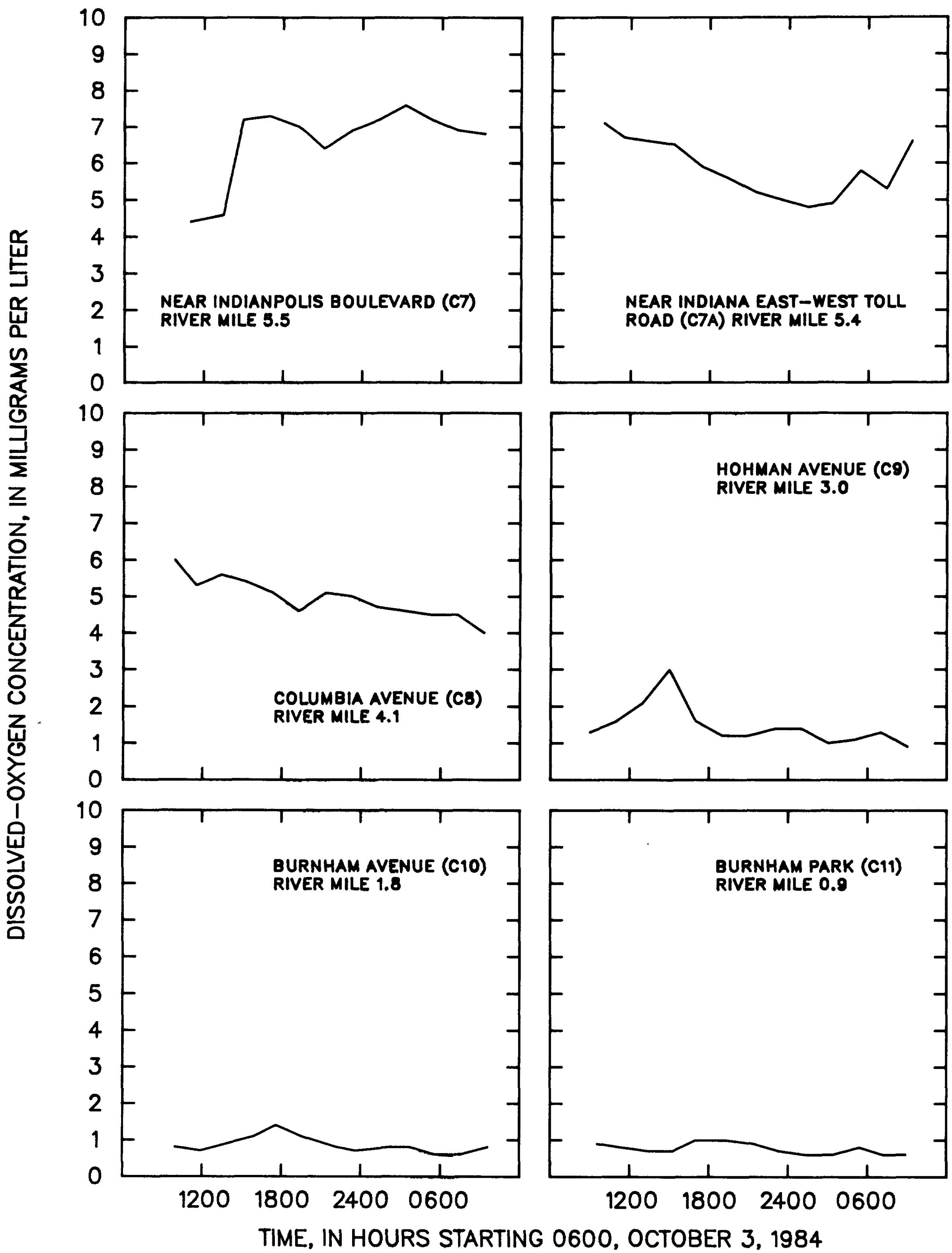


Figure 9.--Relation of dissolved-oxygen concentration to time, West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers given in parentheses refer to locations shown in figure 1).

Specific Conductance

Specific conductance is a measure of the ability of a substance to conduct an electrical current. Pure water has a very low electrical conductance. However, charged ions in the water make the solution conductive. As the ionic concentrations increase, the specific conductance of the solution increases. Therefore, SC provides an indication of ionic concentration (Hem, 1985, p. 66). Specific conductance was measured at five sampling stations in the East Branch and ship canal and four stations in the West Branch to provide an indication of the diel fluctuation in water quality. Linear regression analysis was used to estimate the relation between conductance and concentrations of chloride, sulfate, fluoride, hardness, and dissolved solids determined during this study. The regression equations (table 7) can be used to estimate diel fluctuations in chloride, sulfate, fluoride, hardness, and dissolved solids during the survey. They are not necessarily applicable to data collected at other times.

Average specific conductance in the East Branch ranged from about 360 μS/cm at Virginia Avenue (station C1A) to about 500 μS/cm near the confluence of the East Branch with the ship canal (fig. 10). Diel fluctuations ranged from about 40 to 200 μS/cm (fig. 11).

Specific conductance was substantially higher in the West Branch than in the East Branch. Average conductance ranged from about 1,200 to 1,600 μS/cm (fig. 10). Conductance was highest at stations C7 and C7A. Diel fluctuations ranged from about 300 to 1,500 μS/cm (fig. 12). The diel fluctuation was largest at the station nearest the ship canal (C7) and can be attributed to the interaction of water from the West Branch and ship canal during the reversals in flow.

Table 7.--Regression equations for estimating chloride, sulfate, fluoride, hardness and dissolved-solids concentrations from specific conductance

[Equations predict chloride, sulfate, fluoride, hardness, and dissolved solids in units of milligrams per liter for specific conductance given in units of microsiemens per centimeter at 25 °C; mg/L, milligrams per liter]

Regression equation	Coefficient of determination	Standard error (mg/L)
Chloride = 0.229(specific conductance) - 65	0.96	27
Sulfate = 0.099(specific conductance)	.99	5
Fluoride = 0.002(specific conductance) - 0.3	.97	15.1
Hardness = 0.065(specific conductance) - 101	.77	21
Dissolved solids = 0.592(specific conductance) - 1.8	.99	36

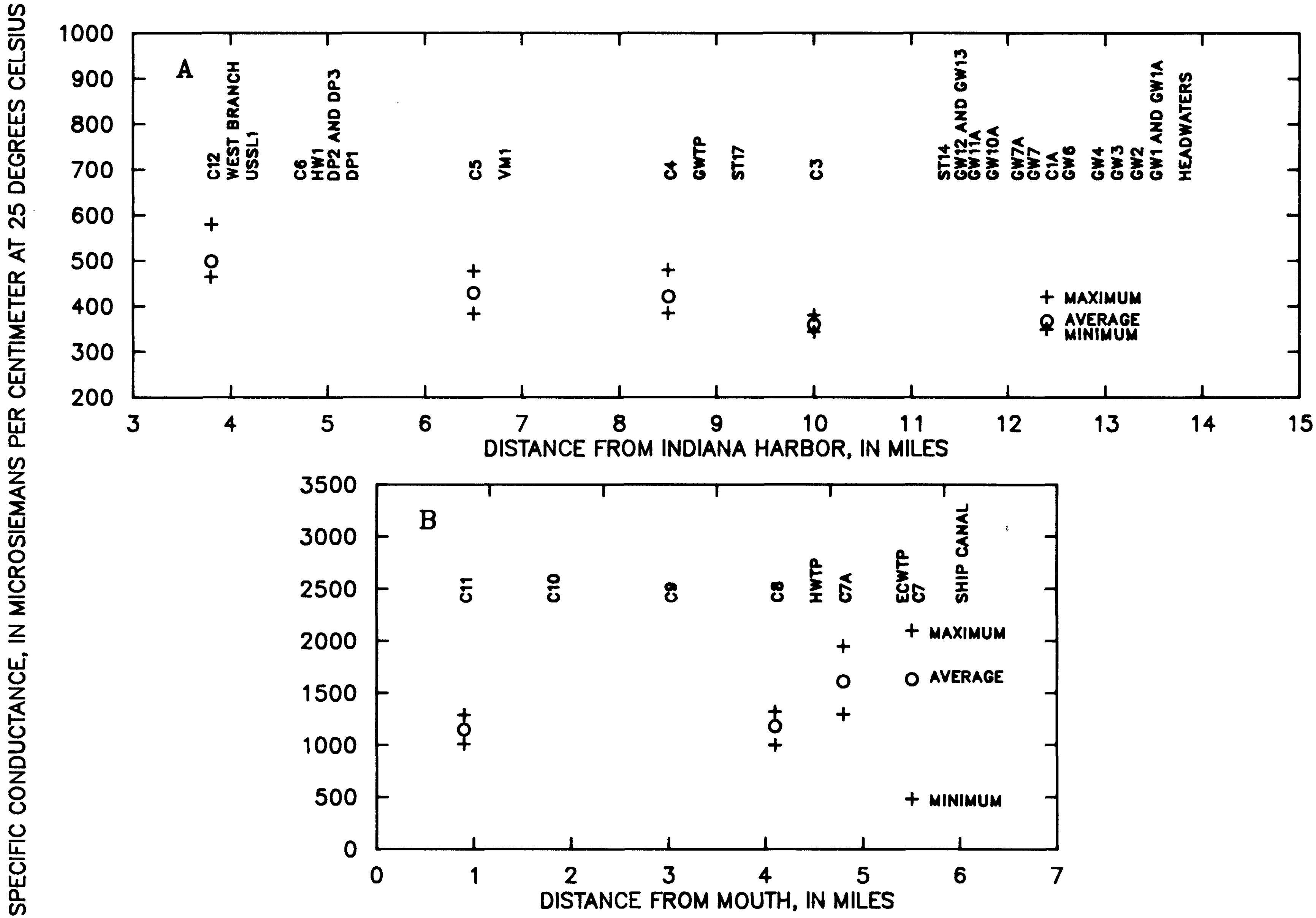


Figure 10.--Longitudinal variation in specific conductance, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

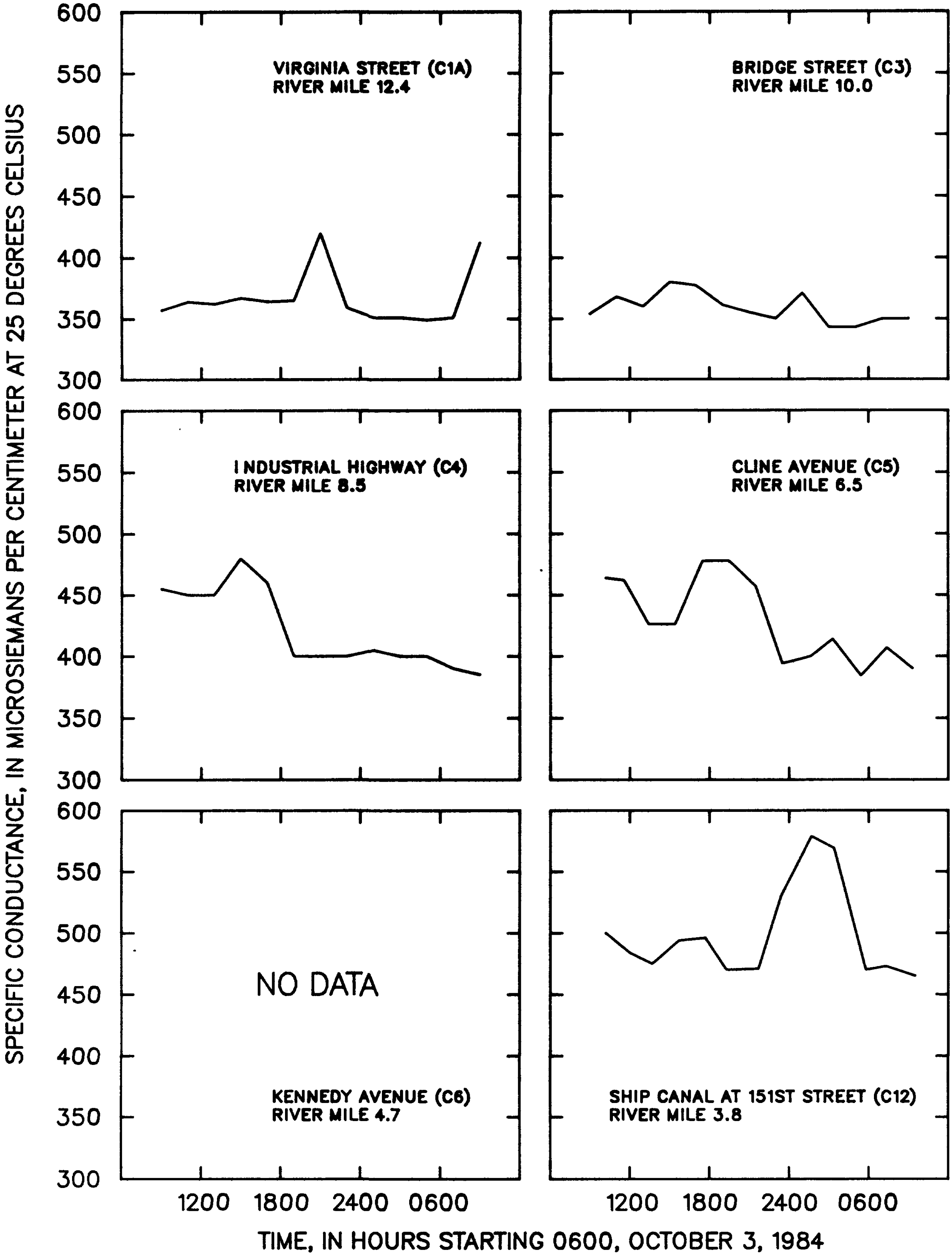


Figure 11.--Relation of specific conductance to time, East Branch Grand Calumet River, October 3-4, 1984. (Station identifiers given in parentheses refer to locations shown in figure 1).

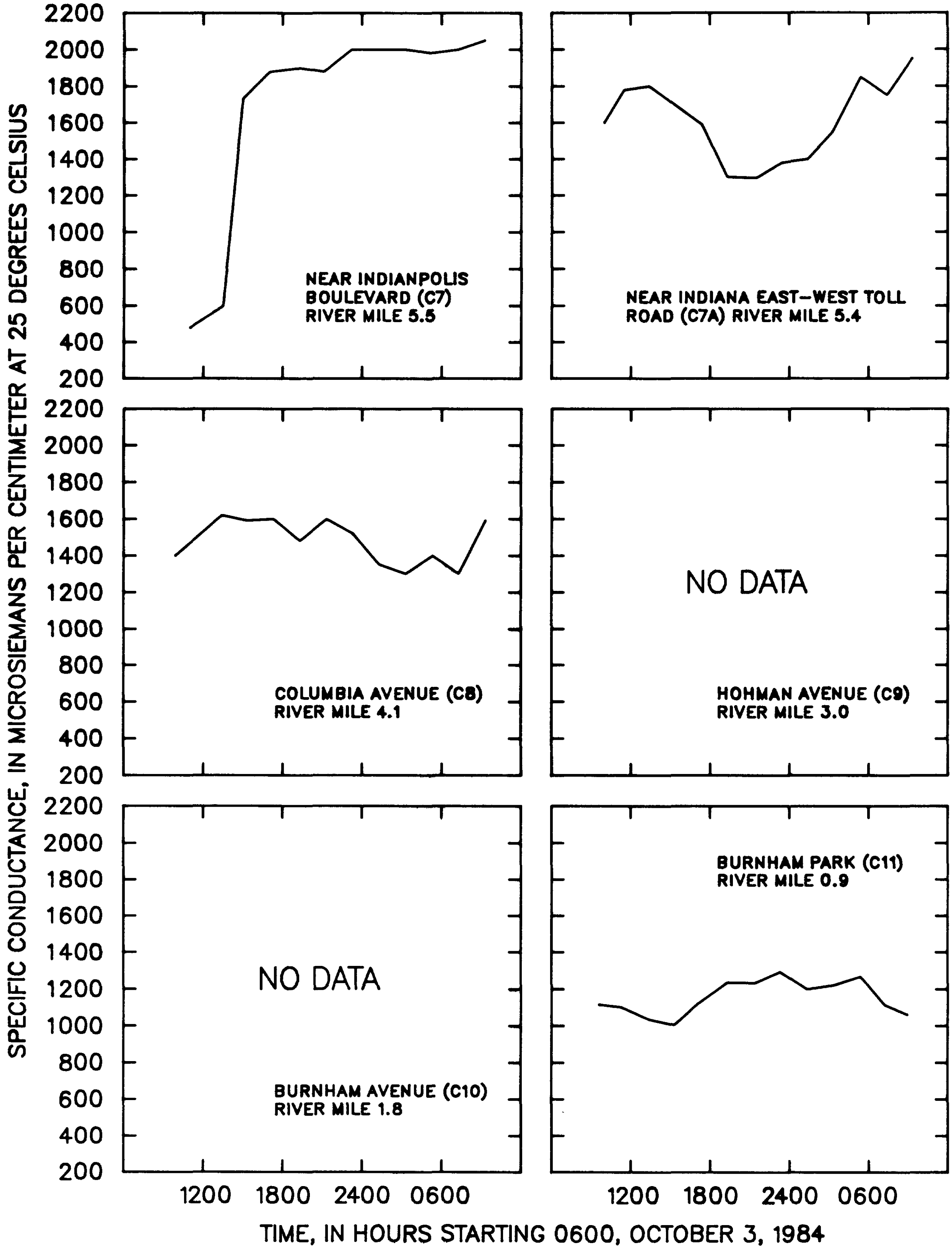


Figure 12.––Relation of specific conductance to time, West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers given in parentheses refer to locations shown in figure 1).

pH

The pH of the East and West Branches Grand Calumet River was near neutrality or slightly basic (fig. 13). The pH was not outside the water-quality standard range of pH 6-9 at any of the sampling stations. Little diel fluctuation was observed in pH (figs. 14 and 15) except in the East Branch at Industrial Highway (station C4). Diel fluctuation at this station was nearly 1 standard unit.

Water Temperature

Average water temperature ranged from about 18 to 20 °C in the East Branch and was relatively uniform through the reach (fig. 16). Diel fluctuations in water temperature ranged from about 2 to 3 °C (fig. 17). In the West Branch, average water temperature ranged from about 17 to 20 °C (fig. 16). Diel water temperature fluctuations in the West Branch were slightly greater than in the East Branch ranging from about 3 to 5 °C (fig. 18). Temperature in the West Branch was highest at stations C8 and C9 and lowest near the confluences with the ship canal and the Little Calumet River. The water-quality standard for water temperature was not exceeded in either the East or West Branches of the river.

Chloride

Chloride concentrations in the East Branch ranged from about 20 to 50 mg/L (fig. 19). Concentrations were lowest in the upstream reaches and increased downstream to the maximum value observed at the confluence with the ship canal. Concentration of chloride in the East Branch was less than the absolute maximum allowable standard (125 mg/L) at all sampling stations.

Chloride concentrations in the West Branch ranged from about 150 mg/L to about 330 mg/L (fig. 19). Concentrations at stations C7 and C7A were about twice those at the other stations in the West Branch. The maximum absolute chloride standard (125 mg/L) was exceeded at all stations on the West Branch.

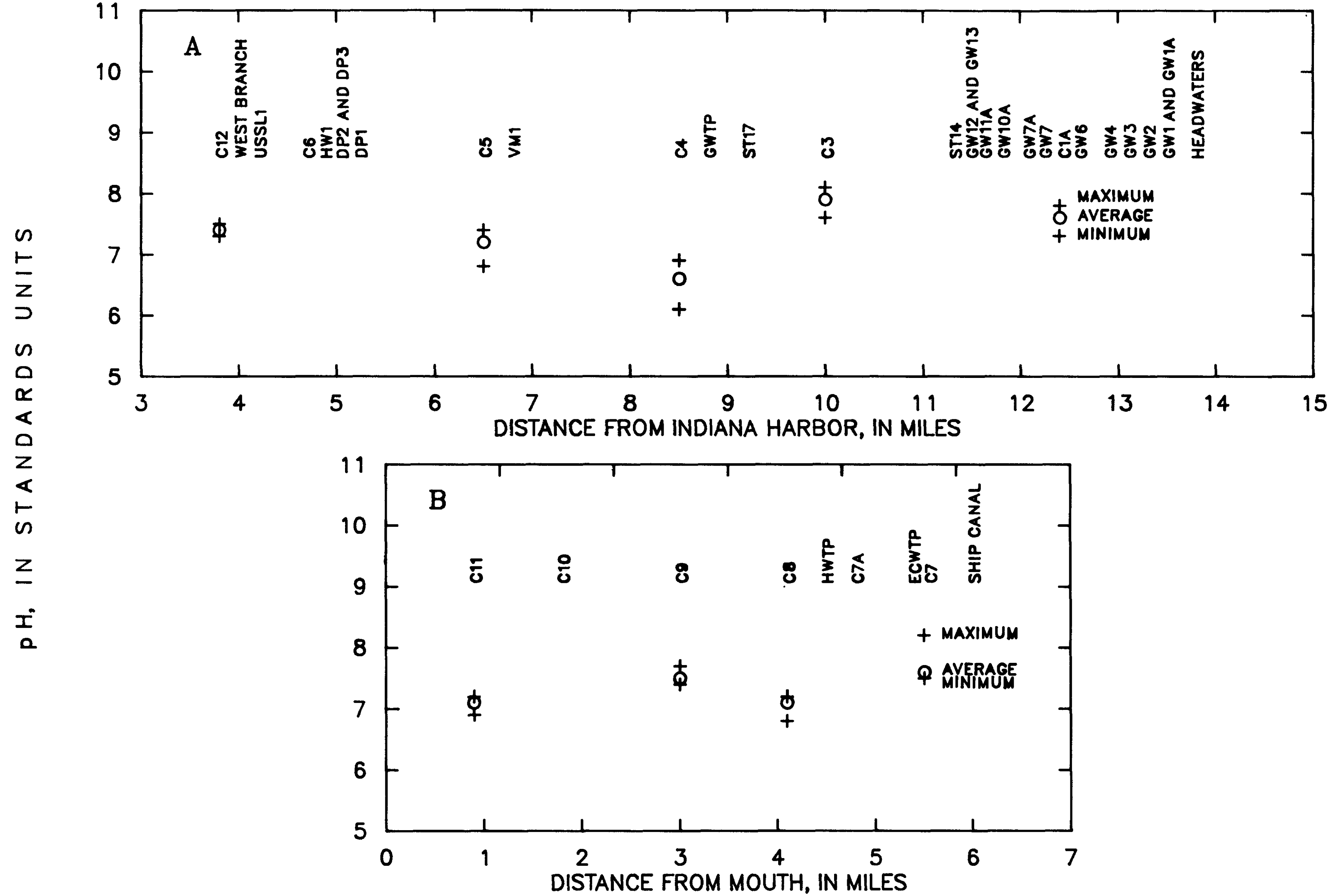


Figure 13.--Longitudinal variation in pH, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

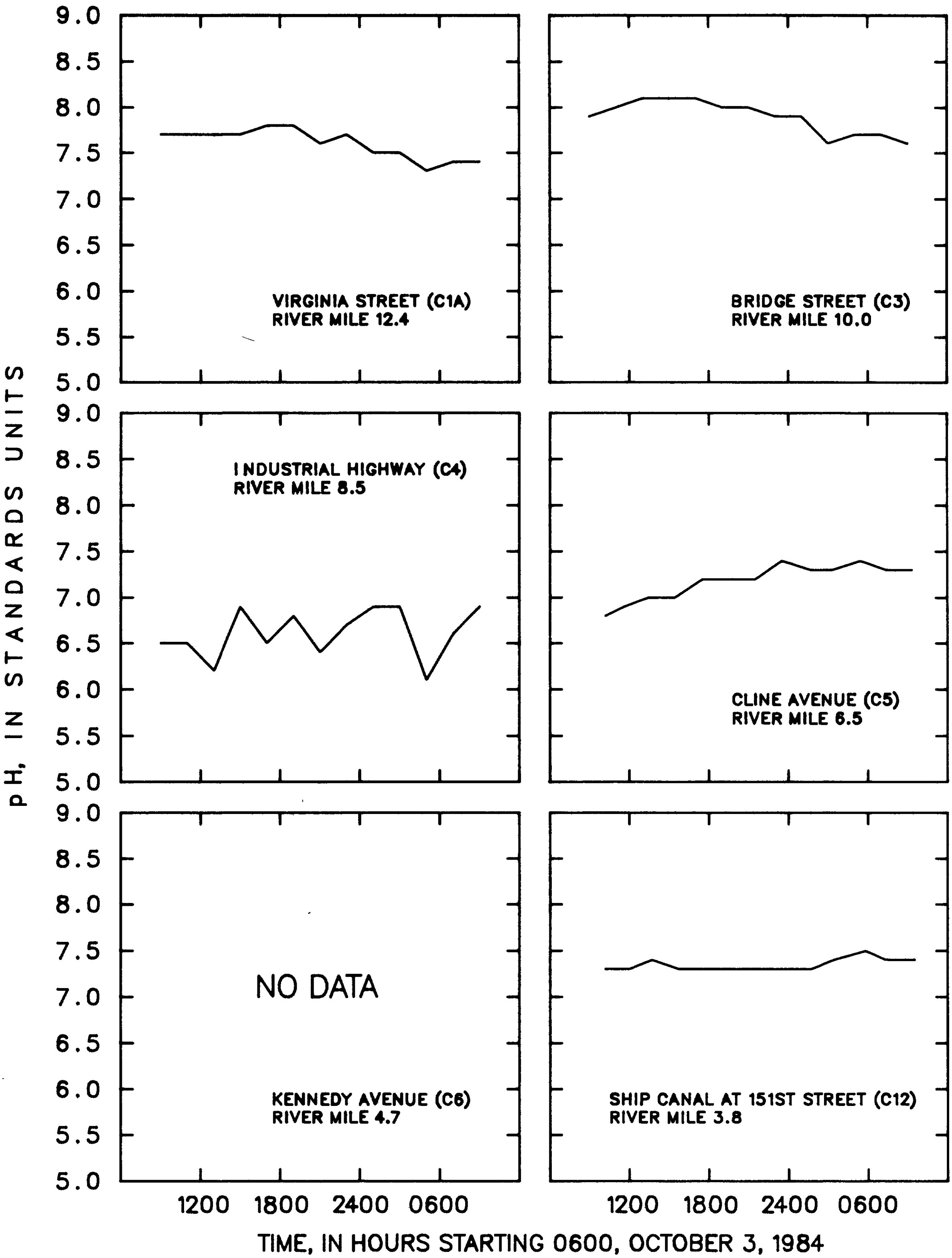


Figure 14.--Relation of pH to time, East Branch Grand Calumet River, October 3-4, 1984. (Station identifiers given in parentheses refer to locations shown in figure 1).

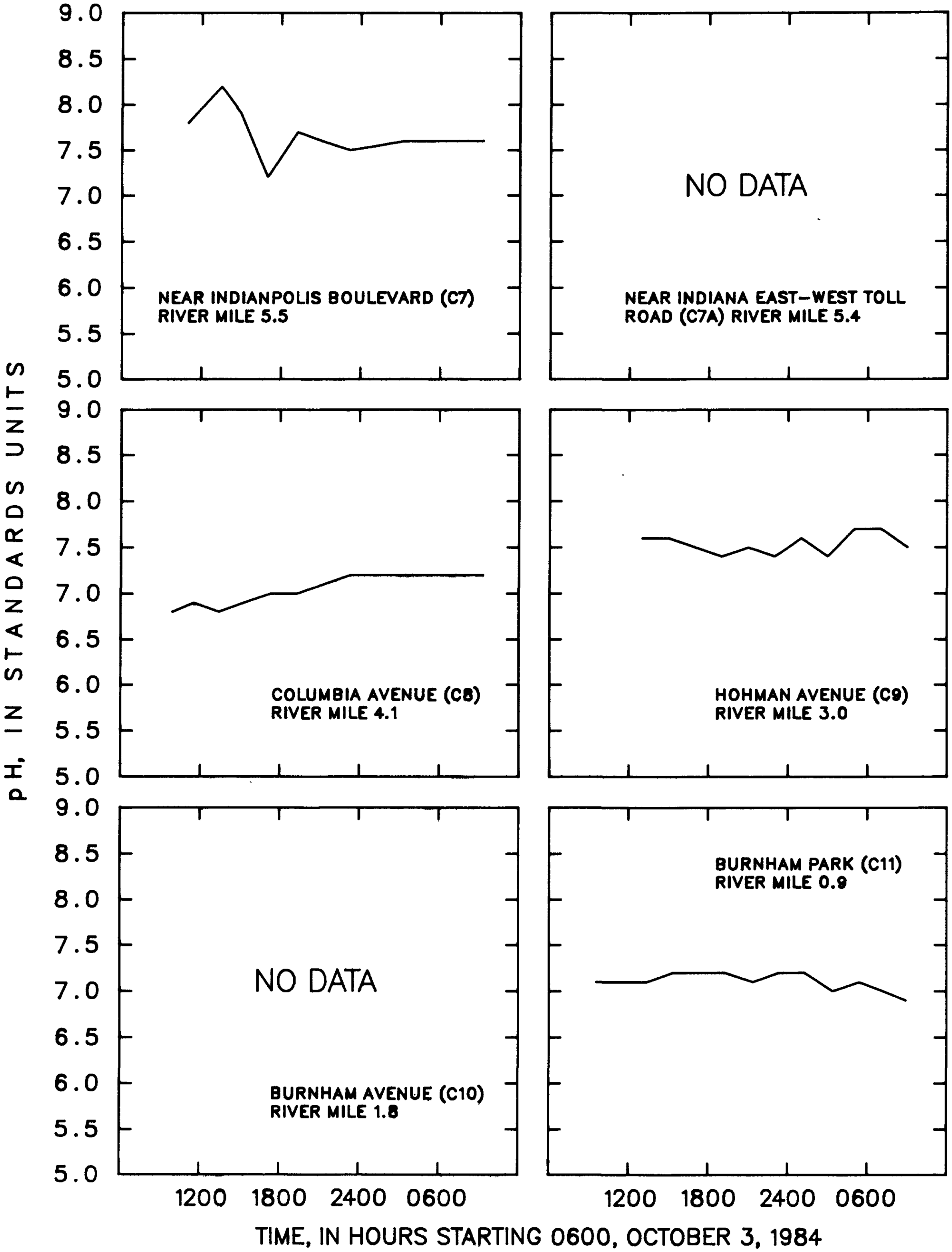


Figure 15.--Relation of pH to time, West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers given in parentheses refer to locations shown in figure 1).

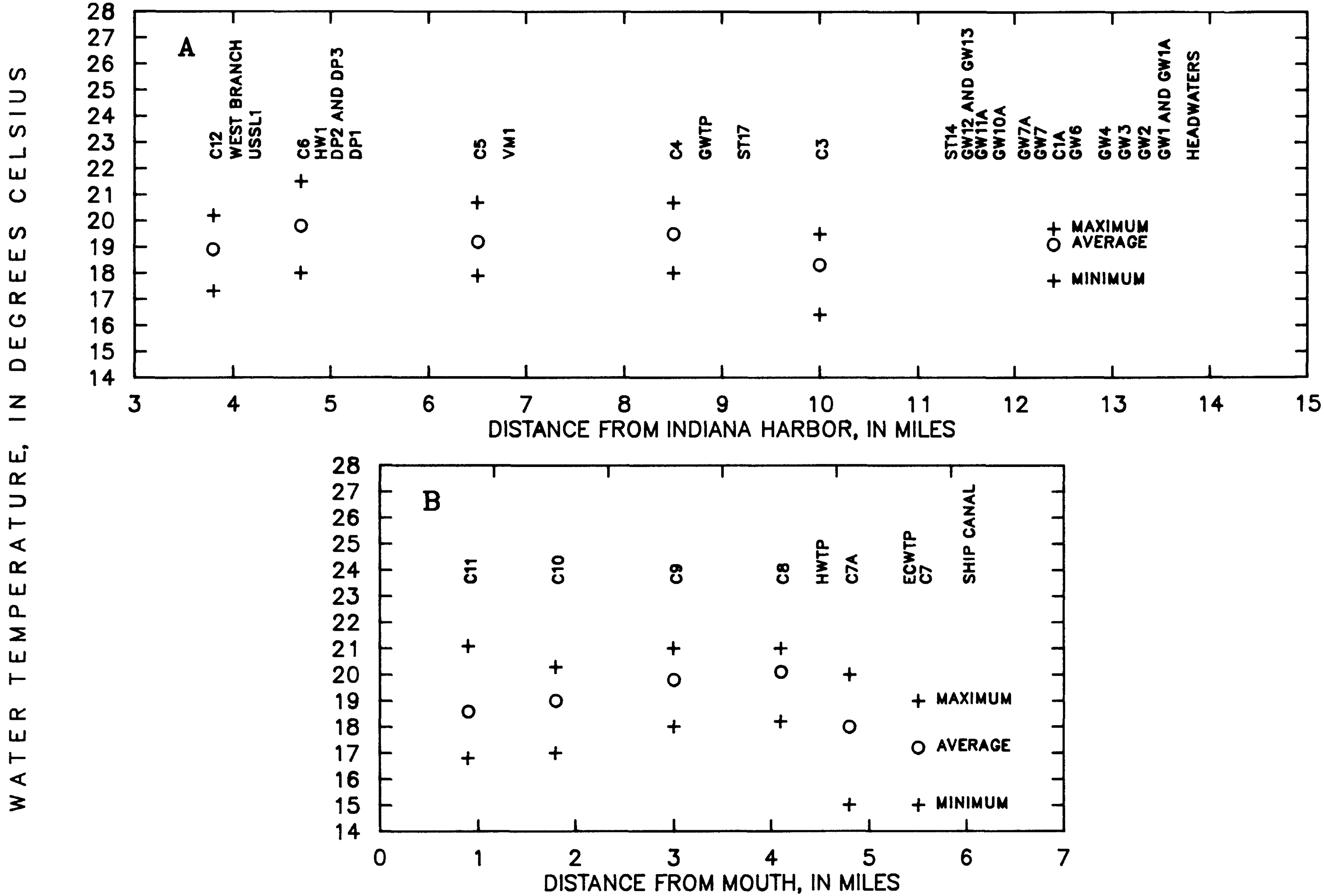


Figure 16.--Longitudinal variation in water temperature, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

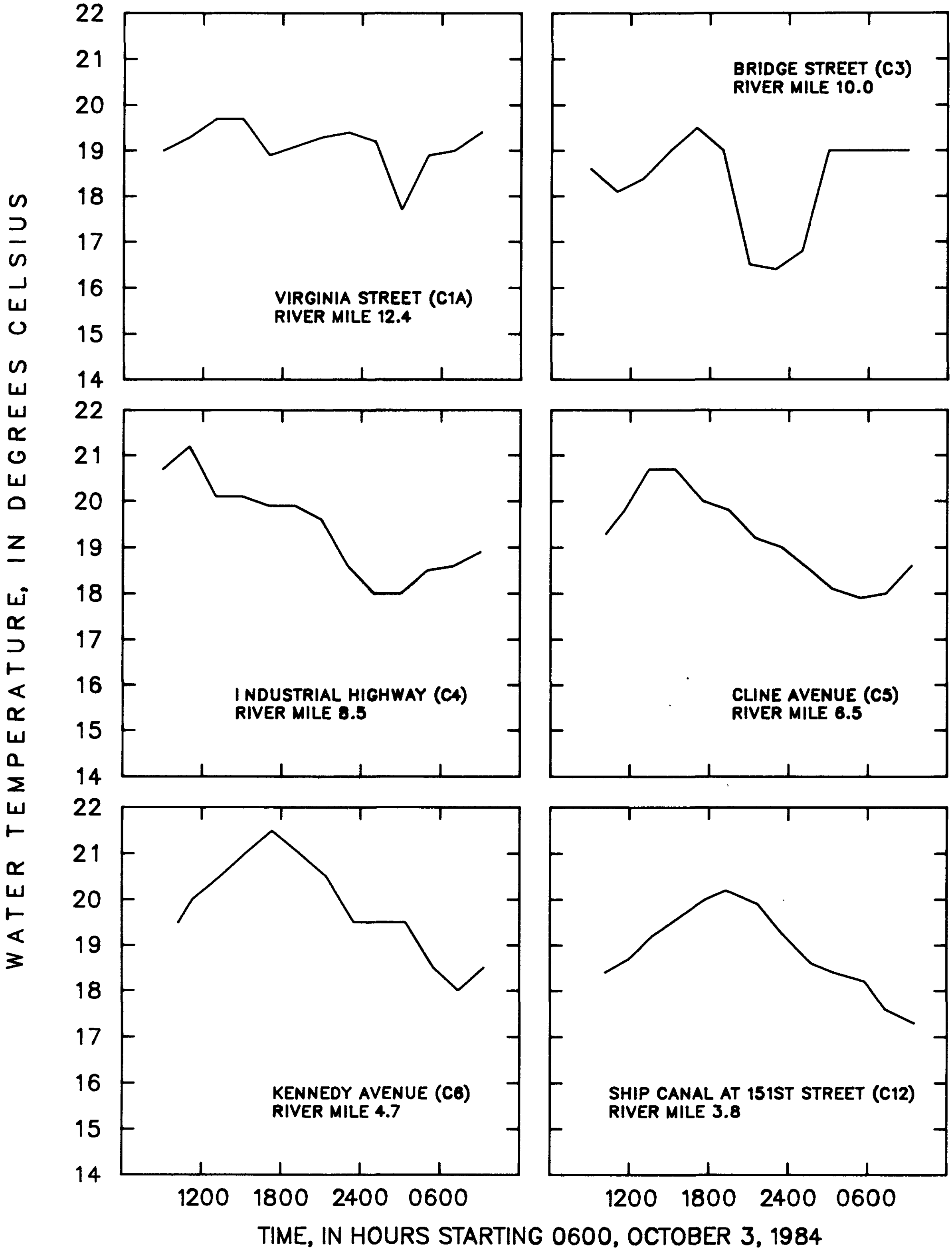


Figure 17.--Relation of water temperature to time, East Branch Grand Calumet River, October 3-4, 1984. (Station identifiers given in parentheses refer to locations shown in figure 1).

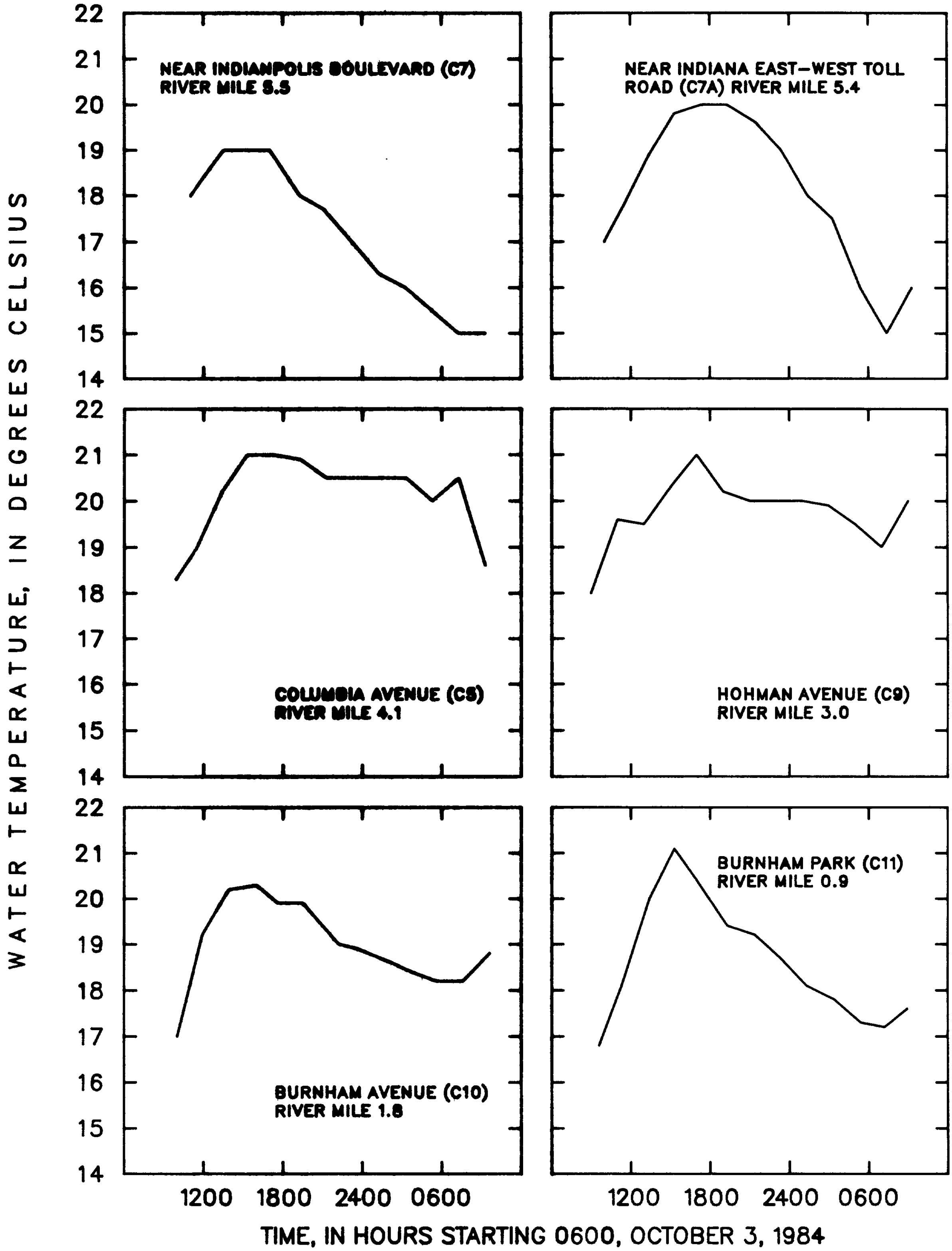


Figure 18.--Relation of water temperature to time, West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers given in parentheses refer to locations shown in figure 1).

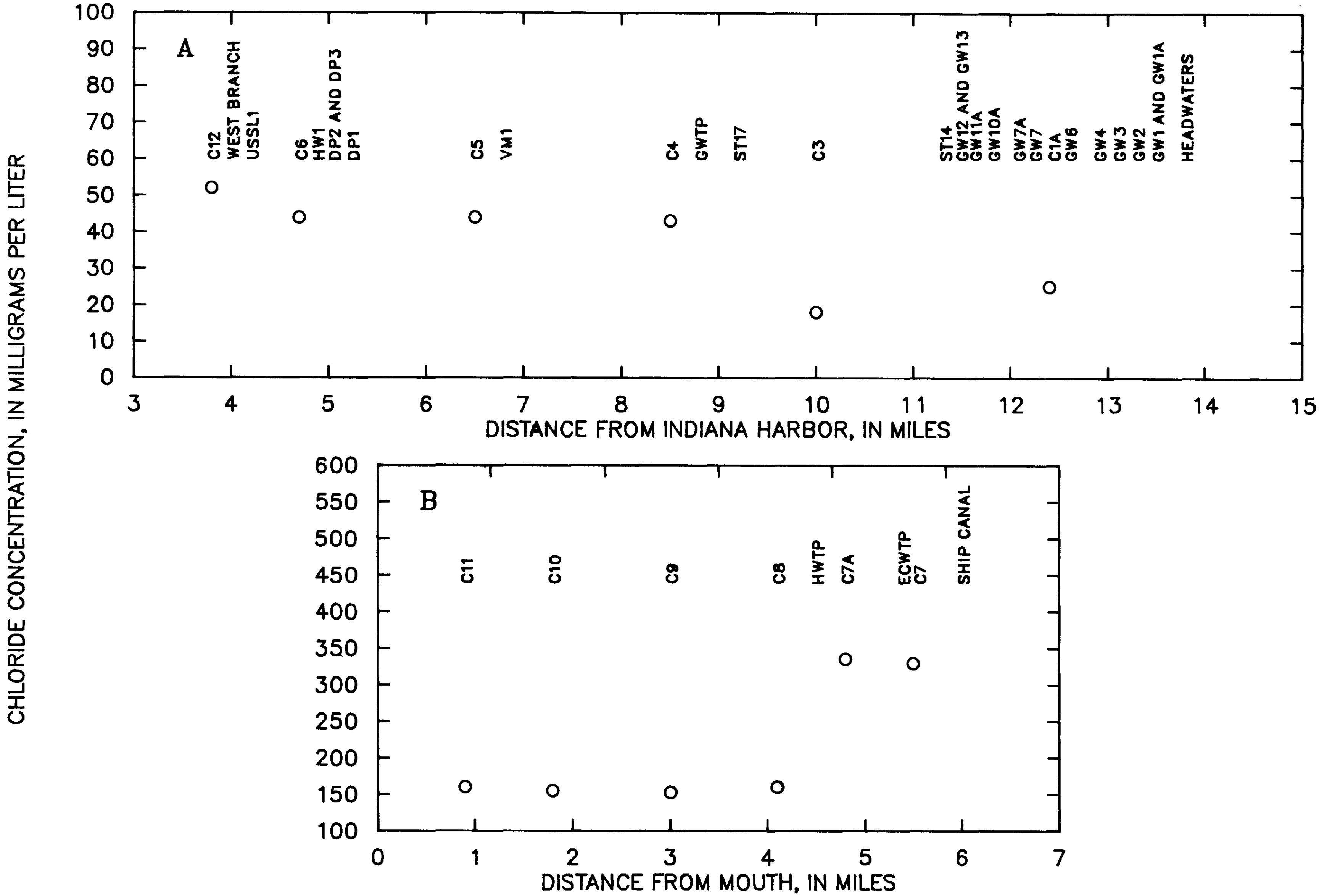


Figure 19.--Longitudinal variation in concentration of chloride, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

Sulfate

Sulfate concentrations in the East Branch ranged from about 30 to 50 mg/L (fig. 20). As with chloride, the values were lowest in the upstream reaches and increased in the downstream direction. Concentrations of sulfate in the West Branch ranged from about 115 to 160 mg/L (fig. 20) and were highest at stations C7A and C7. The absolute maximum standard for sulfate (225 mg/L) was not exceeded at any station in either the East or West Branches of the river.

Fluoride

Fluoride concentrations in the East Branch ranged from 0.2 to 0.5 mg/L (fig. 21), considerably less than the 1.3 mg/L water-quality standard for fluoride. This standard was equaled or exceeded at four of the six stations in the West Branch where the concentrations ranged from 1.2 to 2.3 mg/L (fig. 21).

Hardness

Hardness in the East Branch ranged from 110 to 150 mg/L (fig. 22). Upstream from Bridge Street (station C3), where hardness was 110 mg/L, the water is considered moderately hard on the basis of the classification of Durfor and Becker (1964, p. 27). Downstream from Industrial Highway (station C4), hardness ranged from 140 to 150 mg/L and is classified as hard.

Hardness in the West Branch ranged from 140 to 220 mg/L (fig. 22). Water at all stations except Burnham Park (C11) is classified as very hard. Water at the Burnham Park station is classified as hard.

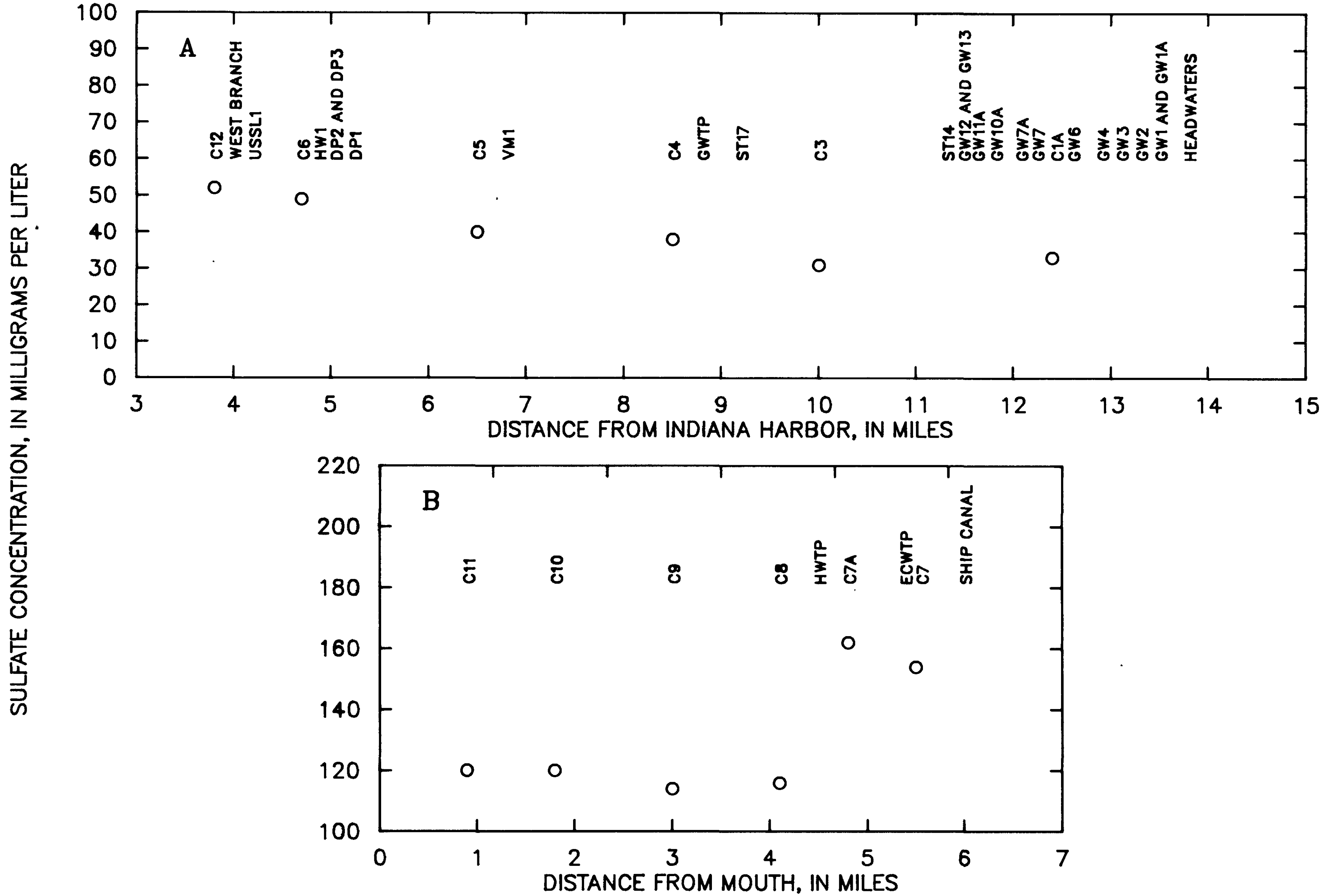


Figure 20.--Longitudinal variation in concentration of sulfate, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

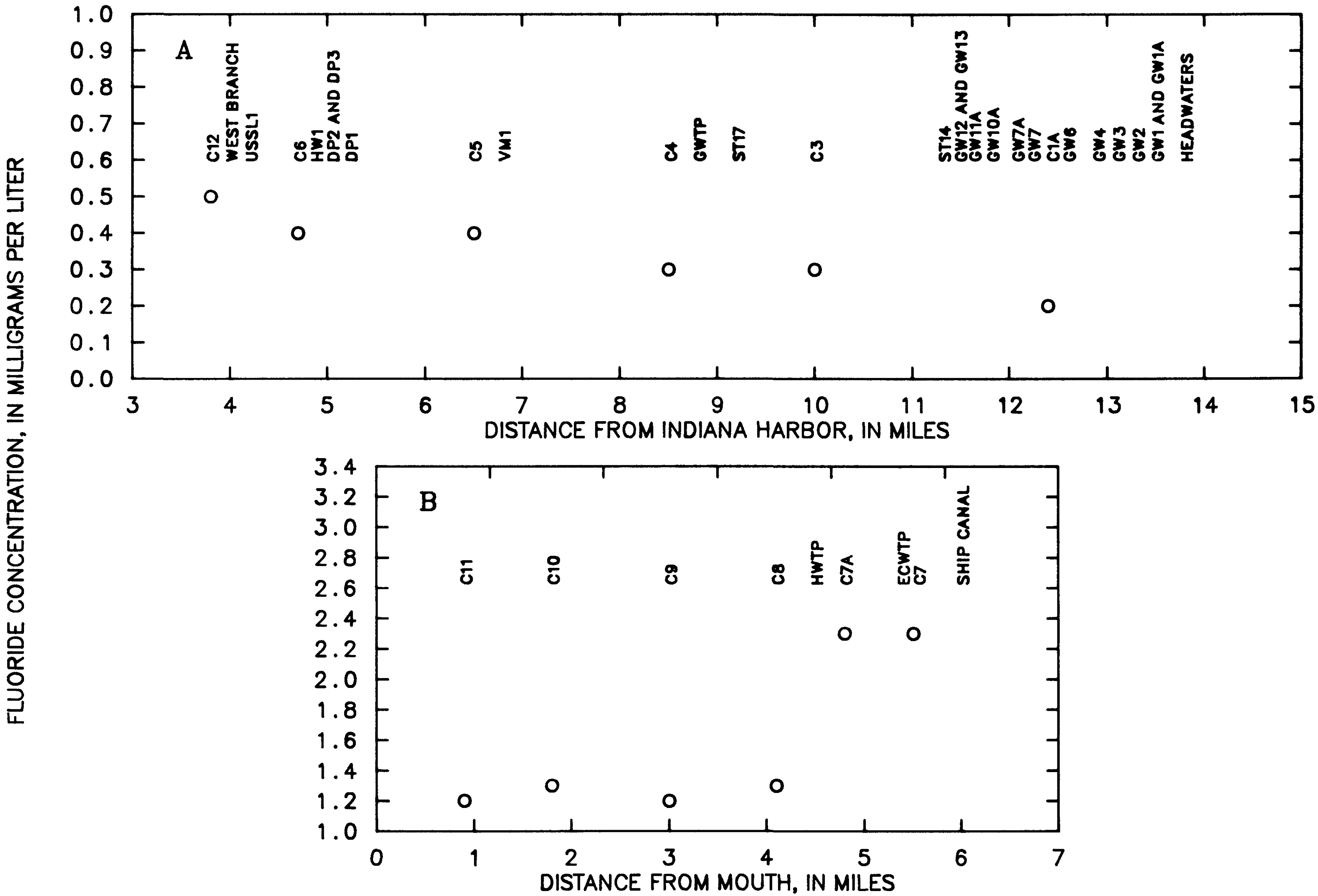


Figure 21.--Longitudinal variation in concentration of fluoride, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

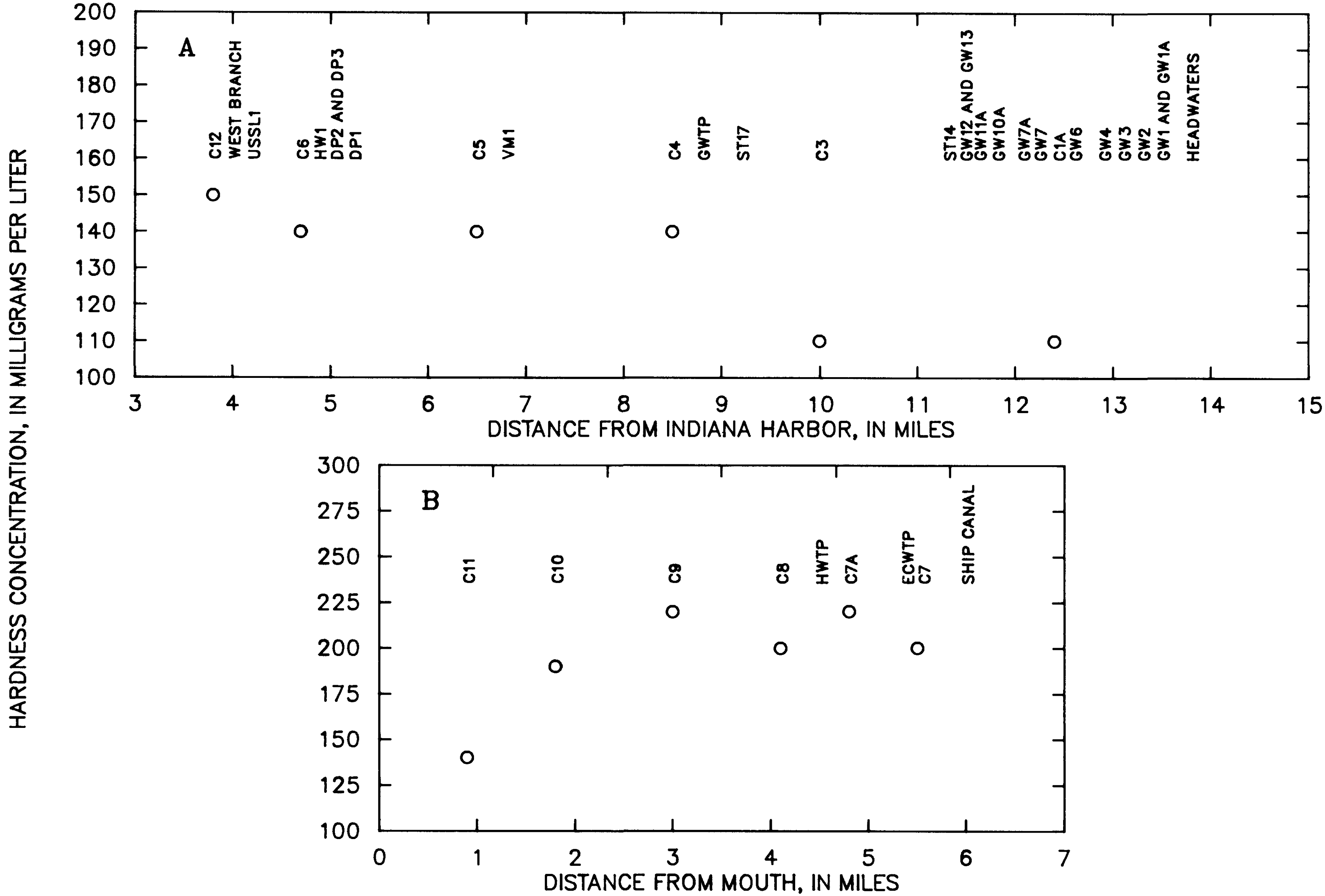


Figure 22.--Longitudinal variation in hardness of water, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

Dissolved and Suspended Solids

Dissolved-solids concentrations in the East Branch ranged from about 200 to 320 mg/L (fig. 23), considerably less than the absolute maximum standard for dissolved solids (500 mg/L). This standard was exceeded at all stations in the West Branch, where dissolved solids concentration ranged from about 650 to 1,000 mg/L (fig. 23).

Suspended-solids concentrations were low in the East Branch ranging from less than 1 to 10 mg/L (fig. 24). Concentrations in the West Branch were higher, ranging from 11 to 16 mg/L (fig. 24). Suspended-solids concentrations at all stations in the West Branch were also higher than those observed in the effluent at either the ECWTP or HWTP. Since these plants are the only known sources of flow to the West Branch, this difference suggests the presence of one or more unknown dry-weather point sources. From a reconnaissance of the area prior to the survey, the authors concluded that the contribution of suspended solids from such a source is more than a temporary phenomenon. Sludge deposits located just upstream of Columbia Avenue (station C8) were found to be more than 7 ft deep. The presence of these deposits, which were not present farther upstream, indicates that the source of these solids is in the immediate vicinity of Columbia Avenue.

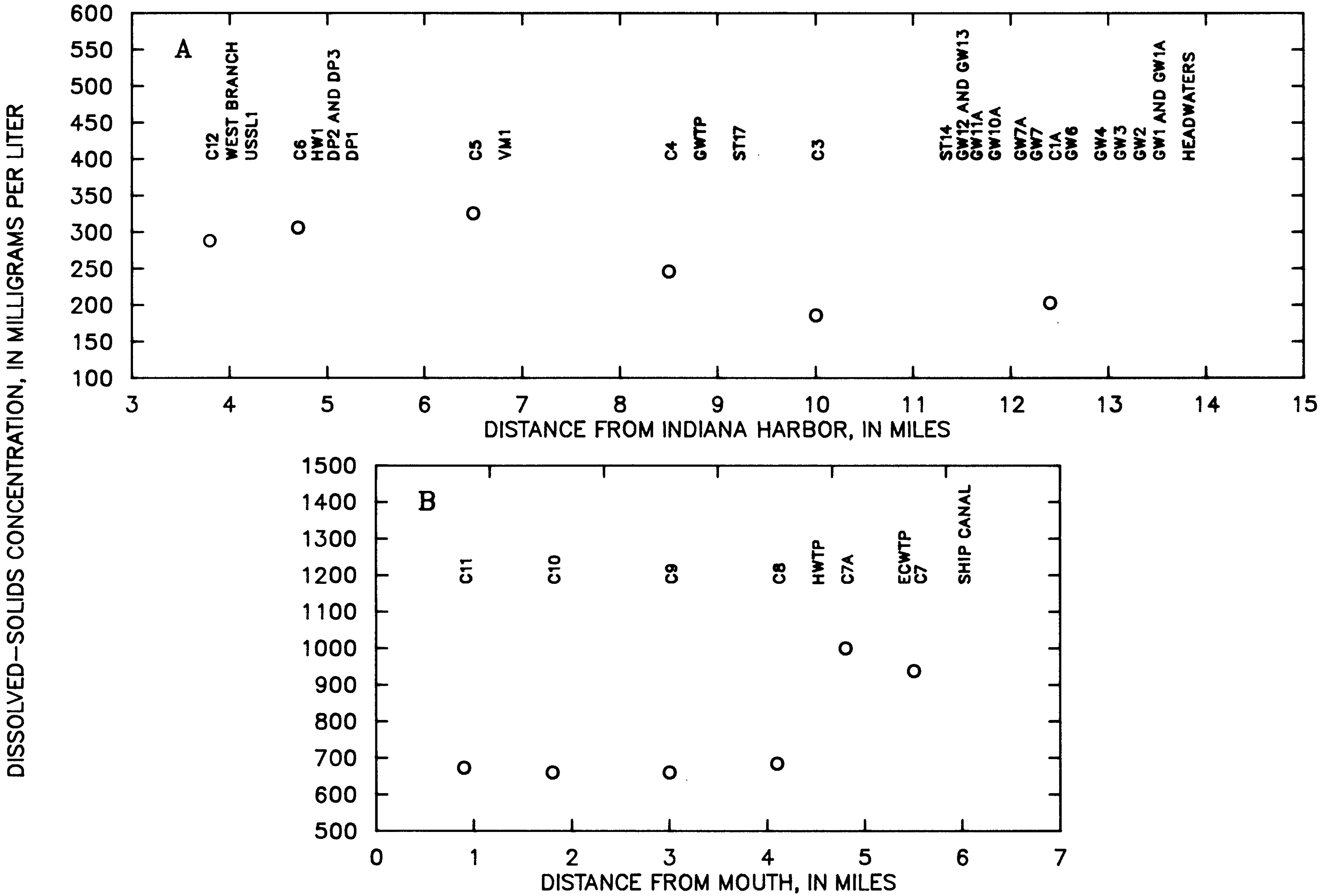


Figure 23.--Longitudinal variation in concentration of dissolved solids, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

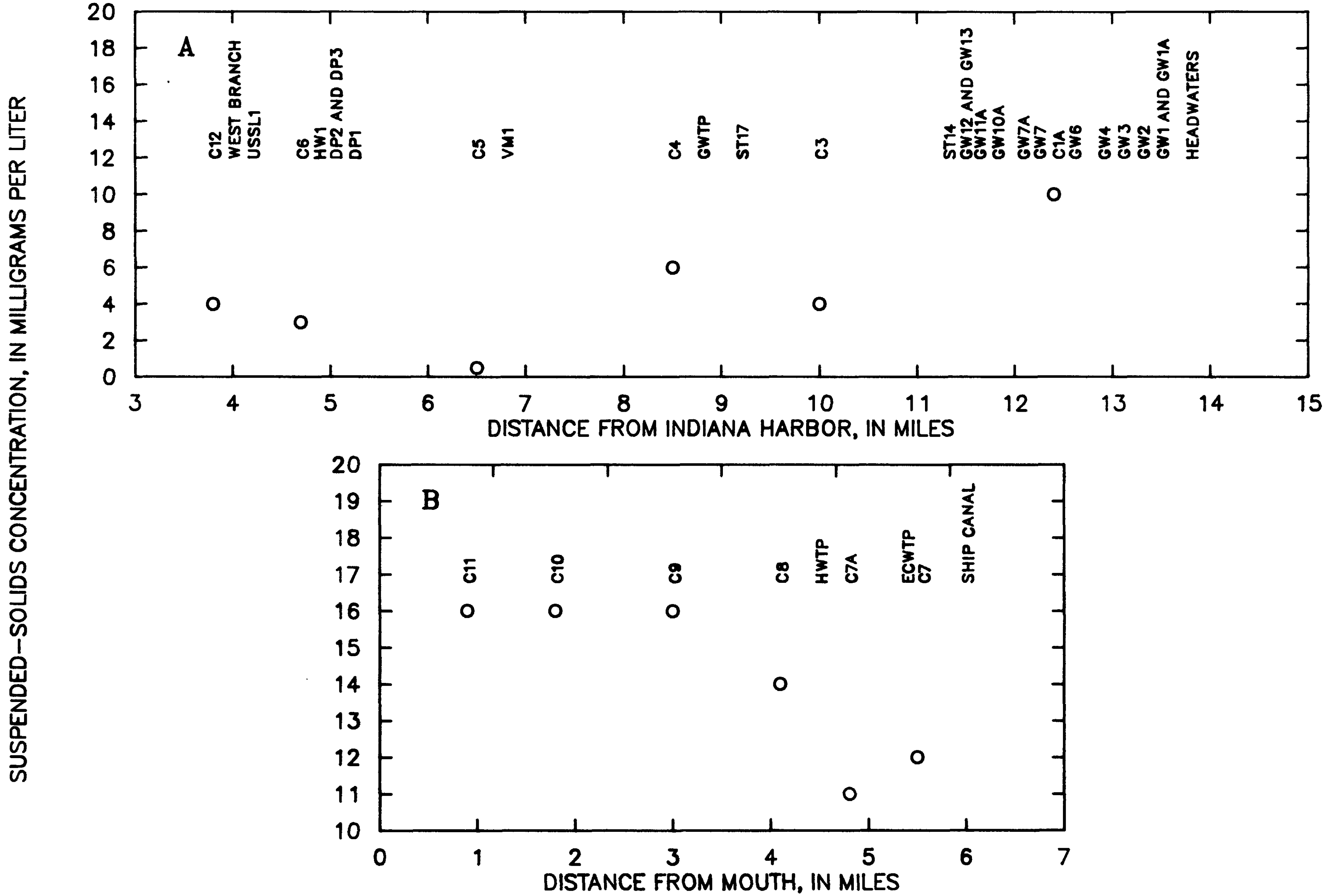


Figure 24.--Longitudinal variation in concentration of suspended solids, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

Nitrogen

Organic-nitrogen concentrations ranged from about 0.1 to 0.6 mg/L as N in the East Branch (fig. 25), and were highest at Virginia Avenue (station C1A) and near the confluence of the East Branch with the ship canal. Concentrations of organic nitrogen were higher in the West Branch where they ranged from 1.6 to 2.6 mg/L as N (fig. 25), and were highest at stations C8, C9, C10, and C11.

Ammonia concentrations ranged from 0.71 to 1.5 mg/L as N in the East Branch (fig. 26). The highest ammonia concentration in the East Branch was observed at Virginia Avenue (station C1A). All other concentrations of ammonia in the East Branch were less than 0.9 mg/L as N. Ammonia concentrations in the West Branch were higher than in the East Branch and ranged from 2.6 to 5.0 mg/L as N (fig. 26). Concentrations of ammonia in the West Branch exceeded the water-quality standard for ammonia (1.5 mg/L as N) at all stations.

Nitrite concentrations in the East Branch ranged from 0.05 to 0.13 mg/L as N (fig. 27). The concentrations, which increased in the downstream direction, were highest at the station in the ship canal (C12). Nitrite concentrations in the West Branch ranged from 0.34 to 1.0 mg/L as N (fig. 27) and were highest at stations C7 and C7A.

Nitrate concentrations in the East Branch ranged from about 0.2 to 1.6 mg/L as N (fig. 28). As with nitrite, concentrations generally increased in the downstream direction. Nitrate concentrations in the West Branch were also higher than in the East Branch, ranging from 2.0 to 8.0 mg/L as N (fig. 28). Nitrate concentrations in the West Branch were highest at stations C7 and C7A.

Phosphorus

Total phosphorus concentrations in the East Branch ranged from 0.02 to 0.13 mg/L (fig. 29). The highest concentration observed at Cline Avenue (station C5), exceeded the absolute maximum water-quality standard for total phosphorus (0.1 mg/L). The standard was exceeded at all stations in the West Branch where total phosphorus concentrations ranged from 0.18 to 0.62 mg/L (fig. 29). Total phosphorus concentrations were highest at stations C8, C9, C10, and C11. However, the 0.1 mg/L standard for total phosphorus is not applicable to water from the West Branch flowing into Illinois.

Ortho-phosphorus concentrations in the East Branch were similar to total phosphorus concentrations except at Cline Avenue (station C5), where ortho-phosphorus did not increase as total phosphorus had (fig. 30). Ortho-phosphorus concentrations in the West Branch ranged from 0.05 to 0.30 mg/L (fig. 30) and equaled roughly one-third to one-half of the total phosphorus concentration.

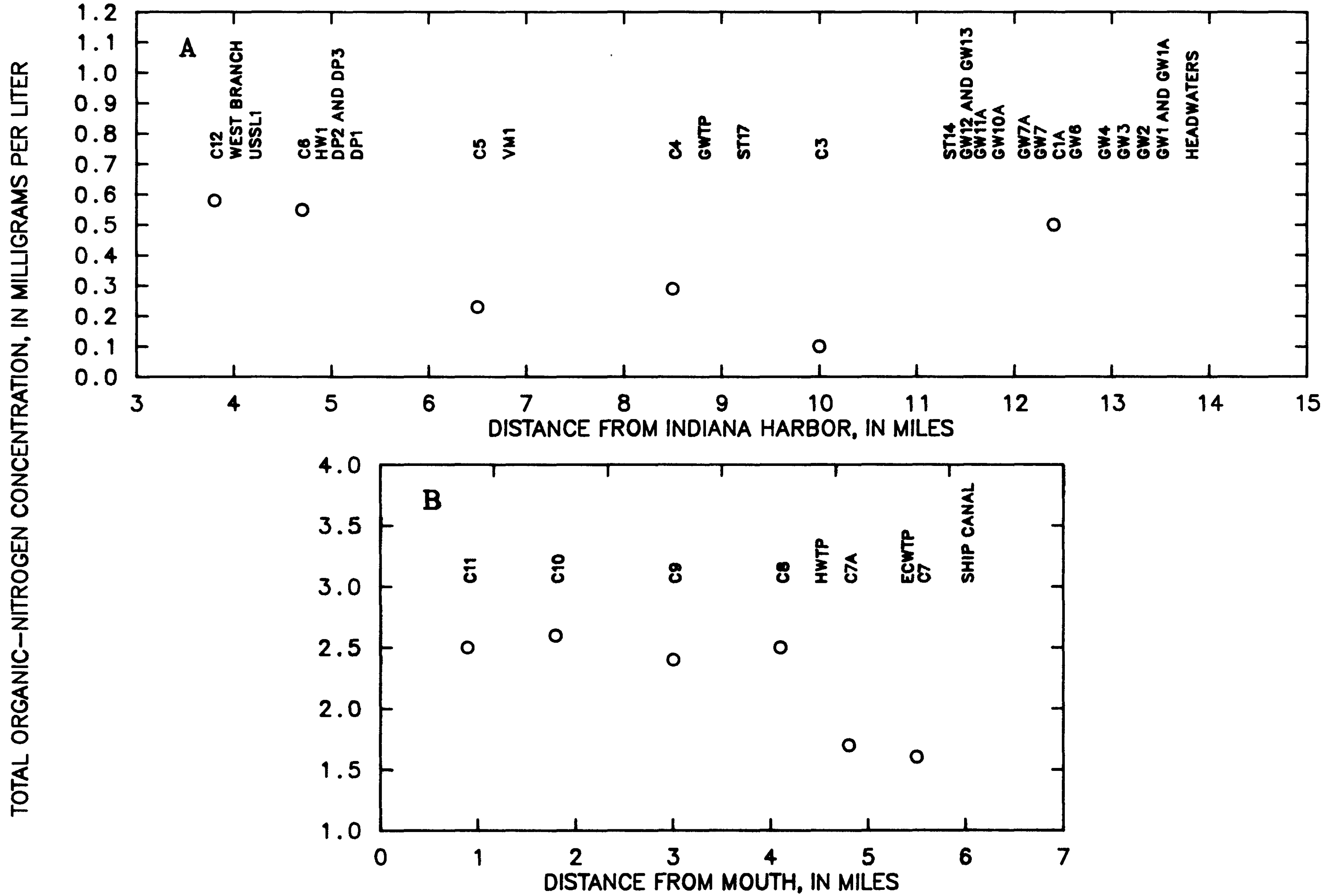


Figure 25.--Longitudinal variation in concentration of total organic nitrogen, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

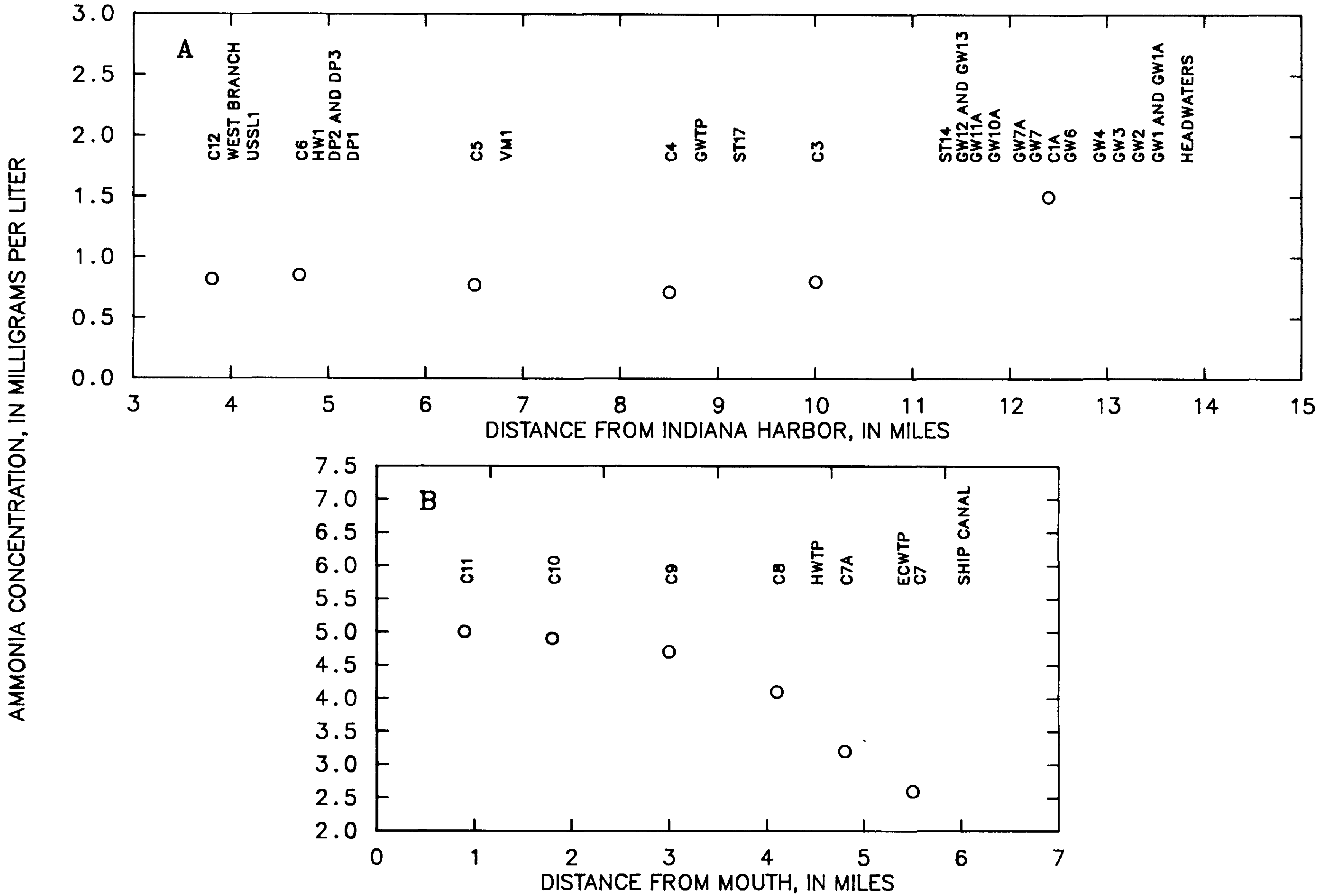


Figure 26.--Longitudinal variation in concentration of ammonia, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

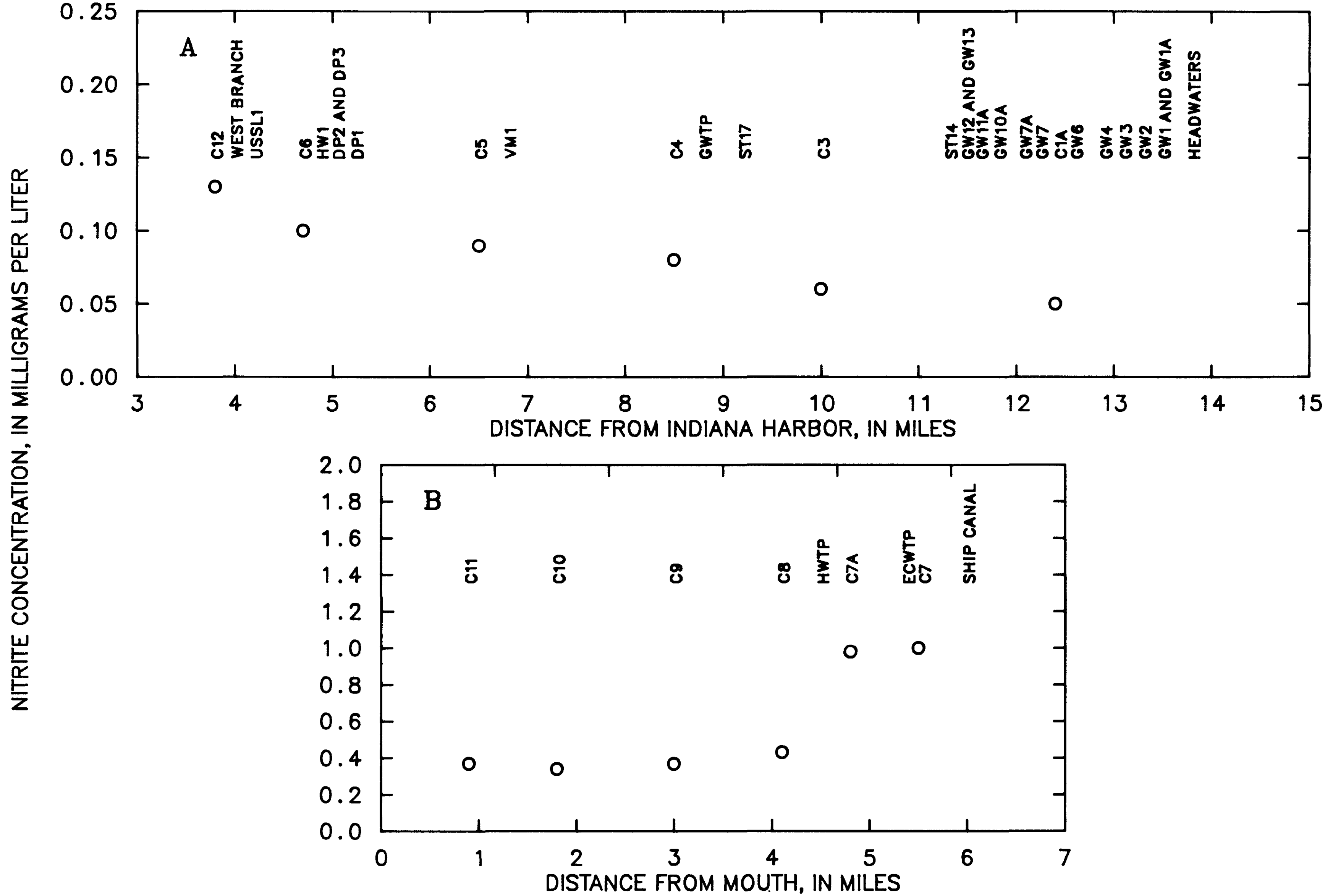


Figure 27.--Longitudinal variation in concentration of nitrite, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

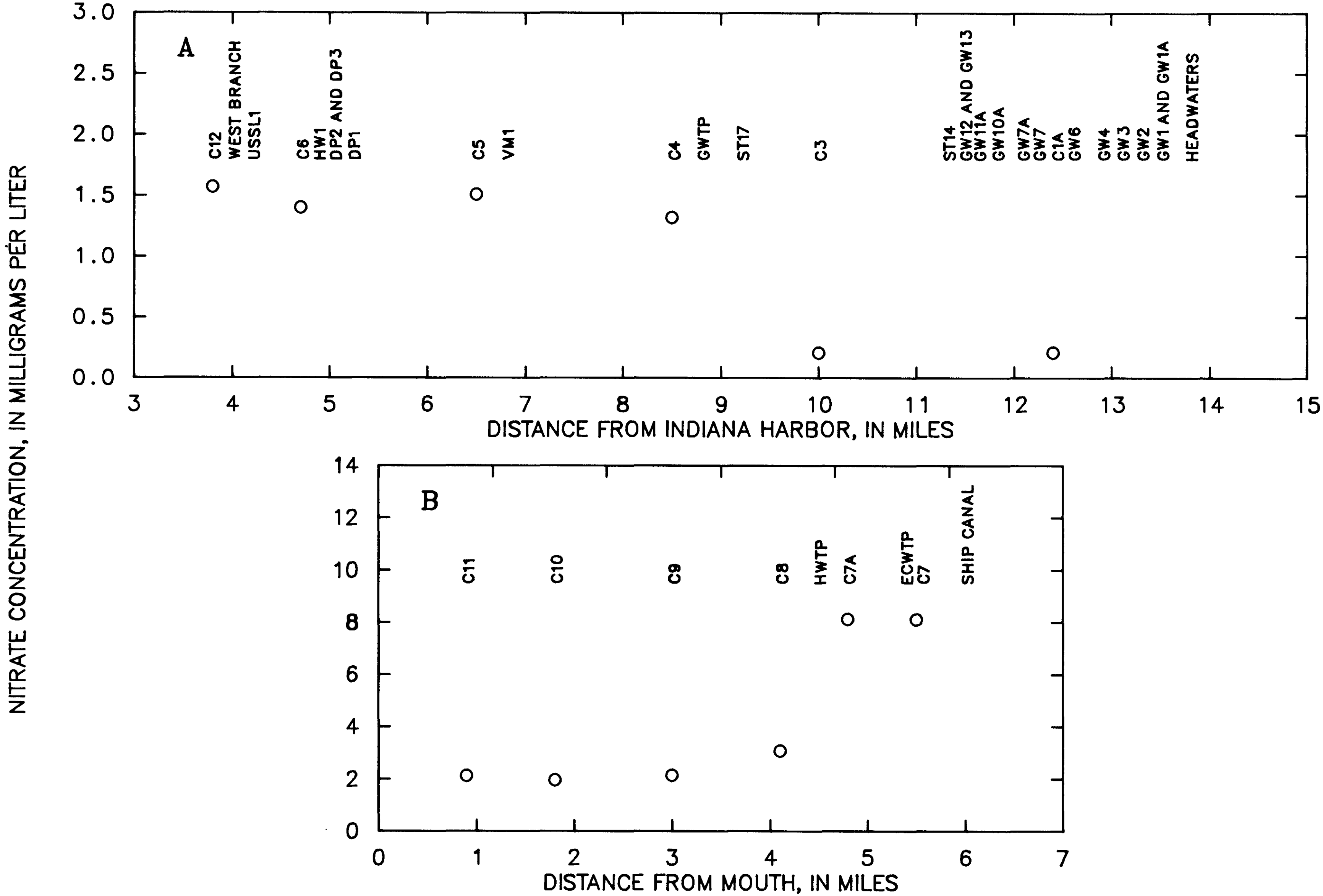


Figure 28.--Longitudinal variation in concentration of nitrate, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

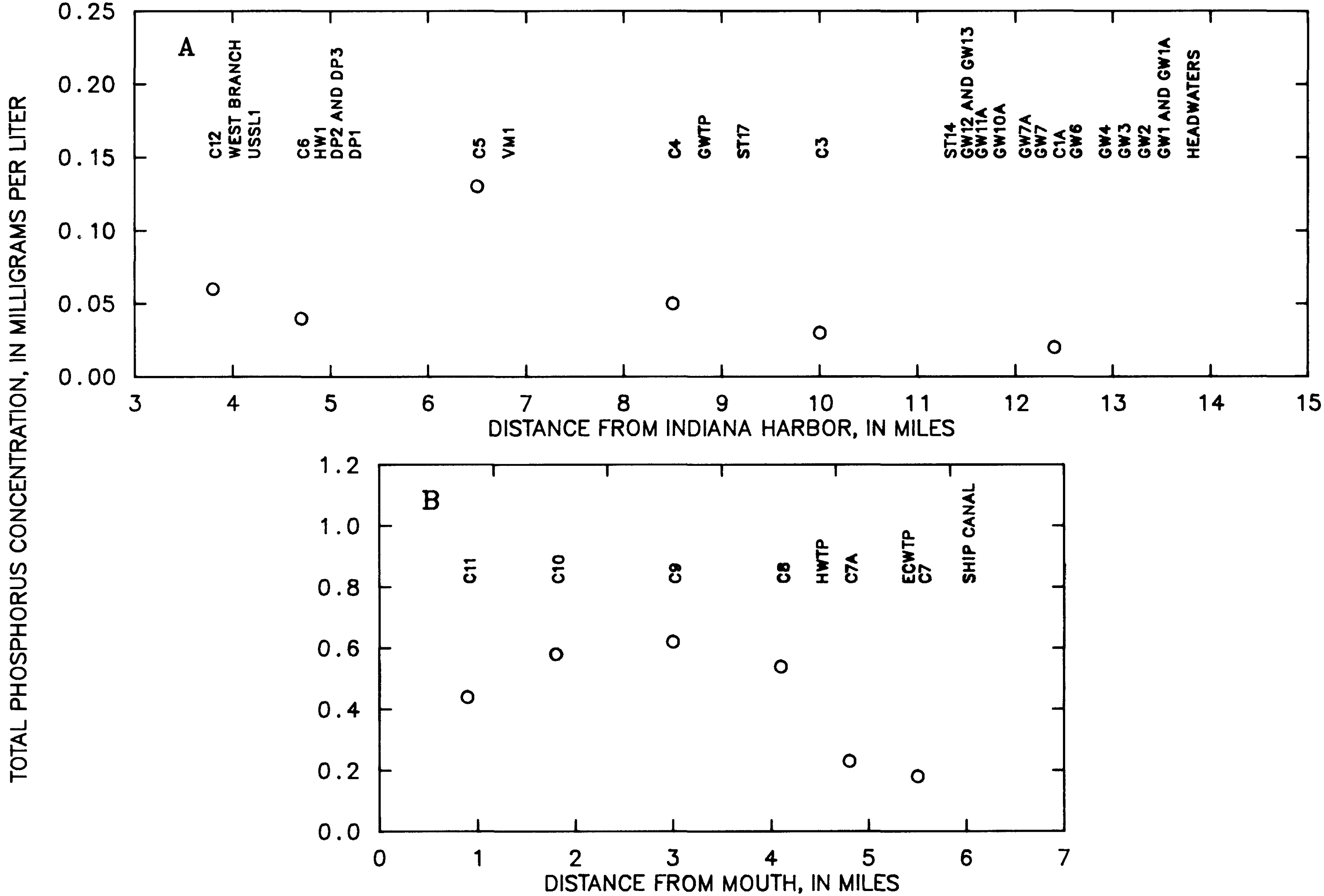


Figure 29.--Longitudinal variation in concentration of total phosphorus, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

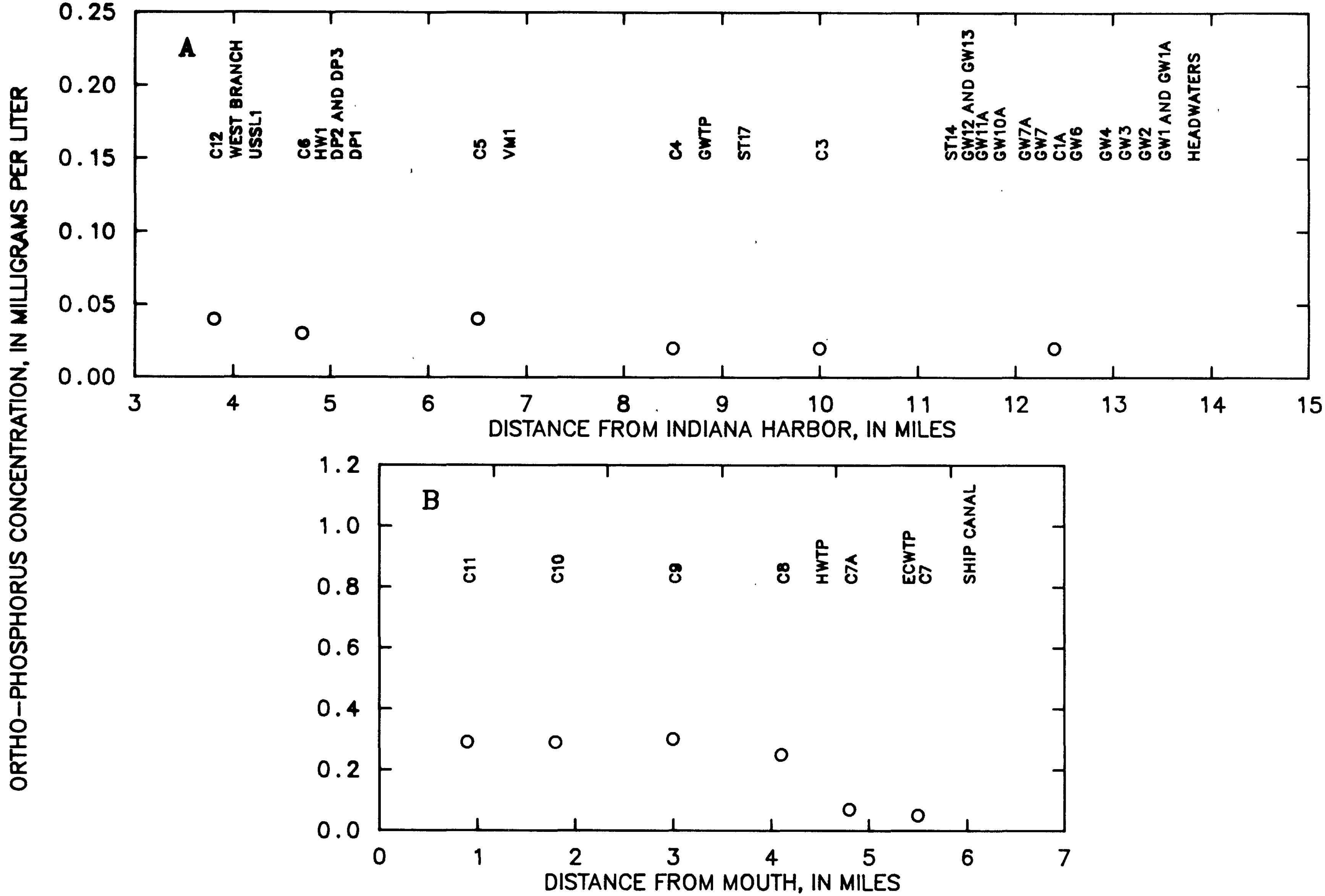


Figure 30.--Longitudinal variation in concentration of ortho-phosphorus, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

Biochemical-Oxygen Demand

The concentration of total biochemical-oxygen demand in the East Branch ranged from 6.5 to 12 mg/L (fig. 31). The concentration of total BOD was generally uniform throughout the reach with five of the six river sampling stations having a BOD concentration between 10 and 12 mg/L. Concentrations of CBOD in the East Branch were estimated to range from 3 to 7.7 mg/L (fig. 32). The estimated concentration of CBOD in the East Branch ranged from 45 to 70 percent of the total BOD.

Concentrations of total BOD in the West Branch ranged from 27 to 50 mg/L (fig. 31), about four times higher than in the East Branch. Concentrations at the two river sampling stations near the ECWTP (C7 and C7A) were approximately 29 mg/L. These values are slightly higher than the BOD concentration in the ECWTP effluent (24 mg/L), possibly owing to the contribution of organic material from the marshy area near the river. Concentrations of BOD at the four sites downstream from the HWTP were approximately 50 mg/L. This is about 1.4 times the concentration of BOD in the HWTP effluent (36 mg/L). Estimates of CBOD concentrations in the West Branch ranged from 16 to 30 mg/L (fig. 32). The estimated concentration of CBOD in the West Branch is approximately 55 to 60 percent of the total BOD. Filtered BOD concentrations were approximately 80 percent of the total BOD. The high BOD concentrations observed downstream from Columbia Avenue (station C8) indicate the presence of an unknown point source, as did the suspended-solids data. This source is probably municipal wastewater because a very high BOD (such as that for raw sewage) would be needed to elevate the stream BOD's to the concentration observed without noticeably increasing the streamflow.

Cyanide

Total cyanide concentrations in the East Branch ranged from less than 0.01 to 0.05 mg/L (fig. 33). The highest concentration was observed at Virginia Avenue (station C1A). The water-quality standard for cyanide (0.1 mg/L) was not exceeded at any station in the East Branch. Cyanide concentrations in the West Branch ranged from 0.01 to 0.17 mg/L (fig. 33). The highest concentration was observed near Indianapolis Boulevard (station C7). This concentration exceeds the water-quality standard for cyanide.

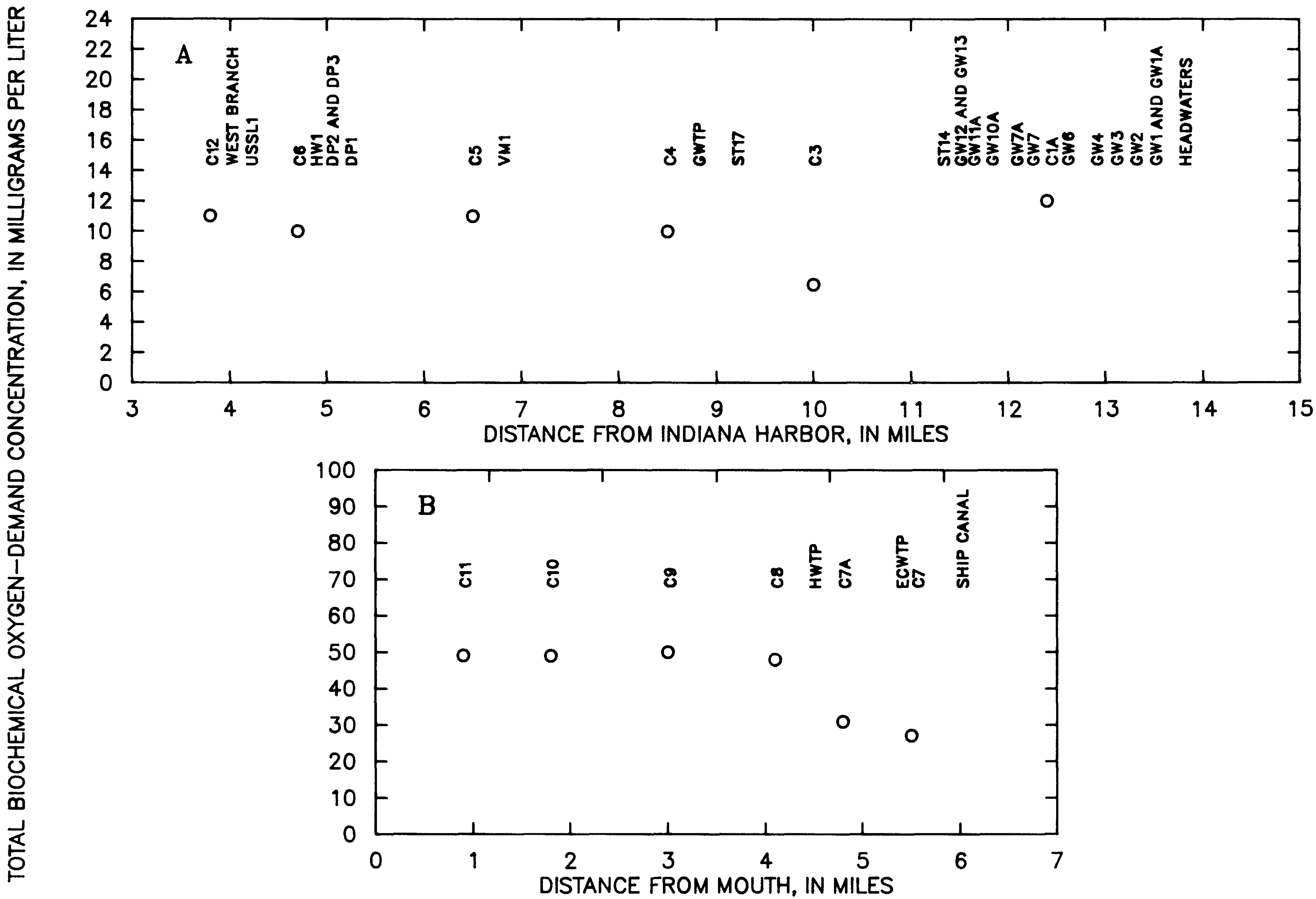


Figure 31.—Longitudinal variation in concentration of total biochemical-oxygen demand, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

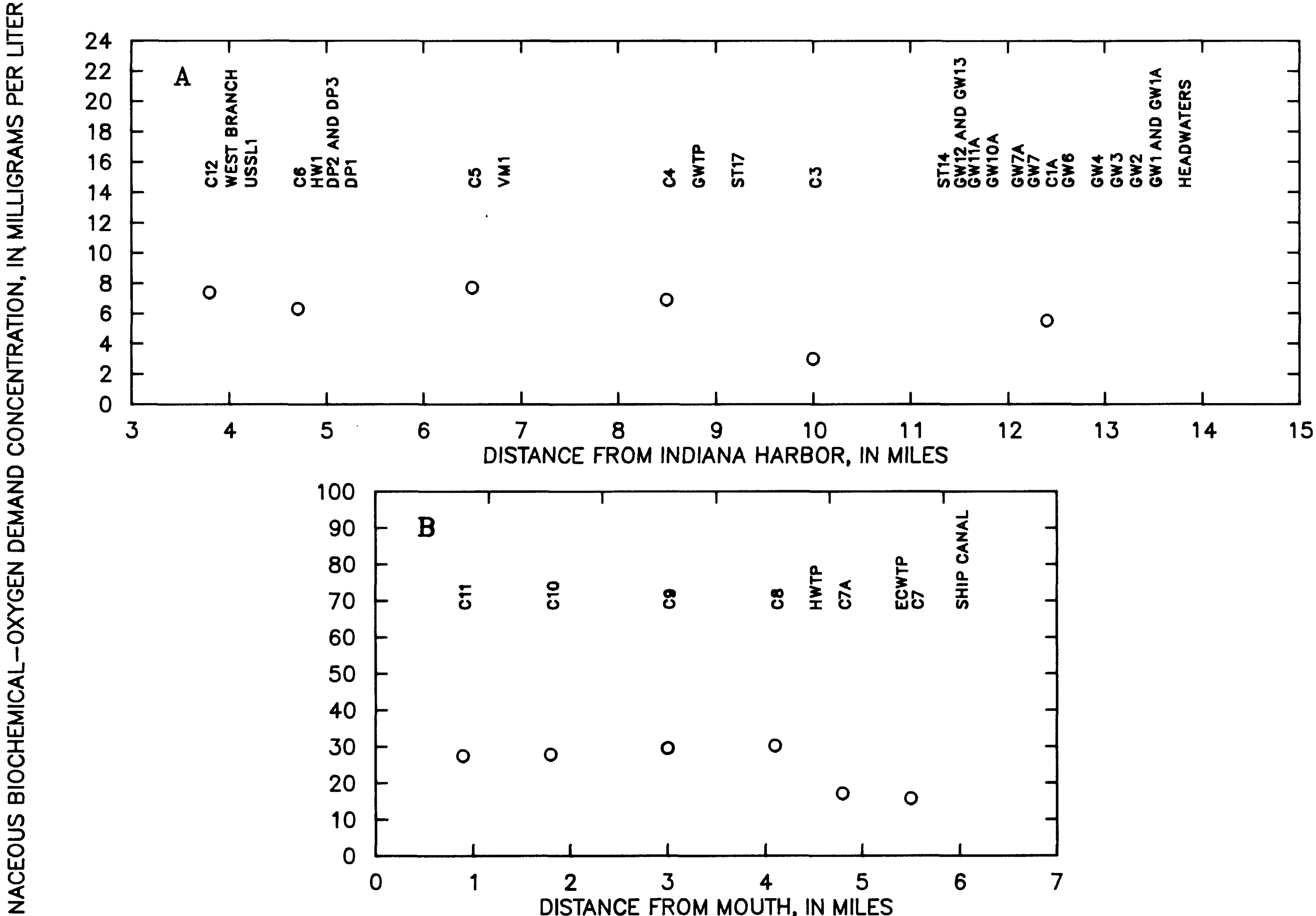


Figure 32.—Longitudinal variation in concentration of carbonaceous biochemical–oxygen demand, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

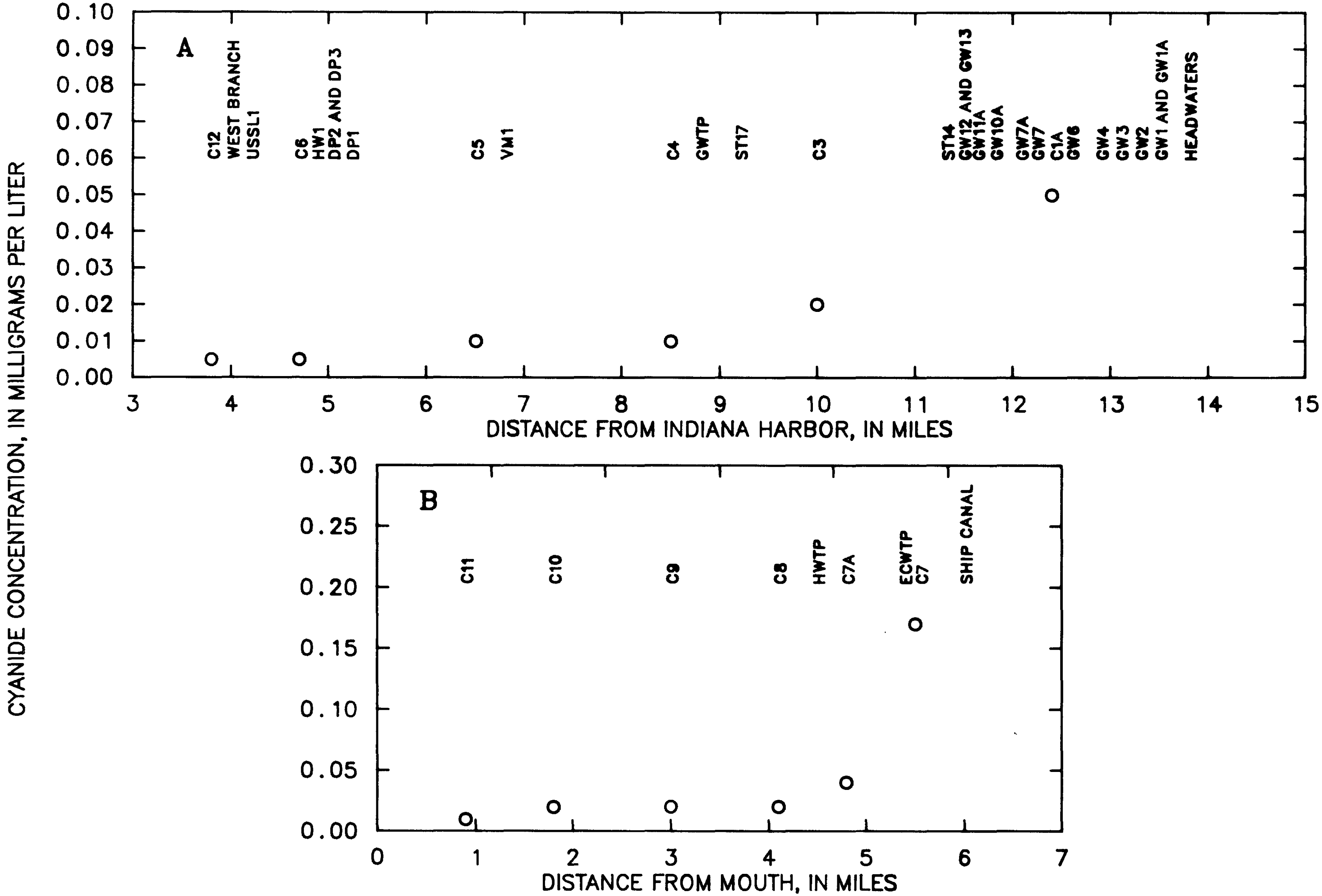


Figure 33.--Longitudinal variation in concentration of cyanide, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

Phenol

Total phenol concentrations ranged from 2 to 34 μg/L in the East Branch (fig. 34). The water-quality standard for phenol (10 μg/L) was exceeded at four of the six stations in the East Branch. No patterns in phenol concentrations in the East Branch are apparent. Phenol concentrations in the West Branch ranged from 2 to 11 μg/L (fig. 34). Phenol concentrations in the West Branch were highest at stations C7 and C7A. The water-quality standard for phenol was exceeded only at the station near the Indiana East-West Toll Road (C7A).

Chromium

Hexavalent chromium concentrations were less than the detection limit of 1 μg/L for all stations sampled in the East and West Branches Grand Calumet River. Total chromium was detectable at five of the six stations sampled in the East Branch and ship canal and four of the six stations sampled in the West Branch. Concentrations in the East Branch ranged from less than 1 to 3 μg/L (fig. 35) and were highest at Virginia Avenue (station C1A). Concentrations were slightly higher in the West Branch where concentrations ranged from less than 1 to 8 μg/L (fig. 35). The maximum concentration was observed near Indianapolis Boulevard (station C7). The source of the high levels of chromium measured near Indianapolis Boulevard is unknown.

Copper

Copper concentrations ranged from 2 to 8 μg/L in the East Branch (fig. 36). The highest concentration was observed at Cline Avenue (station C5) and was twice that at other stations in the East Branch. Copper concentrations in the West Branch ranged from 2 to 12 μg/L (fig. 36). The highest copper concentration in the West Branch was observed near Indianapolis Boulevard (station C7).

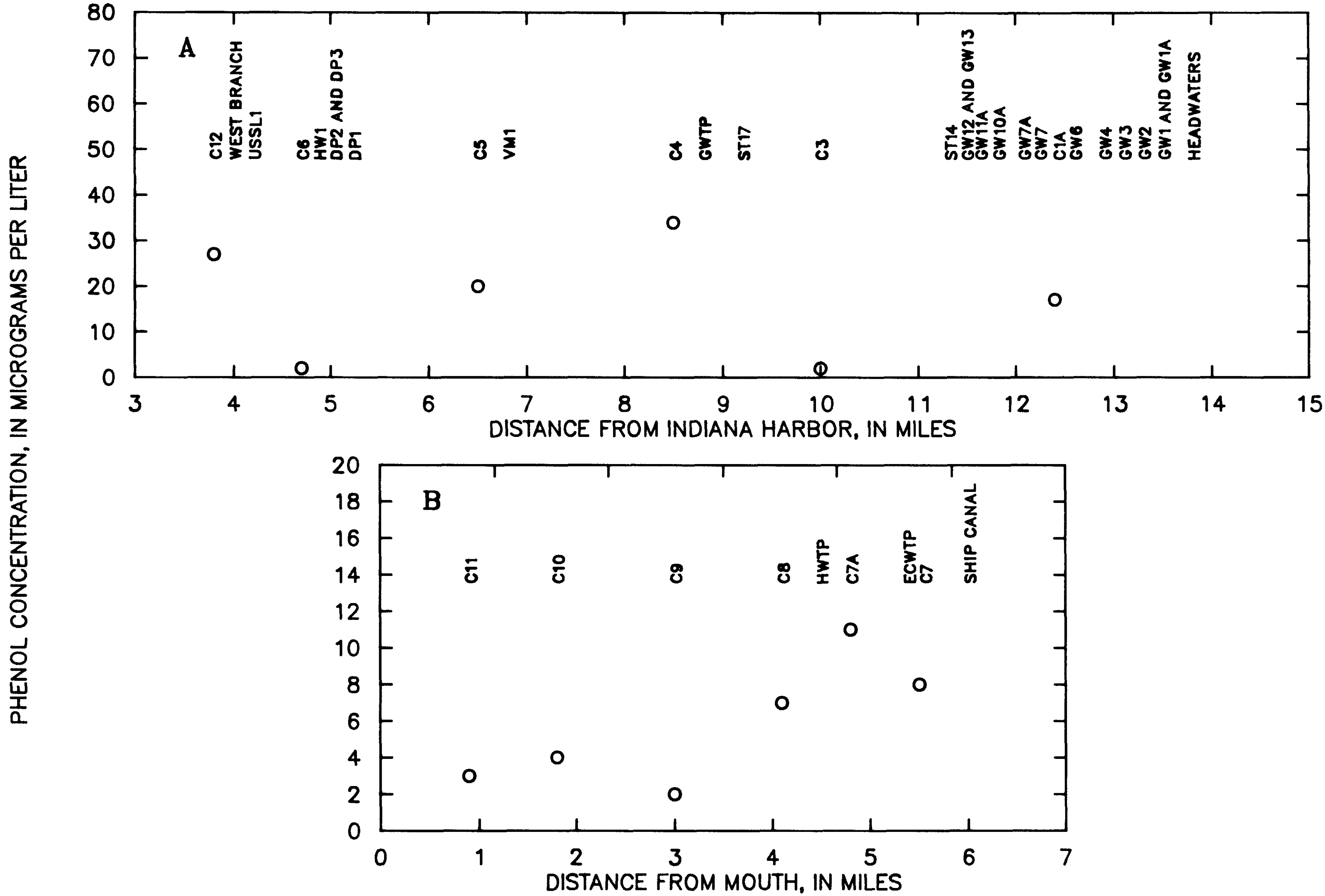


Figure 34.--Longitudinal variation in concentration of phenol, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

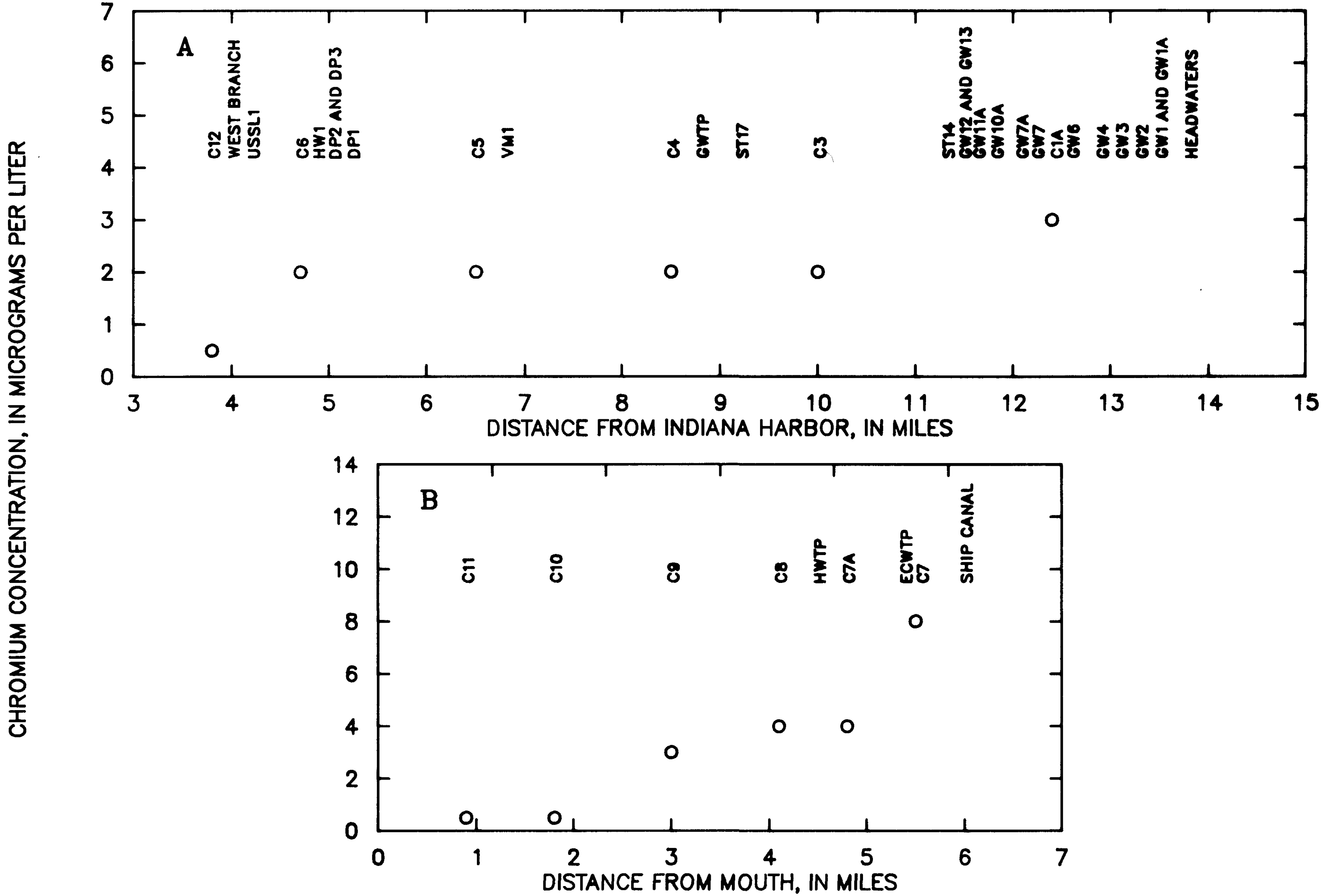


Figure 35.—Longitudinal variation in concentration of chromium, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

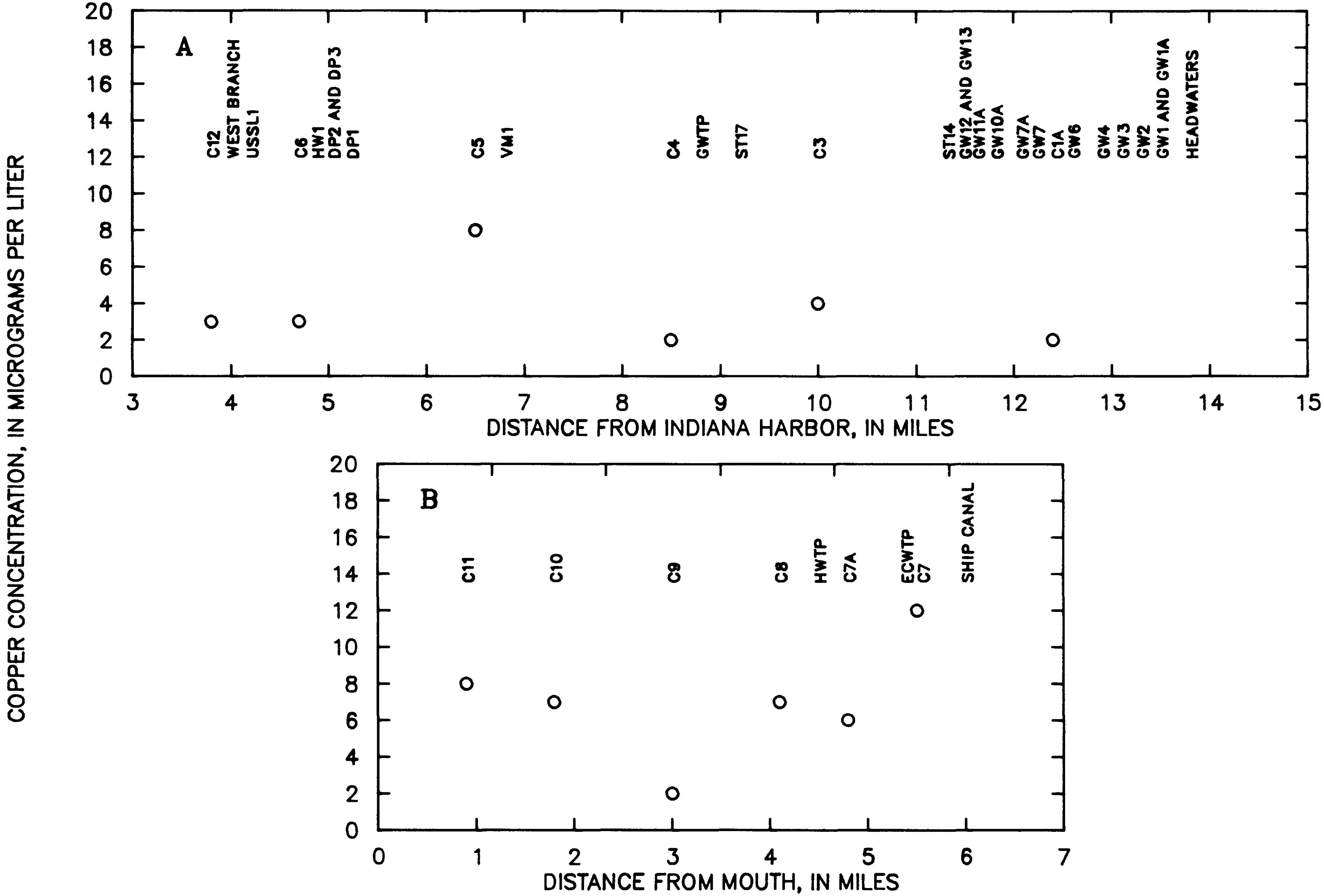


Figure 36.--Longitudinal variation in concentration of copper, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

Iron

Total iron concentrations ranged from 750 to 3,600 µg/L in the East Branch (fig. 37). The highest concentration was found at Cline Avenue (station C5) and was more than twice the concentration observed at any other station in the East Branch and ship canal. Concentrations in the West Branch ranged from 1,100 to 1,900 µg/L (fig. 37). There was little variation in the concentration of total iron in the West Branch.

Lead

Lead concentrations ranged from 4 to 42 µg/L in the East Branch (fig. 38). The highest value in the East Branch (42 µg/L) was found at Cline Avenue (station C5) and was about 10 times the lead concentrations found elsewhere in the East Branch and ship canal. However, this concentration does not exceed the water-quality standard for lead (50 µg/L). Lead concentrations in the West Branch ranged from 12 to 18 µg/L (fig. 38). The concentration of lead in the West Branch was highest at Burnham Park (station C11).

Mercury

Mercury concentrations ranged from 0.2 to 0.3 µg/L in the East Branch (fig. 39). The water-quality standard for mercury, 0.5 µg/L, was not exceeded at any station in the East Branch. The concentration of mercury was not elevated at Cline Avenue (station C5) as were several other metals. Concentrations in the West Branch were slightly higher than in the East Branch, ranging from 0.3 to 0.6 µg/L (fig. 39). The water-quality standard was equaled or exceeded at five of the six stations sampled in the West Branch.

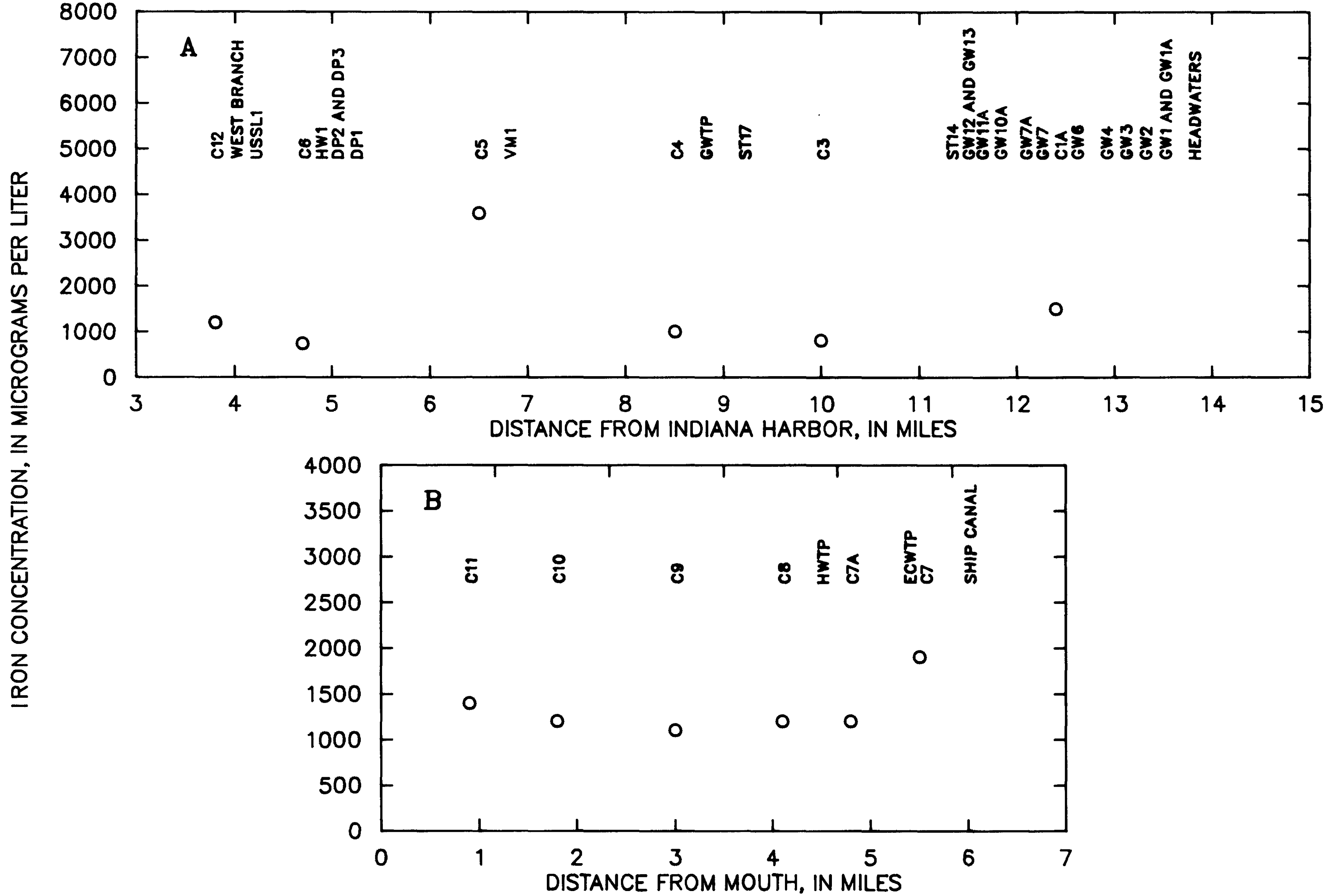


Figure 37.--Longitudinal variation in concentration of iron, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

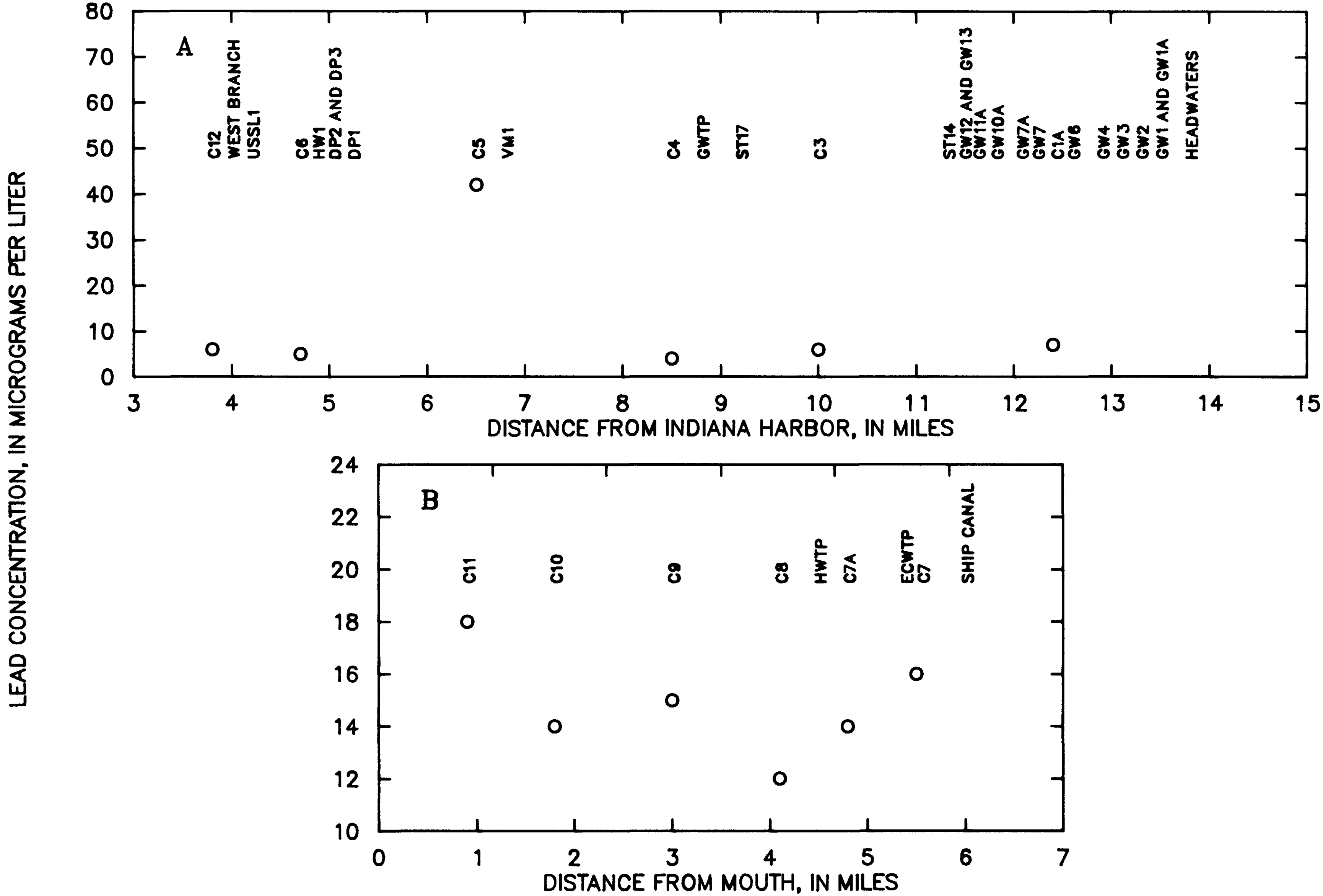


Figure 38.--Longitudinal variation in concentration of lead, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

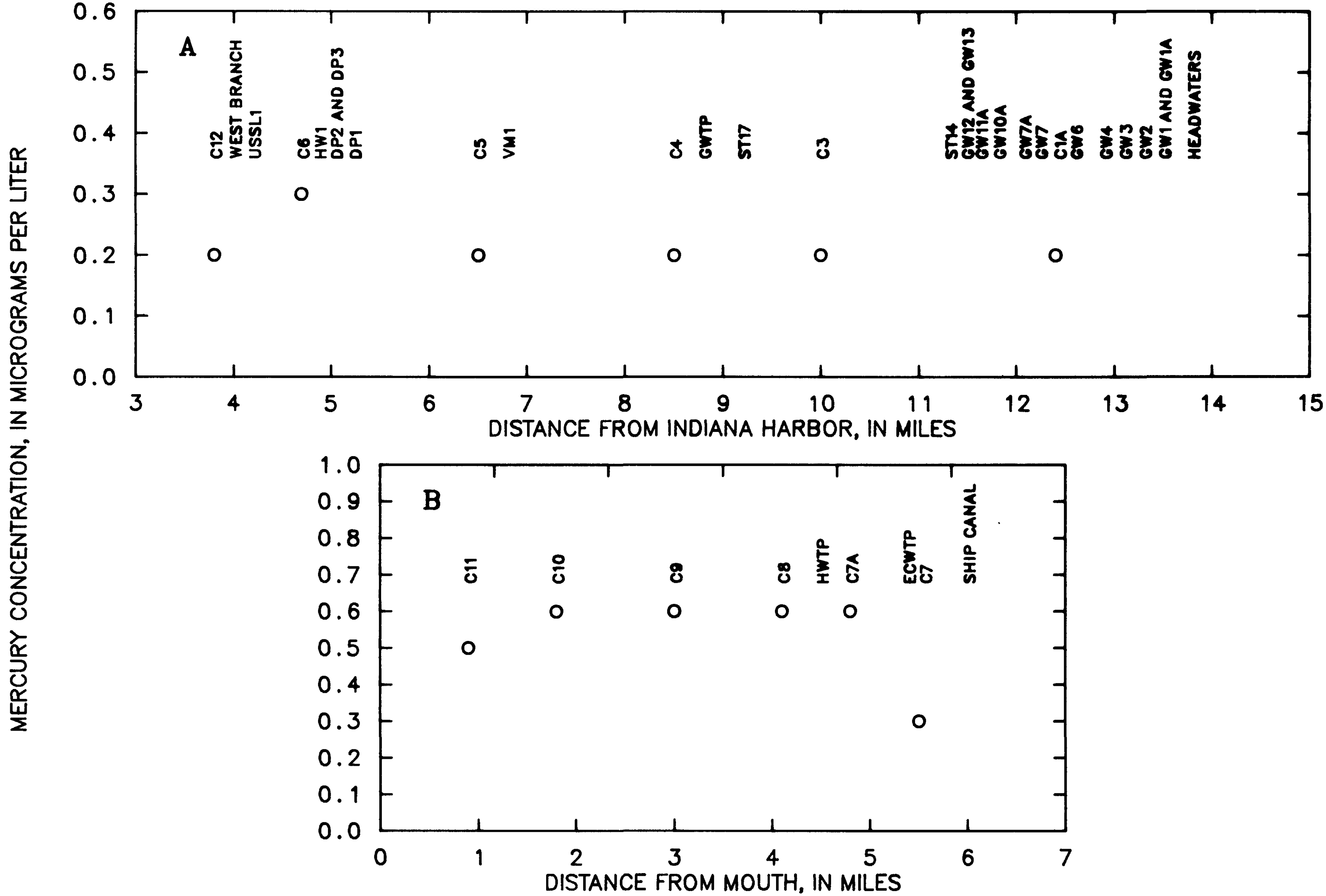


Figure 39.--Longitudinal variation in concentration of mercury, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

Nickel

Nickel concentrations ranged from 4 to 9 μg/L in the East Branch (fig. 40). The concentration of nickel was not elevated at Cline Avenue (station C5) as were several other metals. Nickel concentrations were fairly uniform throughout the East Branch. Nickel concentrations in the West Branch were also uniformly distributed and ranged from 13 to 14 μg/L (fig. 40).

Zinc

Zinc concentrations ranged from 30 to 100 μg/L in the East Branch (fig. 41). Zinc concentrations were elevated at Cline Avenue (station C5) and were twice that of any other site in the East Branch. Concentrations in the West Branch were generally higher than in the East Branch and ranged from 50 to 100 μg/L (fig. 41).

Exceedance of Water-Quality Standards

A summary of the water-quality standards that were exceeded is given in table 8. The standards were exceeded less frequently in the East Branch than the West Branch. In the East Branch, only the water-quality standards for phenol and total phosphorus were exceeded, whereas in the West Branch, the standards for ammonia, chloride, cyanide, DO, dissolved solids, fluoride, mercury, phenal, and total phosphorus were exceeded.

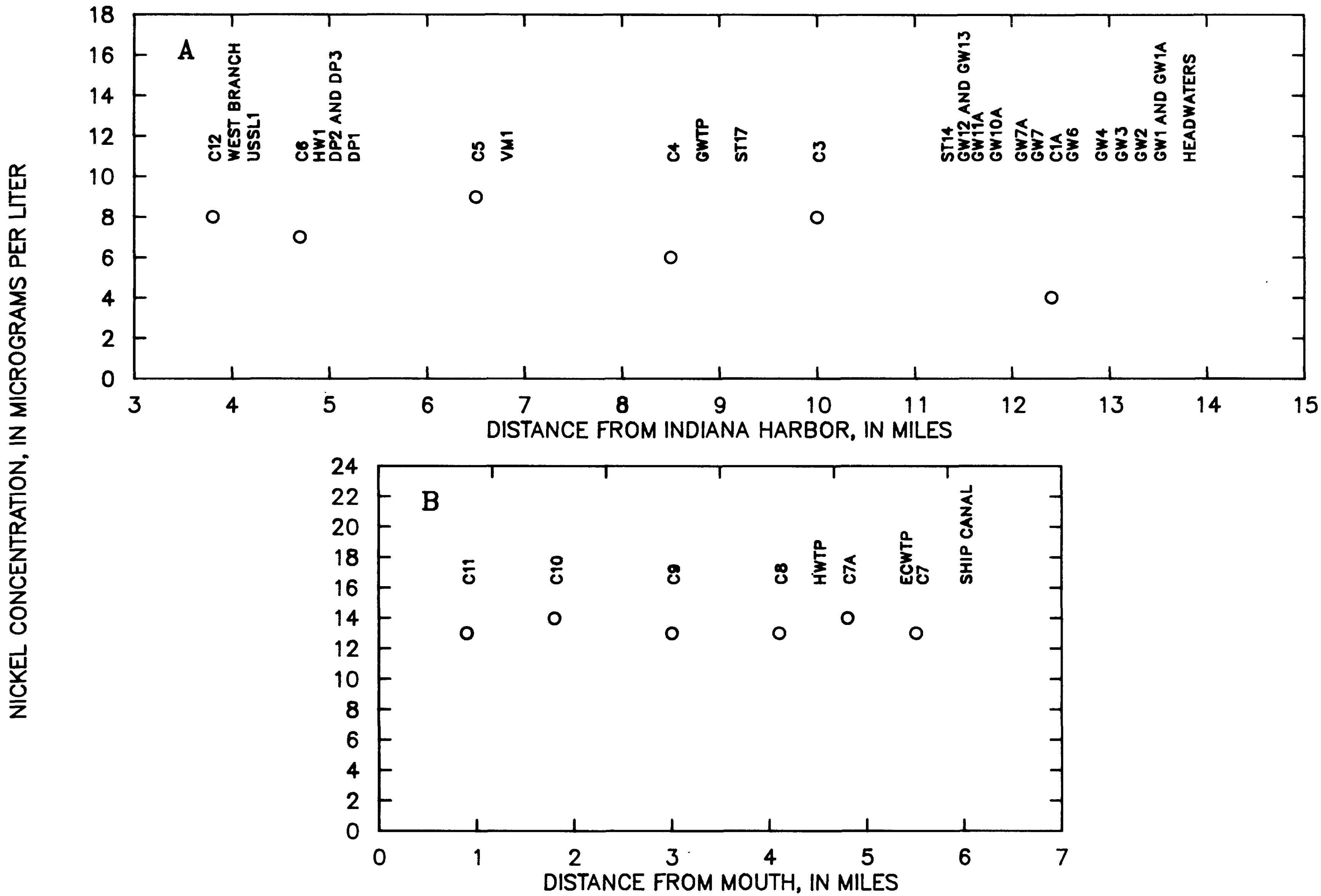


Figure 40.--Longitudinal variation in concentration of nickel, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

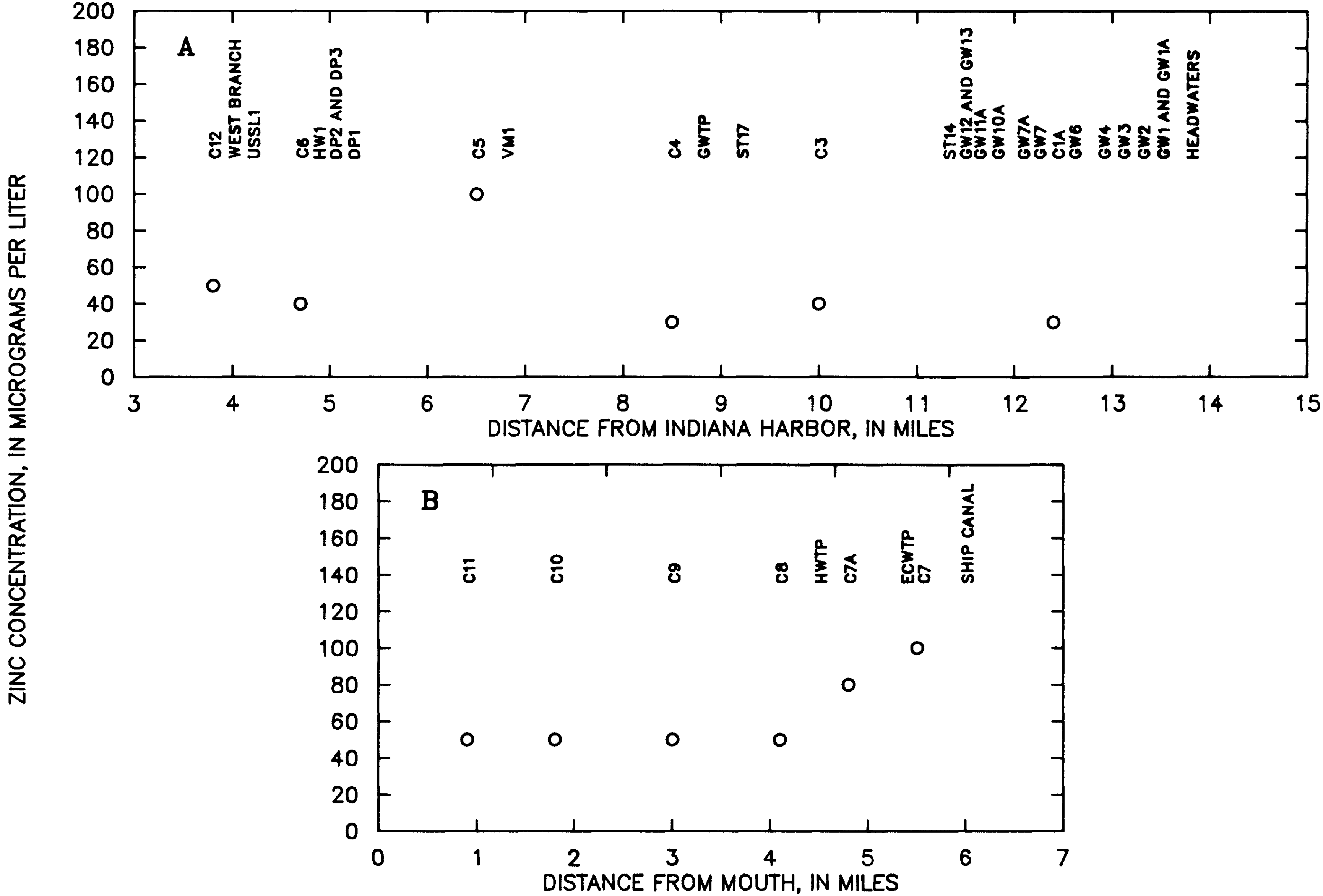


Figure 41.--Longitudinal variation in concentration of zinc, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

Table 8.--Exceedance of water-quality standards, Grand Calumet River, October 3-4, 1984

[Based on Indiana Stream Pollution Control Board water-quality standards listed in table 5 in effect at time of survey; n.d., no data]

Constituent	Percent of stations where standard was exceeded	
	East Branch	West Branch
pH	0	0
Dissolved oxygen	0	50
Temperature	0	0
Ammonia (total)	0	100
Chloride	0	100
Cyanide	0	17
Dissolved solids	0	100
Fluoride	0	33
Phosphorus (total)	17	100
Sulfate	0	0
Chromium (total)	0	0
Iron (dissolved)	n.d.	n.d.
Lead (total)	0	0
Mercury (total)	0	67
PCB's (total)	n.d.	n.d.
Phenol	67	17

Chemical-Mass Discharge

Chemical-mass discharges were calculated by the following equation:

$$\text{Chemical-mass discharge} = \text{concentration} \times \text{flow} \times 5.39$$

where the chemical-mass discharge is in pounds per day, the concentration is in milligrams per liter, the flow is in cubic feet per second, and 5.39 is a conversion factor.

Instream chemical-mass discharges were calculated from the streamflow and concentration measured at the 12 sampling stations. Cumulative effluent chemical-mass discharges were calculated by summing the chemical-mass discharges calculated for effluent outfalls. The cumulative effluent chemical-mass discharge was assumed to be chemically stable and not subject to changes owing to biochemical or physical processes. Adjustment to flow discussed in the section "Streamflow" were taken into account when calculating the cumulative effluent chemical-mass discharges. The cumulative effluent chemical-mass discharge immediately upstream of the HWTP was calculated from the flow immediately upstream of the HWTP estimated by the optimization technique discussed in the section "Streamflow" and the chemical concentration measured near the Indiana East-West Toll Road (station C7A). This was done so that the cumulative effluent chemical-mass discharge downstream of Columbia Avenue (station C8) would not be greatly distorted by the flow difference noted between the two treatment plants.

Chemical-mass discharges for the industrial and municipal effluents and those measured at the river sampling stations are given in table 9. The cumulative effluent and the instream chemical-mass discharge for constituents measured during the survey are shown in figures 42-64.

Table 9.--Chemical-mass discharge for sampling stations in the Grand Calumet River basin, October 3-4, 1984

[Results in pounds per day; loads shown as less than (<) are based on estimate of streamflow and detection limit of given constituent or property; numbers are rounded to 3 or less significant figures; n.d., no data]

Station ID	Suspended solids	Dissolved solids	Chloride	Sulfate	Fluoride	Hardness
C1A	6,850	139,000	17,100	22,600	137	75,300
C3	7,980	371,000	35,900	61,800	598	219,000
C4	15,700	643,000	112,000	99,300	784	366,000
C5	< 2,610	852,000	115,000	105,000	1,050	366,000
C6	8,000	816,000	117,000	131,000	1,070	374,000
C12	10,800	776,000	140,000	140,000	1,350	404,000
GW1	940	43,200	4,000	6,580	23.5	7,050
GW1A	21	1,210	91	182	1.4	771
GW2	334	17,000	4,210	1,940	6.7	8,690
GW3	138	5,590	586	897	10.3	3,800
GW4	78	2,720	234	406	3.1	1,720
GW6	602	50,500	3,610	7,820	60.2	39,100
GW7	622	44,800	3,420	6,840	62.2	37,300
GW7A	1,260	125,000	15,200	25,300	822	82,200
GW10A	166	6,930	457	996	4.2	3,900
GW11A	503	48,600	5,290	9,060	227	30,200
GW12	176	13,800	764	2,120	5.9	8,230
GW13	42	3,410	231	505	2.1	2,730
ST14	168	5,590	911	1,680	4.2	3,500
ST17	364	95,300	34,600	8,560	36.4	51,010
GWTP	1,110	133,000	23,300	7,760	222	52,600
VM1	2	306	100	26	.9	97
DP1	226	10,700	1,660	2,380	15.1	6,790
DP2	39	12,000	2,130	1,840	10.7	1,160
DP3	24	n.d.	190	35,000	4.2	1,900
HW1	1	54	4	8	.3	36
USSL1	1	38	3	17	.3	19
C7	168	13,100	4,610	2,160	32.2	2,800
C7A	860	78,200	26,200	12,700	180	17,200
C8	3,850	188,000	44,000	31,900	357	55,000
C9	4,400	181,000	42,100	31,300	330	60,500
C10	4,400	182,000	42,600	33,000	357	52,200
C11	4,400	185,000	44,000	33,000	330	38,500
ECWTP	751	116,000	47,000	20,400	333	23,600
HWTP	690	136,000	27,600	24,000	253	48,300

Table 9.--Chemical-mass discharge for sampling stations in the Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Total biochemical-oxygen demand	Carbonaceous biochemical-oxygen demand	Total phenol	Total cyanide
C1A	8,210	3,770	11.6	34.2
C3	13,000	6,060	4.00	39.9
C4	26,100	18,100	88.9	26.1
C5	28,800	20,000	52.3	26.1
C6	26,700	16,900	5.3	< 26.7
C12	29,600	20,100	72.8	< 26.9
GW1	1,530	937	< .24	9.4
GW1A	32	3	.10	.1
GW2	869	377	4.28	< .7
GW3	241	147	.45	1.7
GW4	47	41	< .02	< .2
GW6	1,500	814	5.11	< 3.0
GW7	1,240	1,120	< .31	< 3.1
GW7A	1,900	1,430	32.9	37.9
GW10A	540	306	.04	< .4
GW11A	3,020	1,970	< .25	12.6
GW12	176	146	< .06	< .6
GW13	63	59	< .02	< .2
ST14	98	64	< .01	< .1
ST17	5,650	5,470	12.2	< 1.8
GWTP	3,880	3,150	.55	< 2.8
VM1	3	3	< .01	< .1
DP1	453	224	.60	.4
DP2	243	188	< .01	< .1
DP3	24	20	.03	< .1
HW1	1	1	n.d.	< .1
USSL1	< 1	< 1	< .01	< .1
C7	378	221	.11	2.4
C7A	2,420	1,340	.86	3.1
C8	13,200	8,320	1.92	5.5
C9	13,700	8,150	.55	5.5
C10	13,500	7,640	1.10	5.5
C11	13,500	7,520	.82	2.7
ECWTP	2,600	1,460	.21	27.9
HWTP	8,300	4,800	.23	< 2.3

Table 9.--Chemical-mass discharge for sampling stations in the Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Total organic nitrogen	Total ammonia	Total nitrite	Total nitrate	Total phosphorus	Total ortho-phosphorus
C1A	342	1,030	34.2	144	13.7	13.7
C3	199	1,600	120	419	59.8	39.9
C4	758	1,860	209	3,450	131	52.3
C5	601	2,010	235	3,950	340	105
C6	1,470	2,270	267	3,740	107	80.0
C12	1,560	2,210	350	4,230	162	108
GW1	28.2	136	4.7	49.4	9.4	7.1
GW1A	< .9	6.5	.2	1.8	< .1	< .1
GW2	13.4	114	2.0	17.4	< .7	.7
GW3	12.8	21.7	1.0	7.2	< .3	.7
GW4	3.3	1.4	.5	4.1	< .2	< .2
GW6	21.1	159	9.0	51.1	< 3.0	< 3.0
GW7	65.3	28.0	3.1	56.0	3.1	6.2
GW7A	145	108	6.3	88.5	12.6	6.3
GW10A	4.2	54.0	2.5	8.7	.4	< .4
GW11A	10.1	242	12.6	50.3	< 2.5	< 2.5
GW12	4.7	7.1	.6	13.5	< .6	1.2
GW13	3.2	1.1	.4	5.5	< .2	< .2
ST14	.4	8.0	.3	5.3	< .1	.1
ST17	69.2	40.1	32.8	20.0	5.5	3.6
GWTP	413	169	19.4	2,500	97.0	55.4
VM1	.2	< .1	.3	0.2	.1	.1
DP1	7.5	52.8	4.5	55.8	2.3	1.1
DP2	793	12.6	.1	1.6	< .1	< .1
DP3	3.4	.8	.1	0.5	< .1	< .1
HW1	< .1	.1	< .1	0.2	< .1	< .1
USSL1	< .1	< .1	< .1	0.1	< .1	< .1
C7	22.4	36.4	14.0	114	2.5	.7
C7A	133	250	76.6	635	18.0	5.5
C8	687	1,130	118	844	148	68.7
C9	660	1,290	102	586	170	82.5
C10	715	1,350	93.5	539	159	79.7
C11	687	1,375	102	586	121	79.7
ECWTP	204	257	193	1,090	61.1	30.0
HWTP	391	806	41.4	350	80.5	64.5

Table 9.--Chemical-mass discharge for sampling stations in the Grand Calumet River basin, October 3-4, 1984--Continued

Station ID	Total chromium	Total copper	Total iron	Total lead	Total mercury	Total nickel	Total zinc
C1A	2.05	1.37	1,030	4.79	.14	2.74	20.5
C3	3.99	7.98	1,620	12.0	.40	16.0	79.8
C4	5.23	5.23	2,610	10.5	.52	15.7	78.4
C5	5.23	20.9	9,410	110	.52	23.5	261
C6	5.34	8.00	1,970	13.3	.80	18.7	107
C12	< 2.69	8.08	3,230	16.2	.54	21.6	135
GW1	< .24	< .24	89.3	.24	.12	1.18	4.70
GW1A	< .01	.03	2.2	< .01	< .01	.03	.21
GW2	< .07	.07	24.1	< .07	.17	.67	1.34
GW3	.07	< .03	14.1	< .03	.01	.24	.69
GW4	< .02	< .02	8.4	.31	< .01	.08	.31
GW6	.30	< .30	75.2	< .30	.15	1.50	9.02
GW7	< .31	< .31	109	< .31	.09	2.18	12.4
GW7A	< .63	1.90	544	2.53	.63	3.16	12.6
GW10A	.08	.04	19.5	< .04	.01	.25	.83
GW11A	.25	< .25	191	.76	.25	1.76	7.55
GW12	.06	< .06	28.8	.06	.04	.24	1.18
GW13	.04	< .02	4.4	.02	.01	.11	.42
ST14	.01	.01	84.1	.04	.02	.10	.42
ST17	.18	< .18	200	< .18	.16	1.46	5.47
GWTP	n.d.	2.49	125	.28	.11	3.05	11.1
VM1	< .01	< .01	.2	< .01	< .01	< .01	.02
DP1	.04	.04	64.1	.57	.01	.23	15.5
DP2	.08	.05	11.6	.10	< .01	.12	.39
DP3	.04	.04	5.9	.17	< .01	.05	.53
HW1	< .01	< .01	.1	< .01	< .01	< .01	.01
USSL1	< .01	< .01	.1	n.d.	< .01	< .01	.02
C7	.11	.17	26.6	.22	< .01	.18	1.40
C7A	.31	.47	93.8	1.09	.05	1.09	6.25
C8	1.10	1.92	330	3.30	.16	3.57	13.7
C9	.82	.55	302	4.12	.16	3.57	13.7
C10	< .27	1.92	330	3.85	.16	3.85	13.7
C11	< .27	2.20	385	4.95	.14	3.57	13.7
ECWTP	.11	.32	75.1	.86	.14	1.29	6.44
HWTP	.23	< .23	75.9	< .23	.11	2.53	4.61

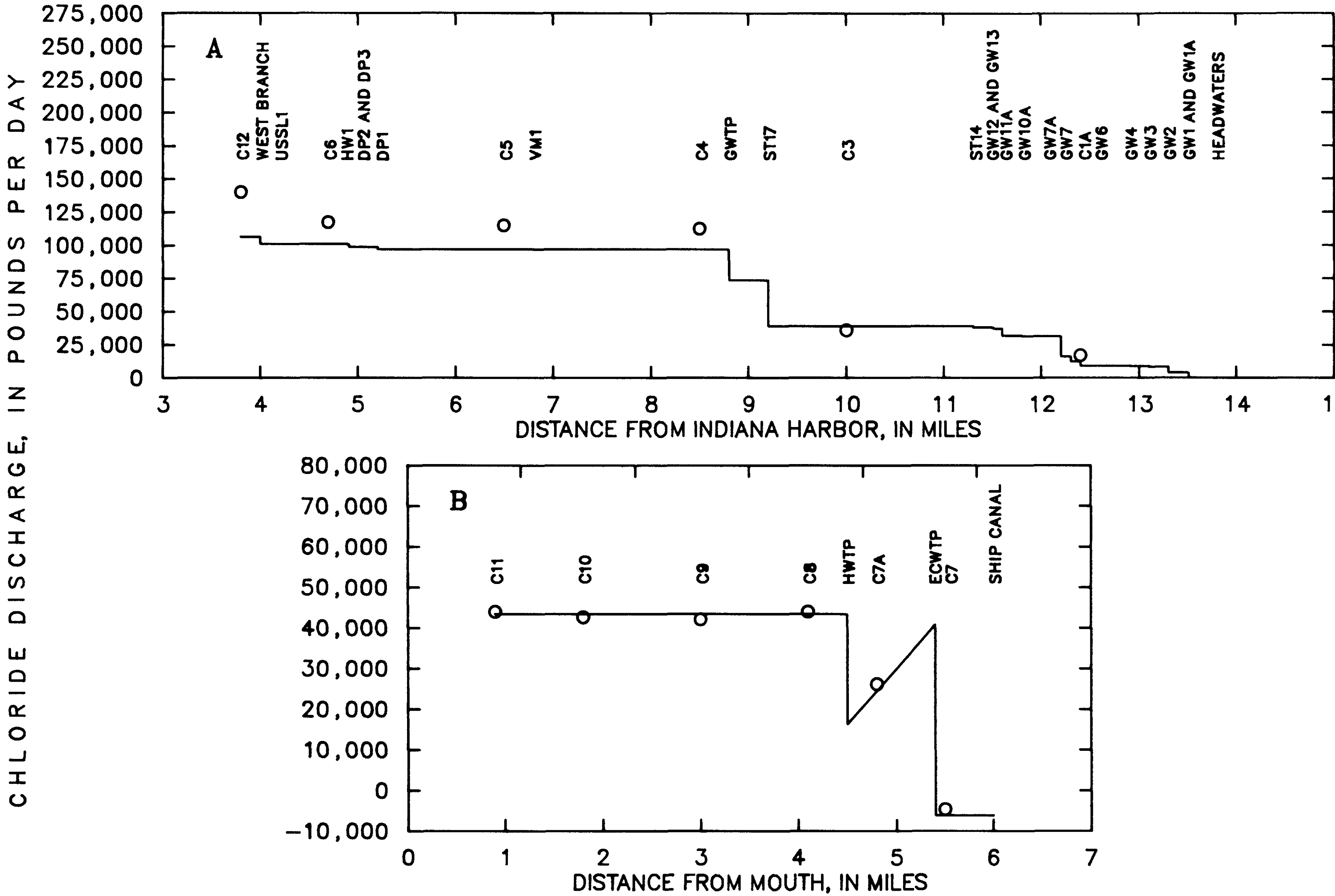


Figure 42.--Relation of cumulative effluent to instream discharges of chloride, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

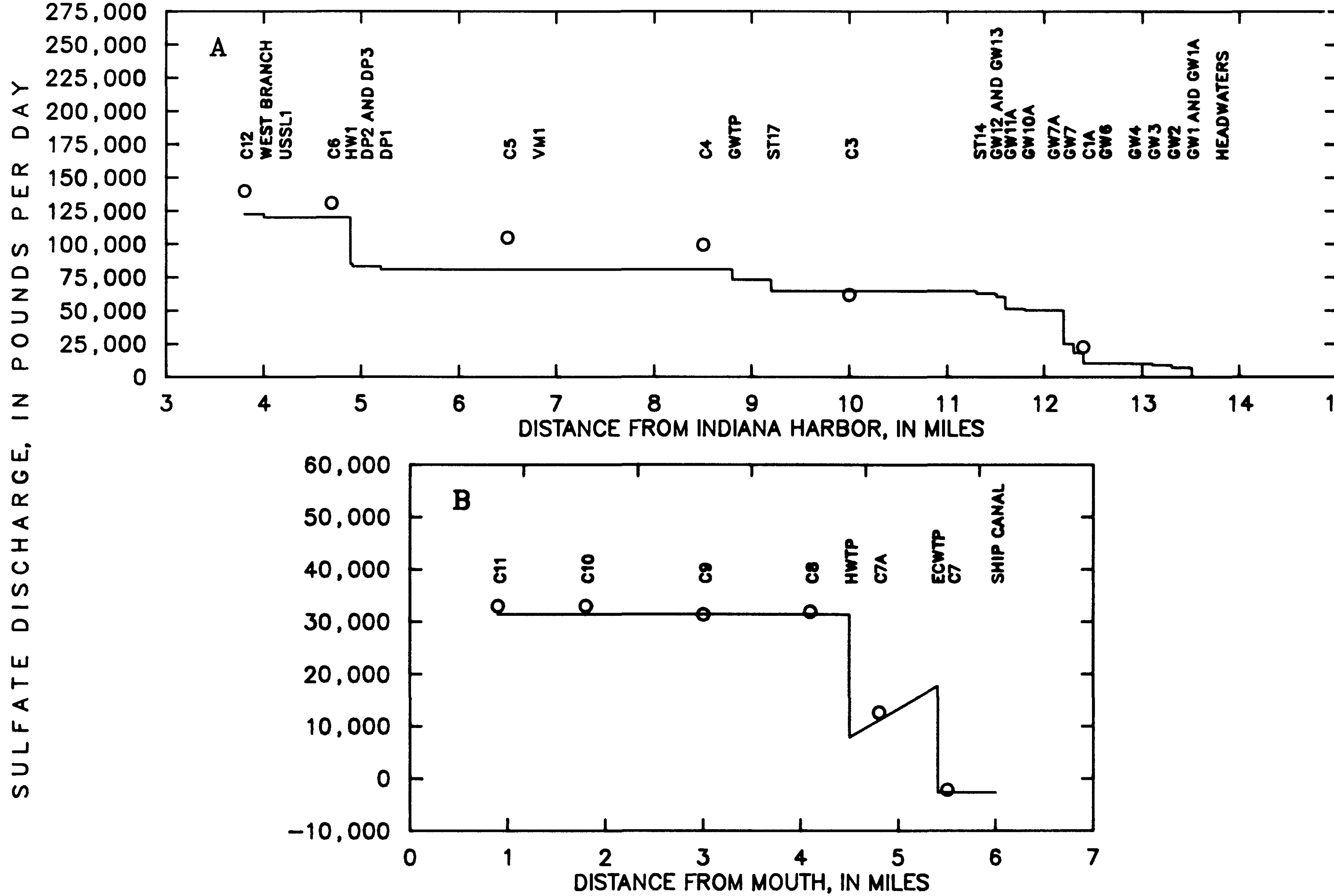


Figure 43.––Relation of cumulative effluent to instream discharges of sulfate, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

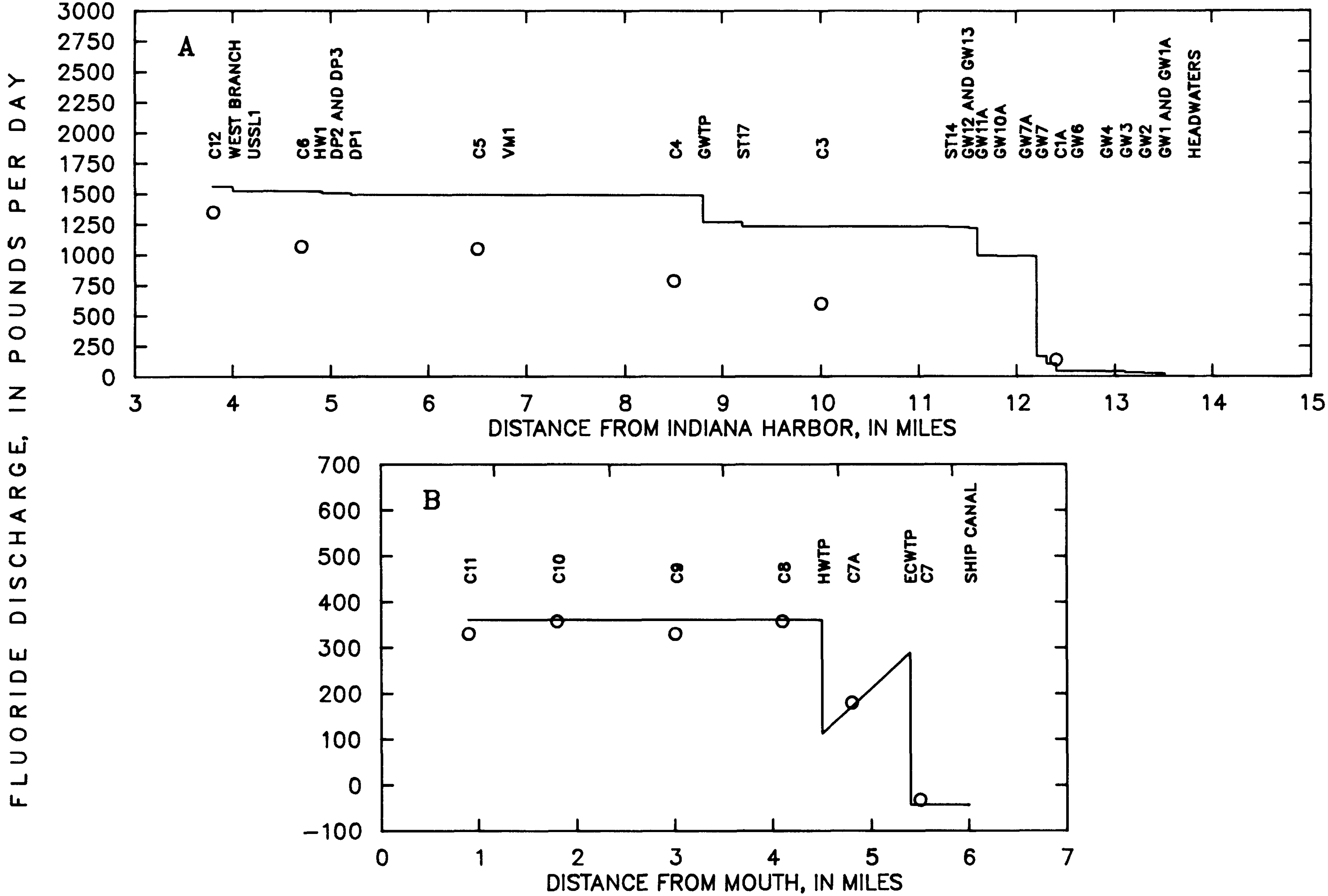


Figure 44.--Relation of cumulative effluent to instream discharges of fluoride, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

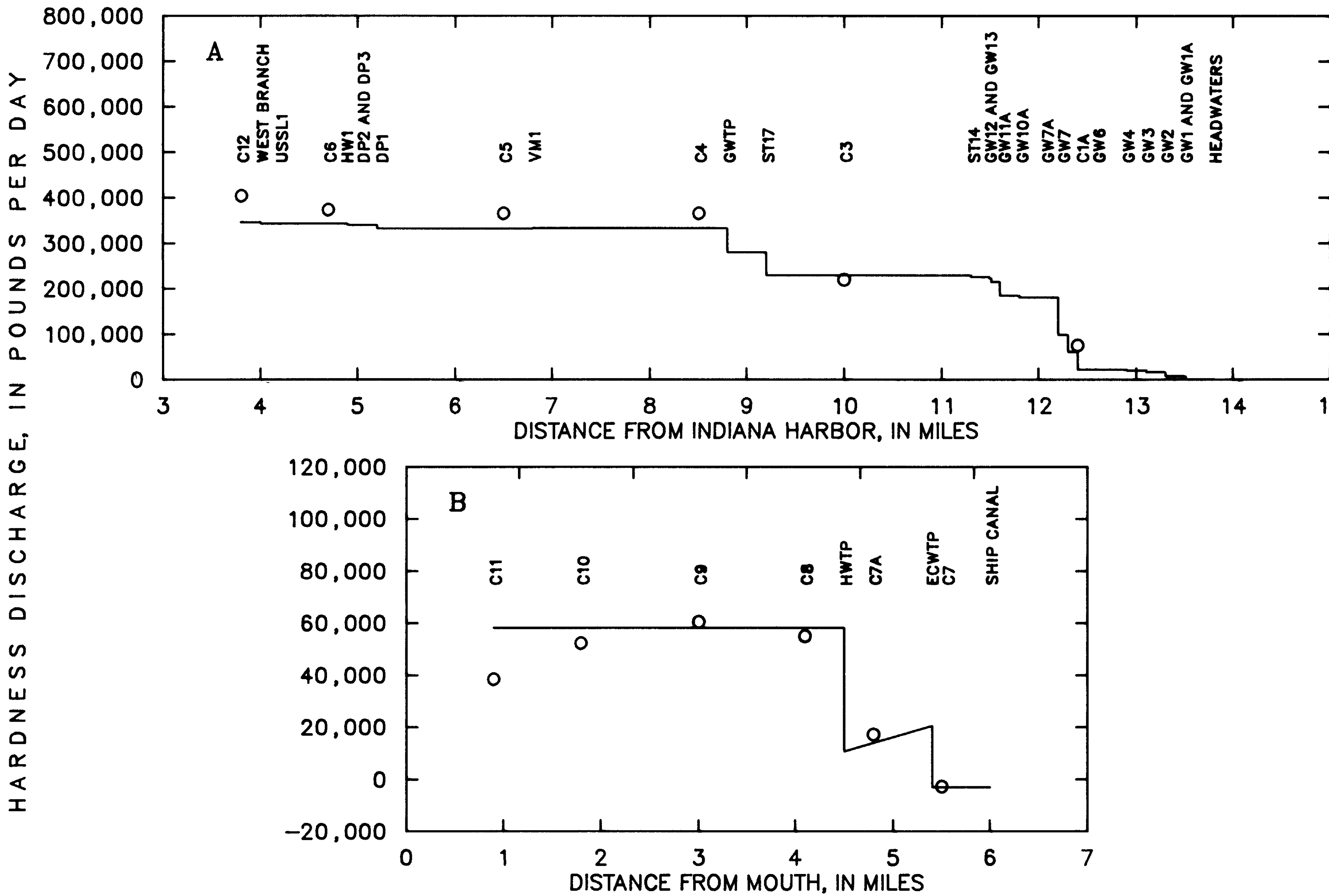


Figure 45.--Relation of cumulative effluent to instream discharges of water hardness, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

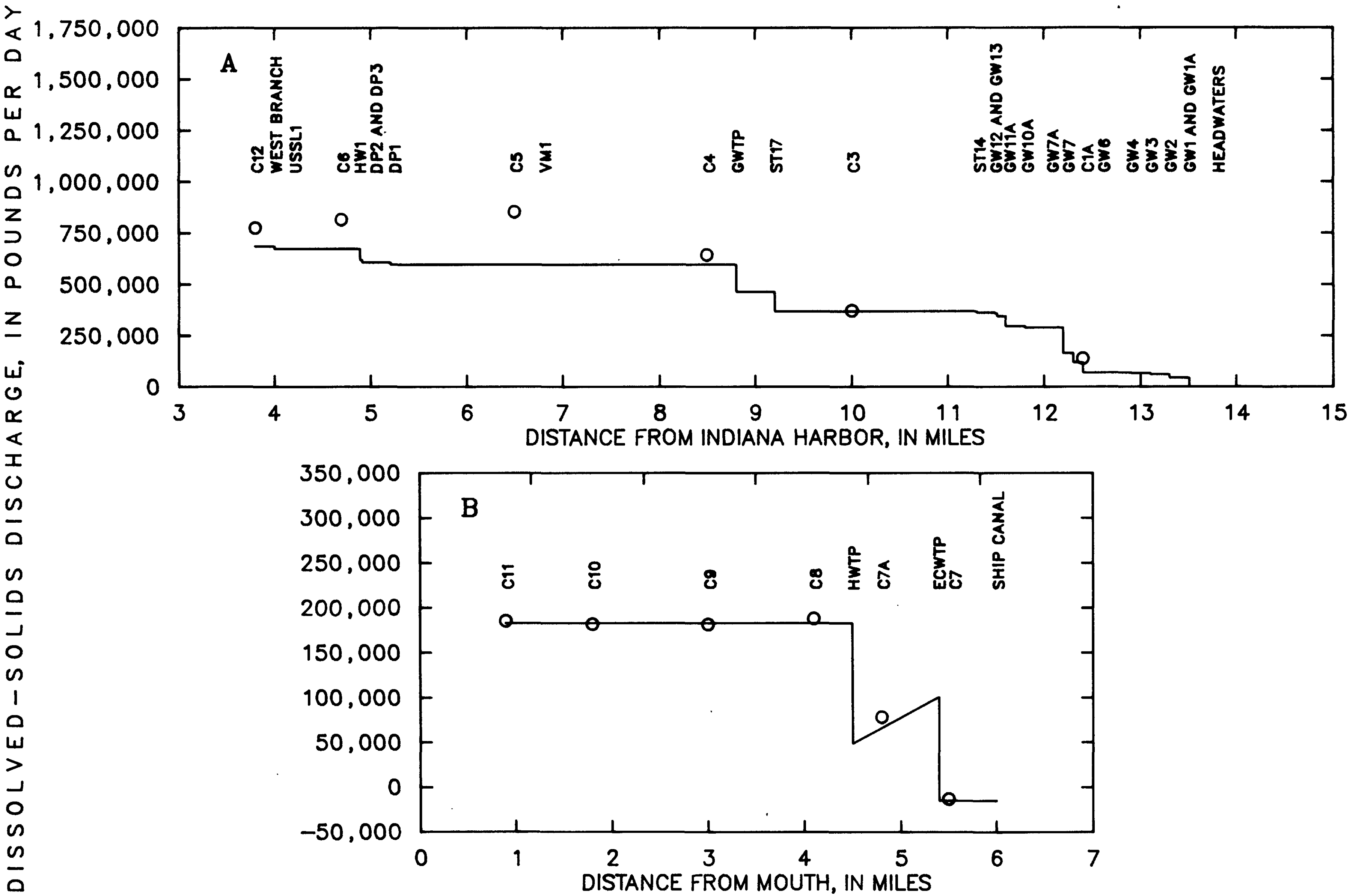


Figure 46.--Relation of cumulative effluent to instream discharges of dissolved solids, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

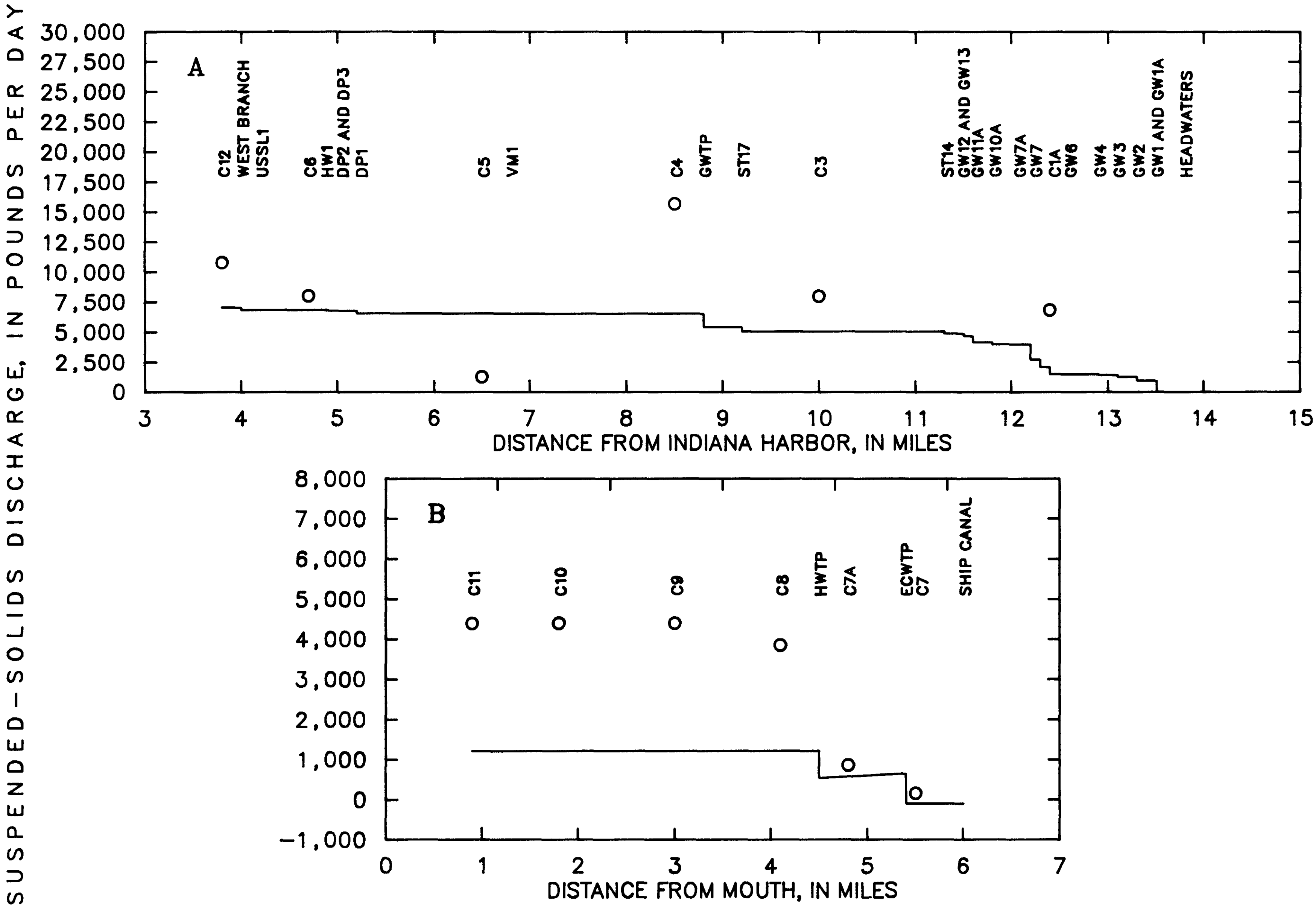


Figure 47.––Relation of cumulative effluent to instream discharges of suspended solids, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

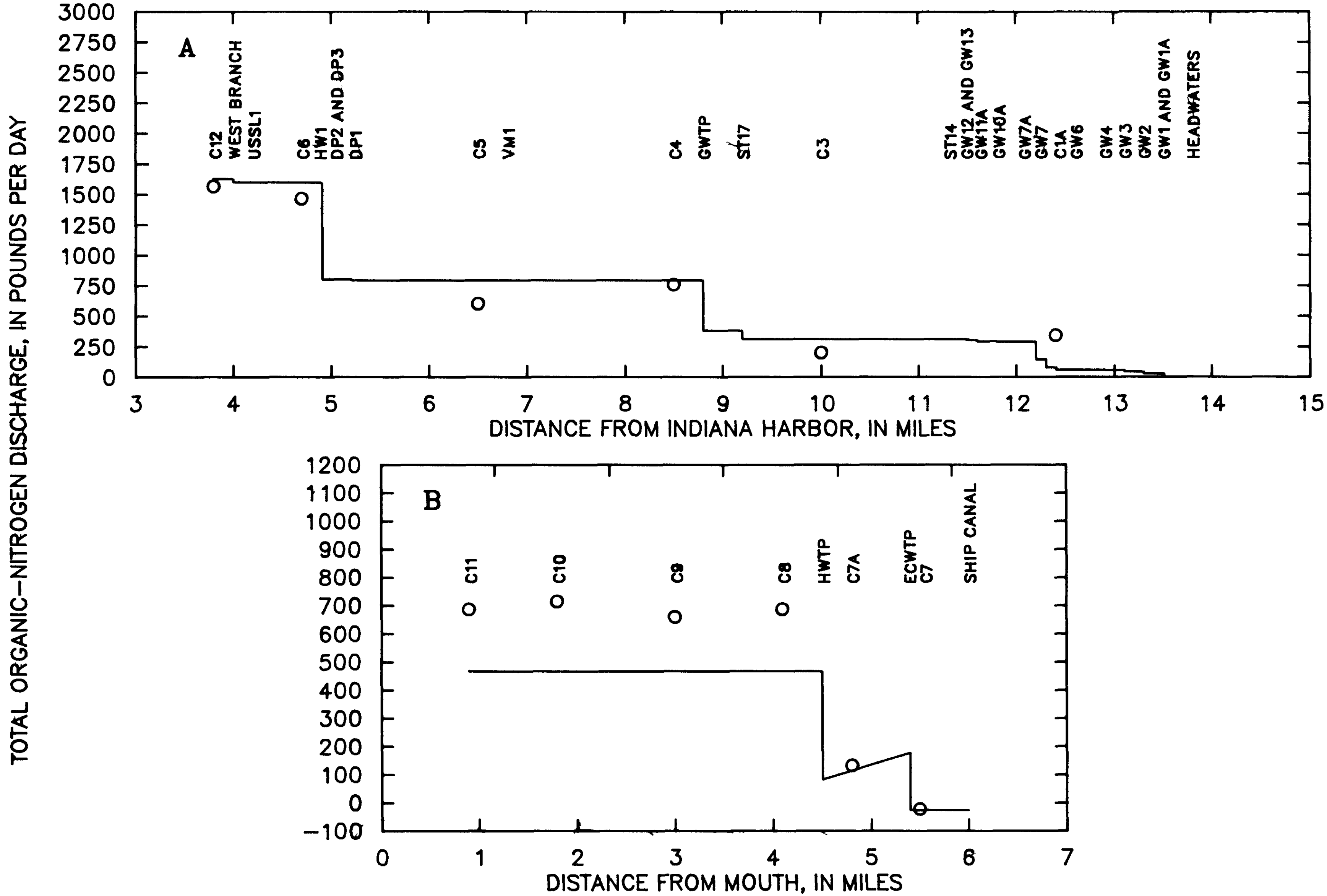


Figure 48.--Relation of cumulative effluent to instream discharge of total organic nitrogen, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

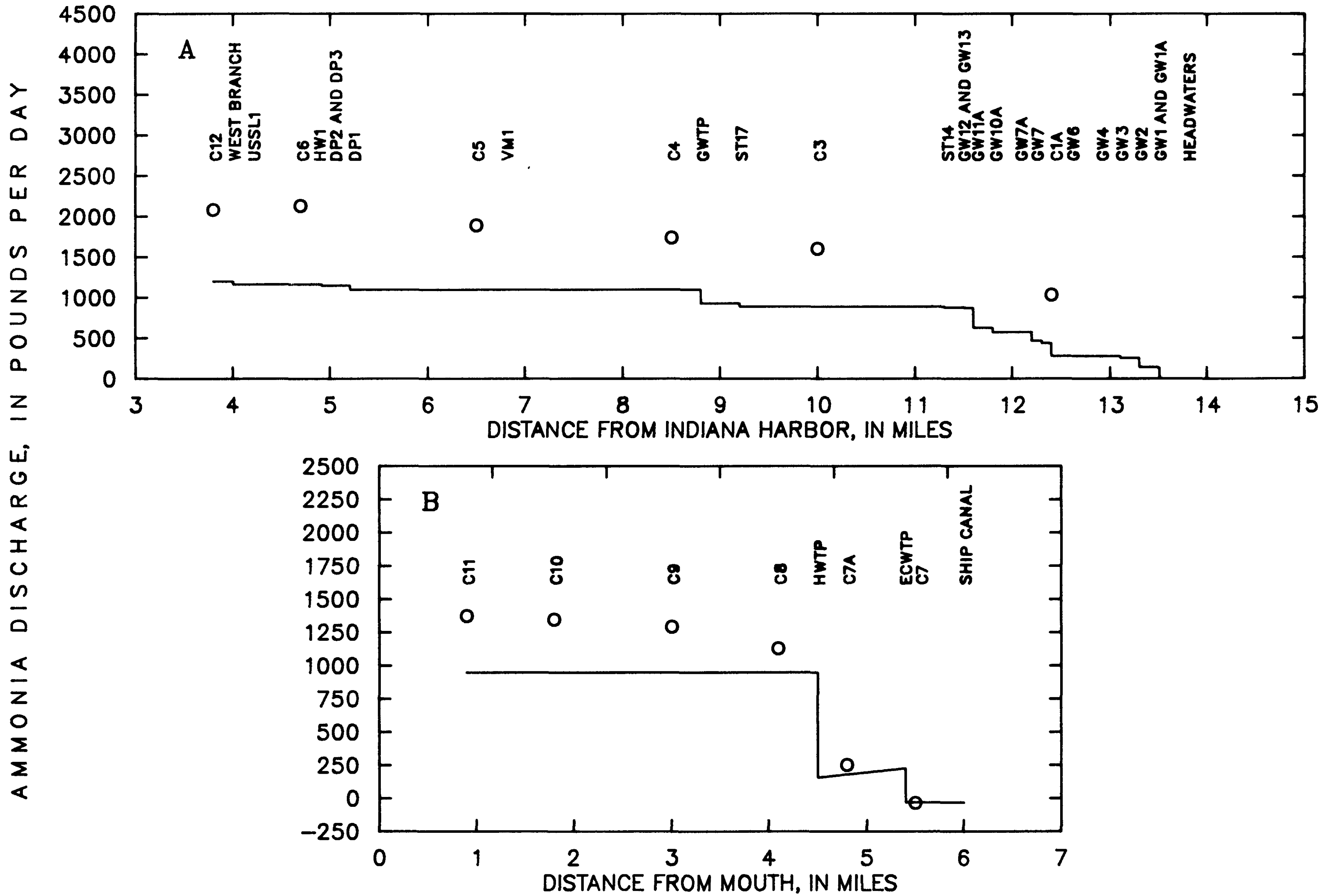


Figure 49.--Relation of cumulative effluent to instream discharge of ammonia, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

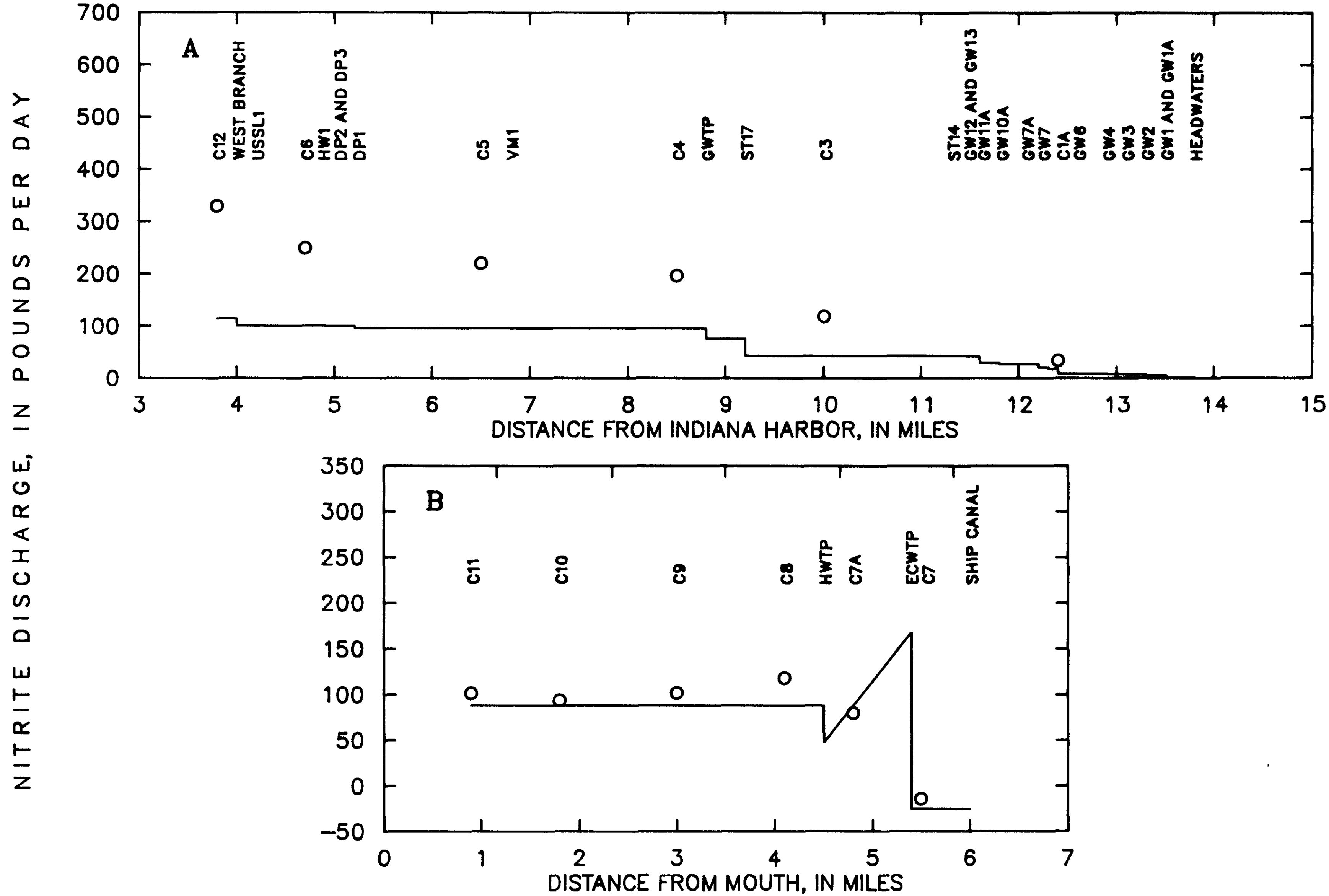


Figure 50.--Relation of cumulative effluent to instream discharge of nitrite, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

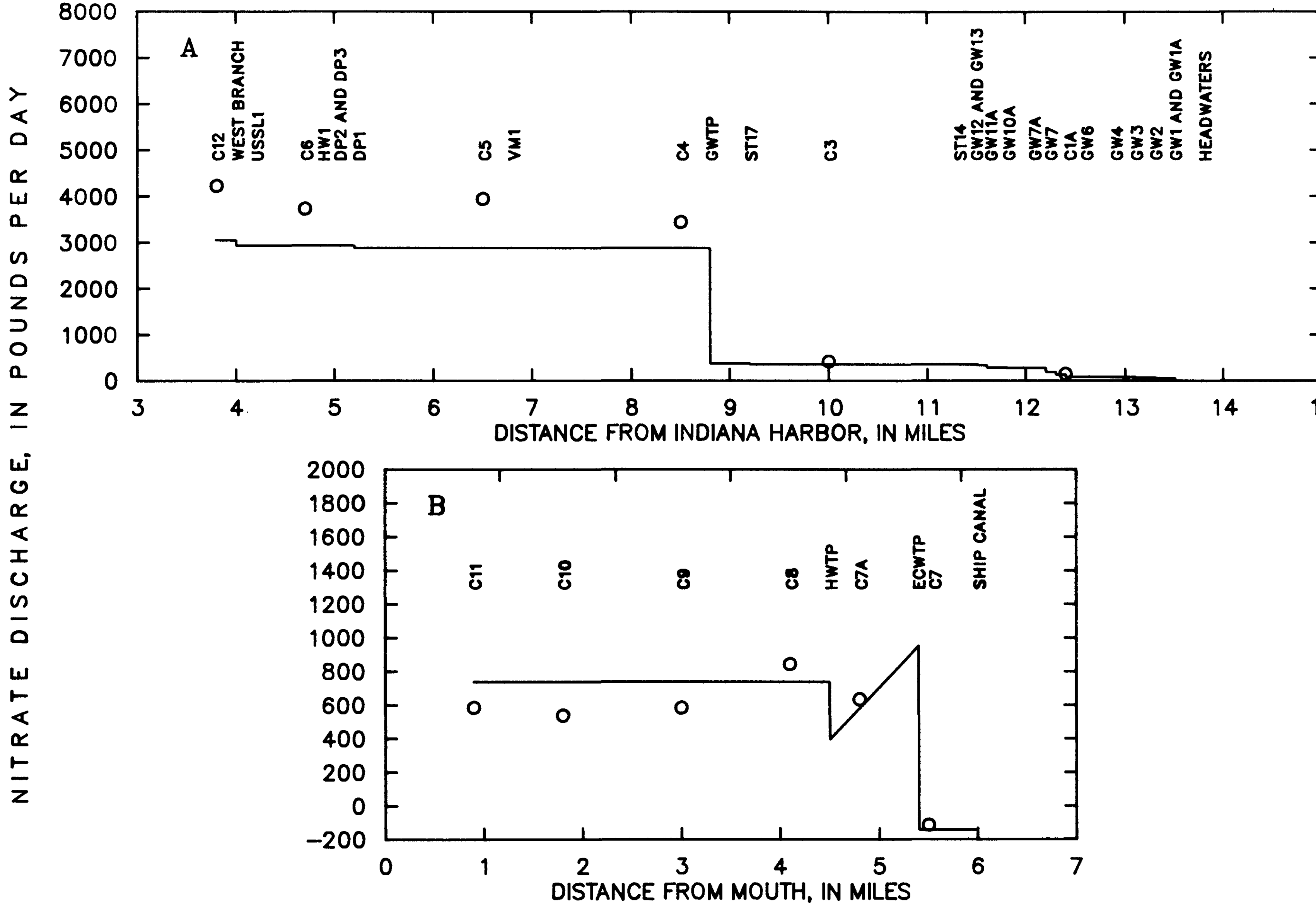


Figure 51.—Relation of cumulative effluent to instream discharge of nitrate, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

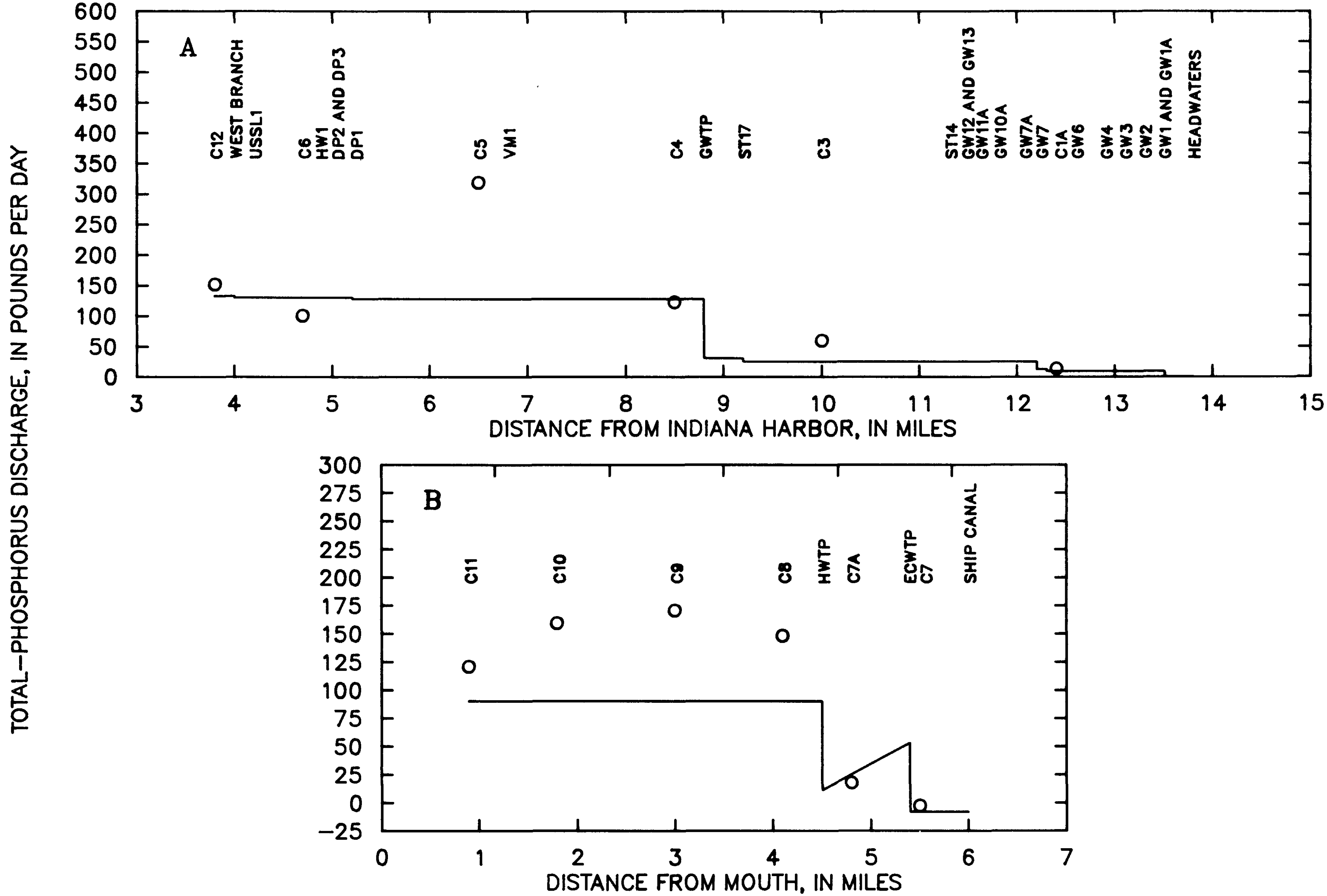


Figure 52.--Relation of cumulative effluent to instream discharge of total phosphorus, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

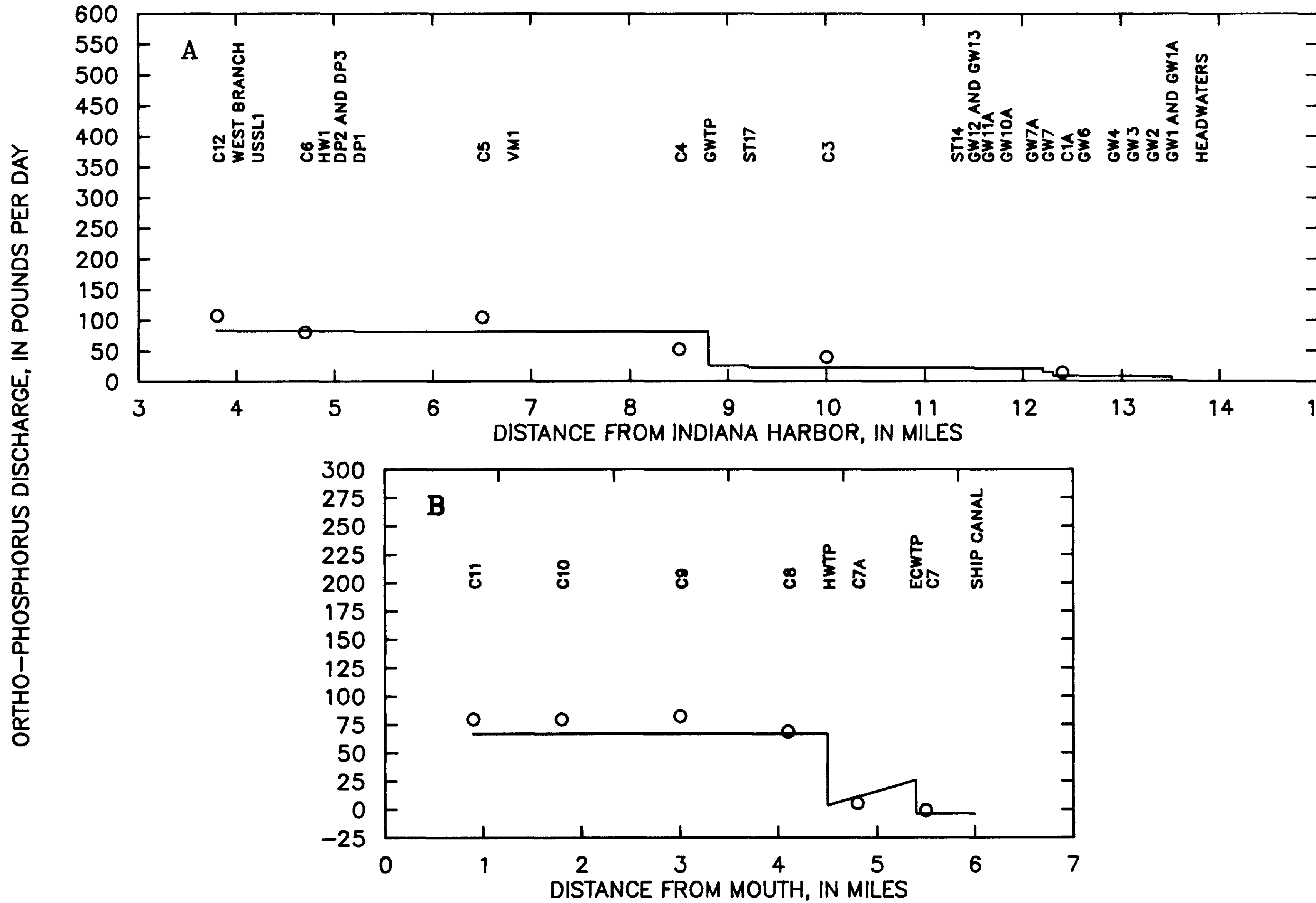


Figure 53.--Relation of cumulative effluent to instream discharge of ortho-phosphorus, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

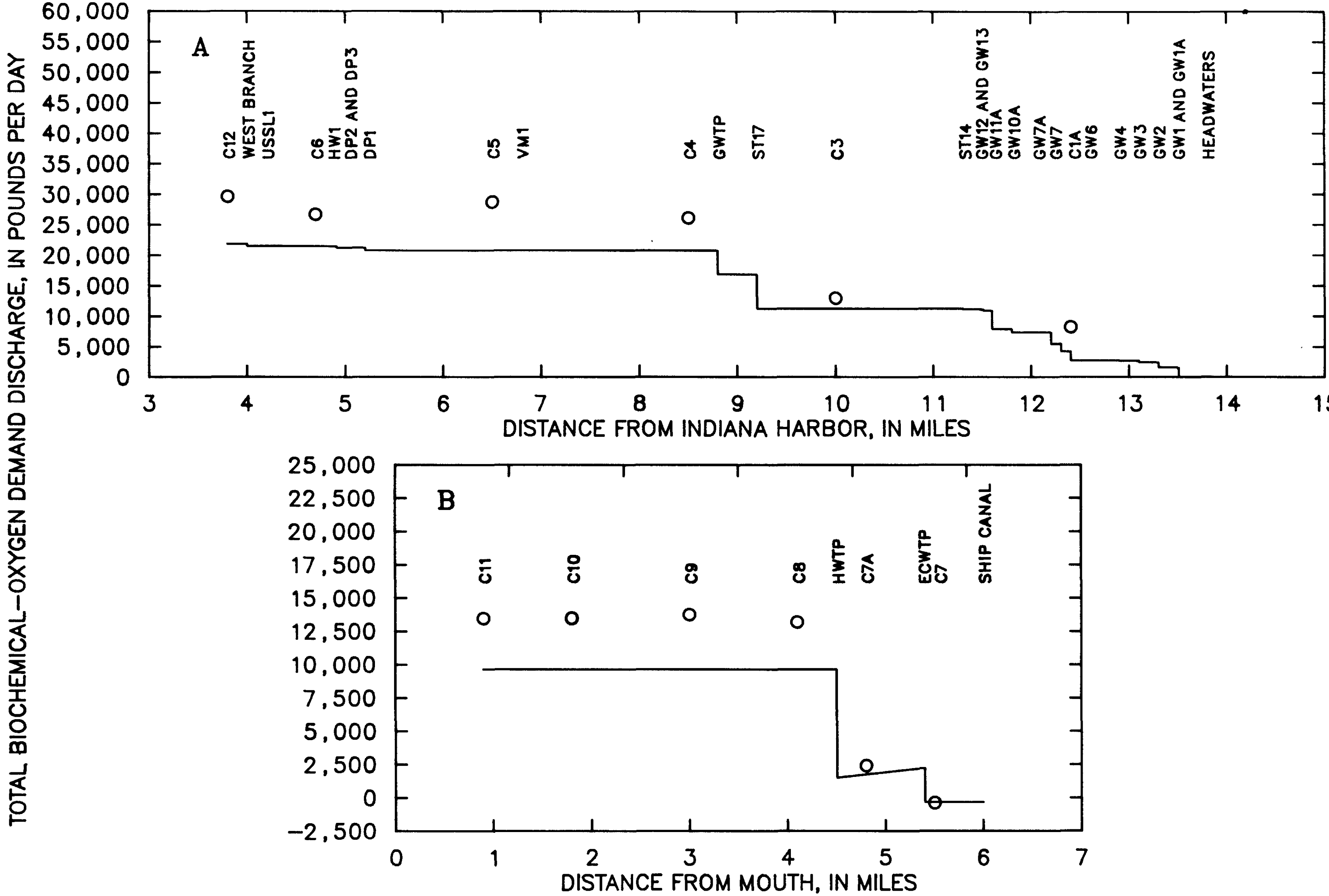


Figure 54.--Relation of cumulative effluent to instream discharge of total biochemical-oxygen demand, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

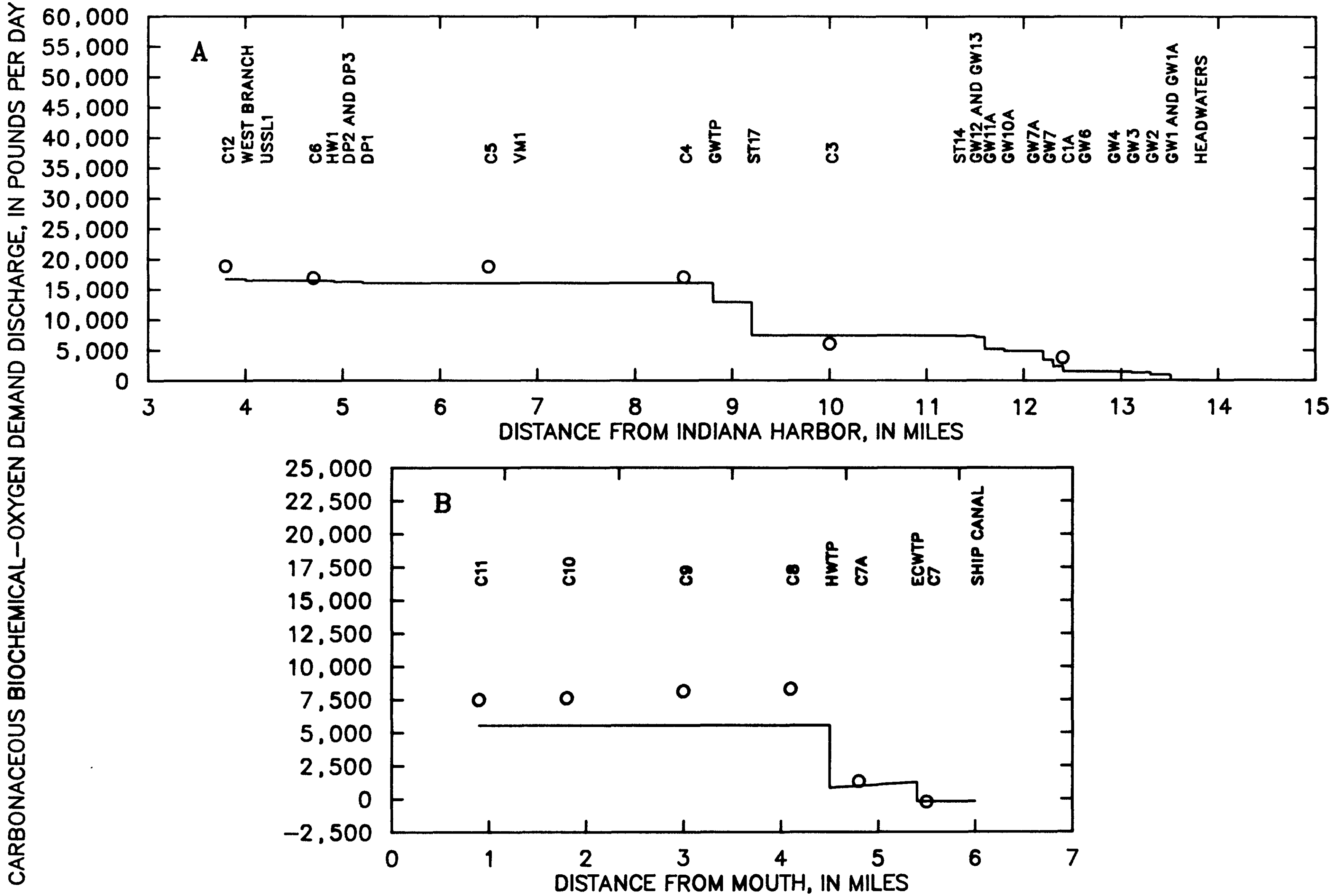


Figure 55.—Relation of cumulative effluent to instream discharge of carbonaceous biochemical–oxygen demand, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

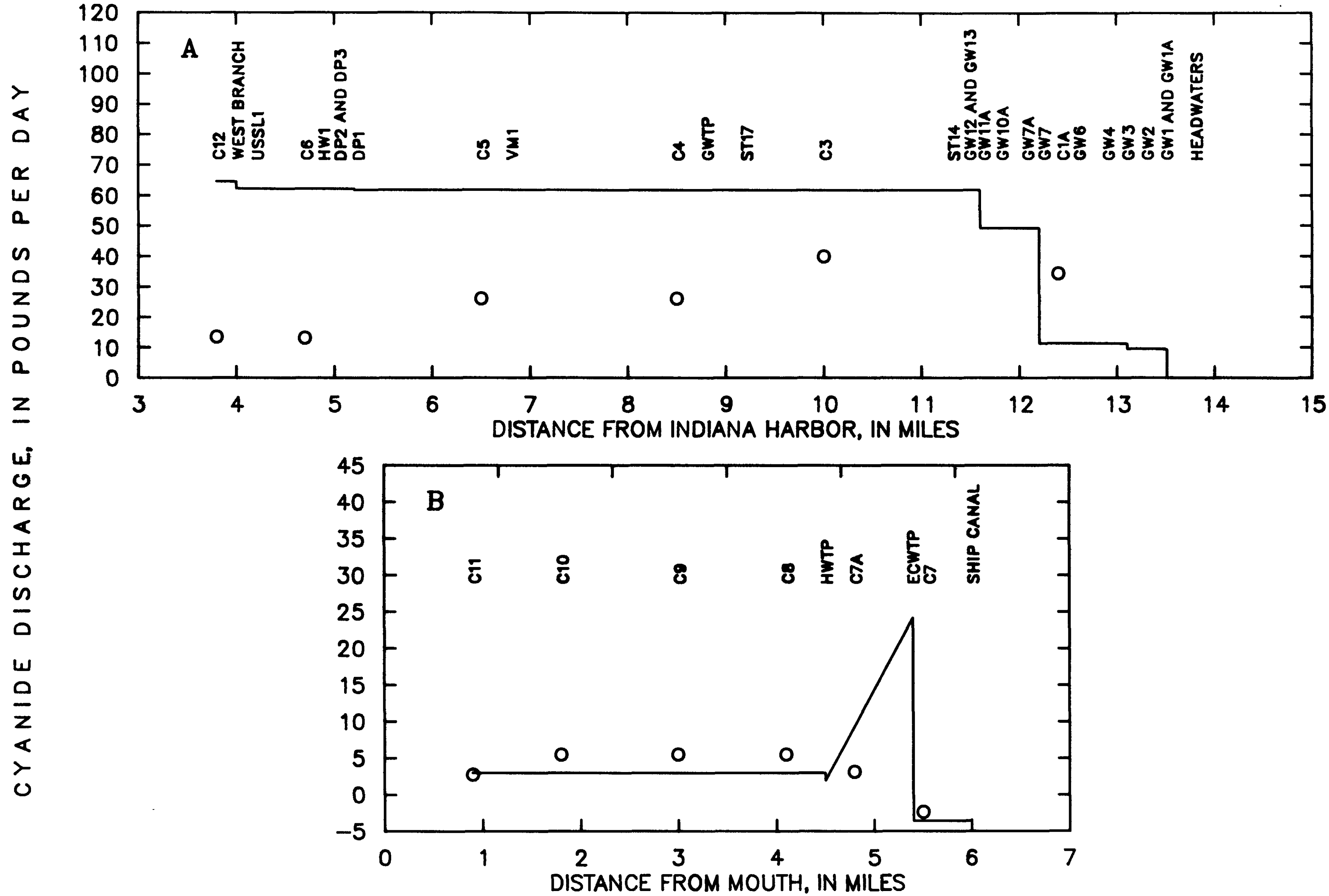


Figure 56.--Relation of cumulative effluent to instream discharge of cyanide, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

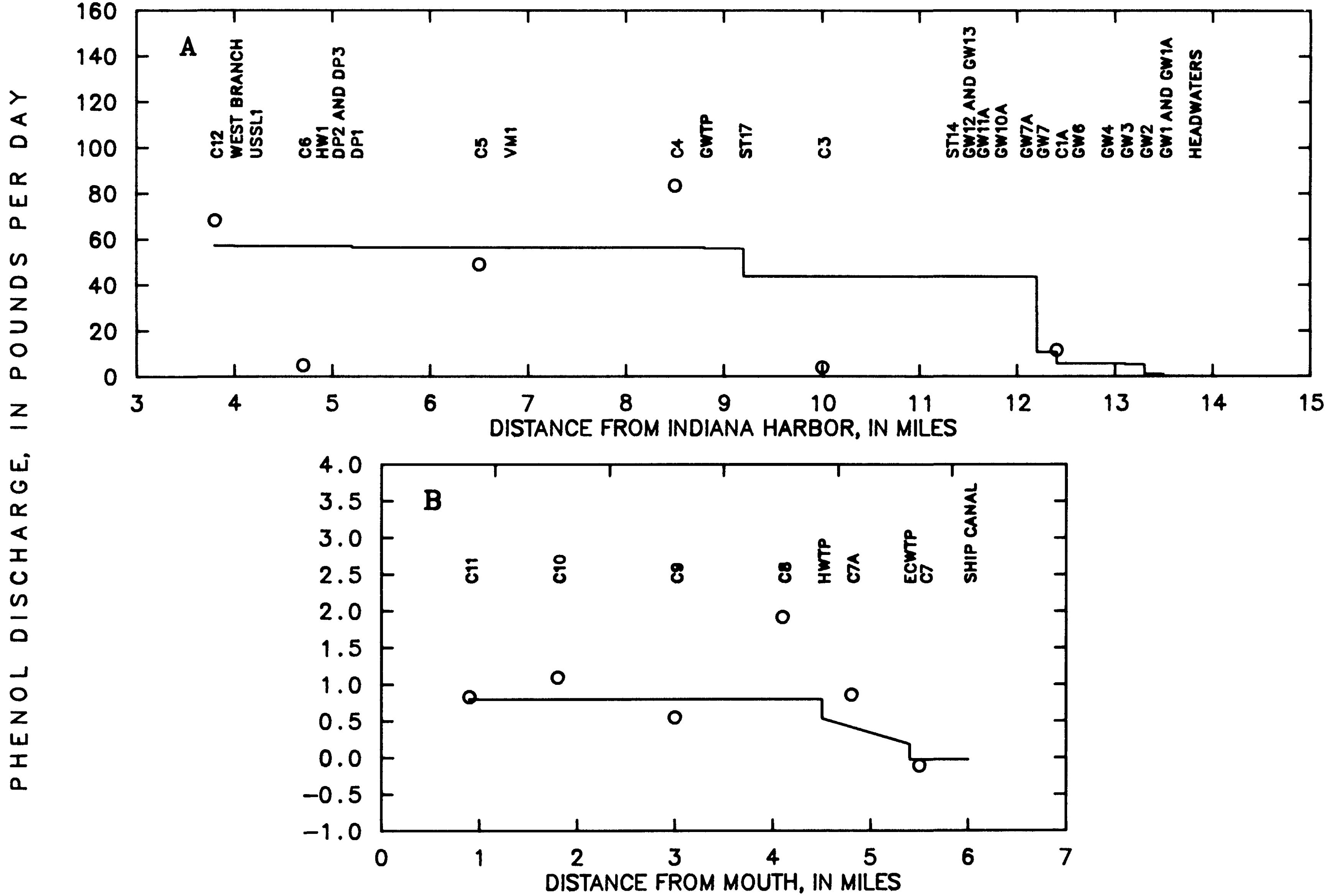


Figure 57.--Relation of cumulative effluent to instream discharge of phenol, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

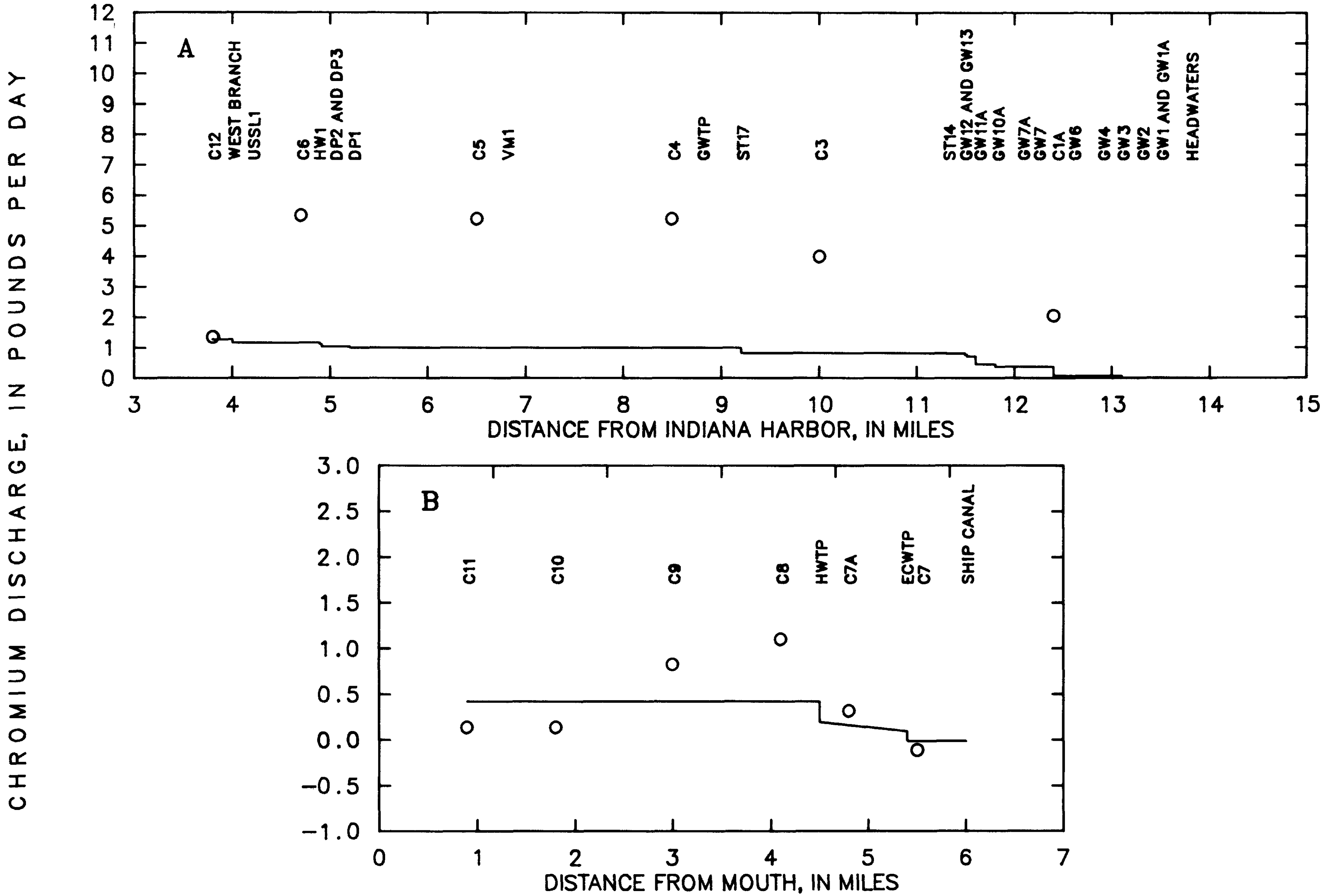


Figure 58.--Relation of cumulative effluent to instream discharge of chromium, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

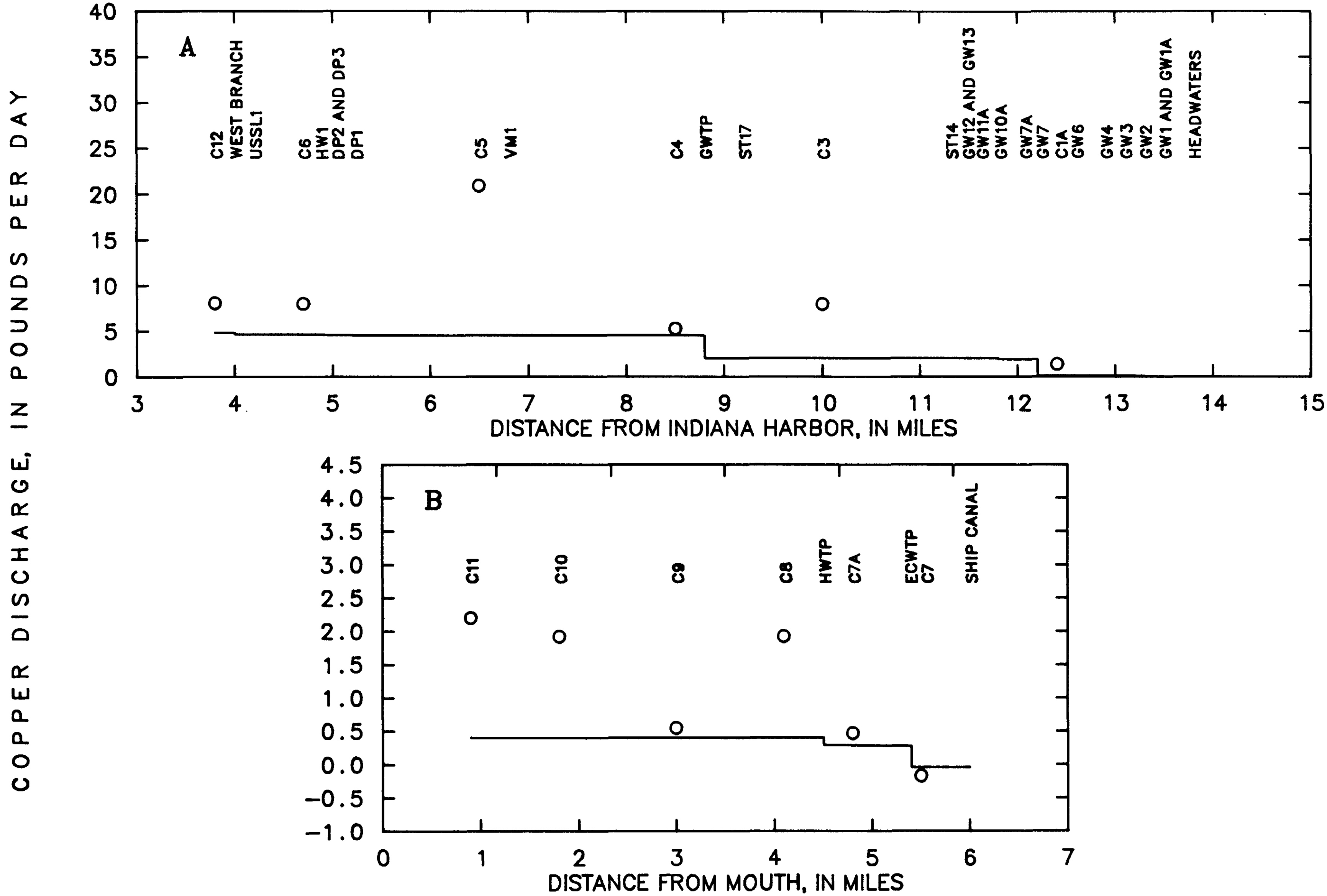


Figure 59.---Relation of cumulative effluent to instream discharge of copper, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

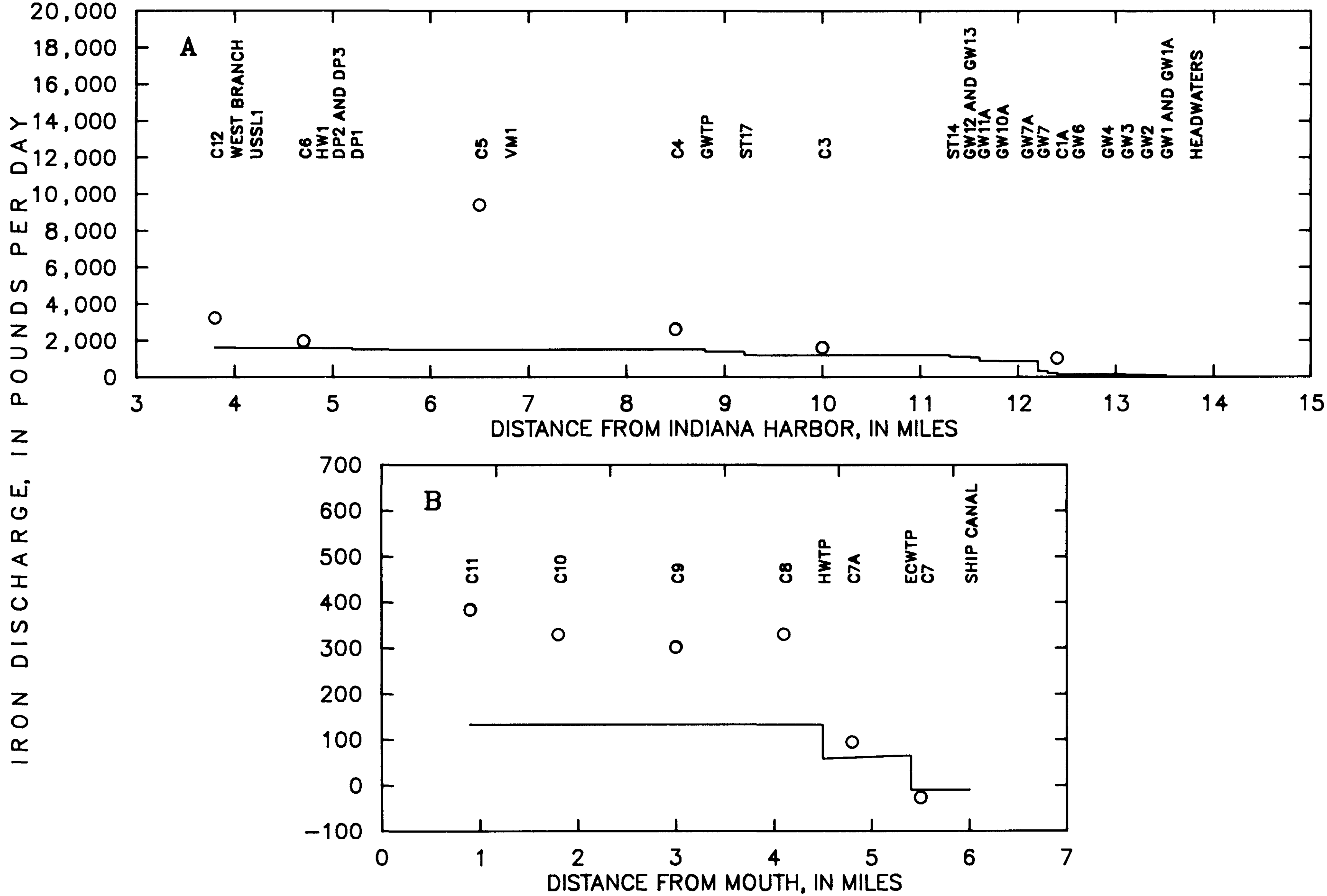


Figure 60.--Relation of cumulative effluent to instream discharge of iron, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

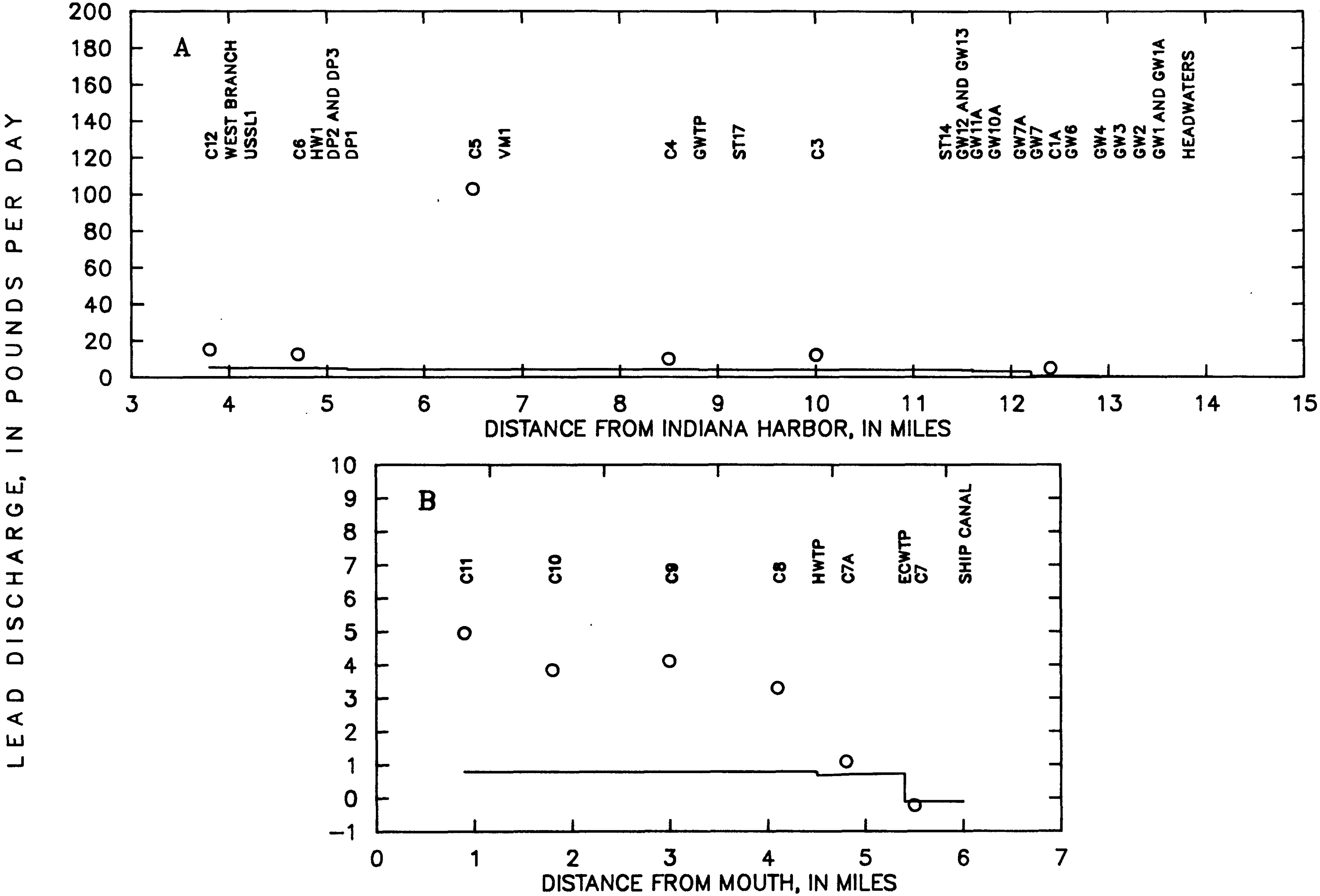


Figure 61.--Relation of cumulative effluent to instream discharge of lead, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

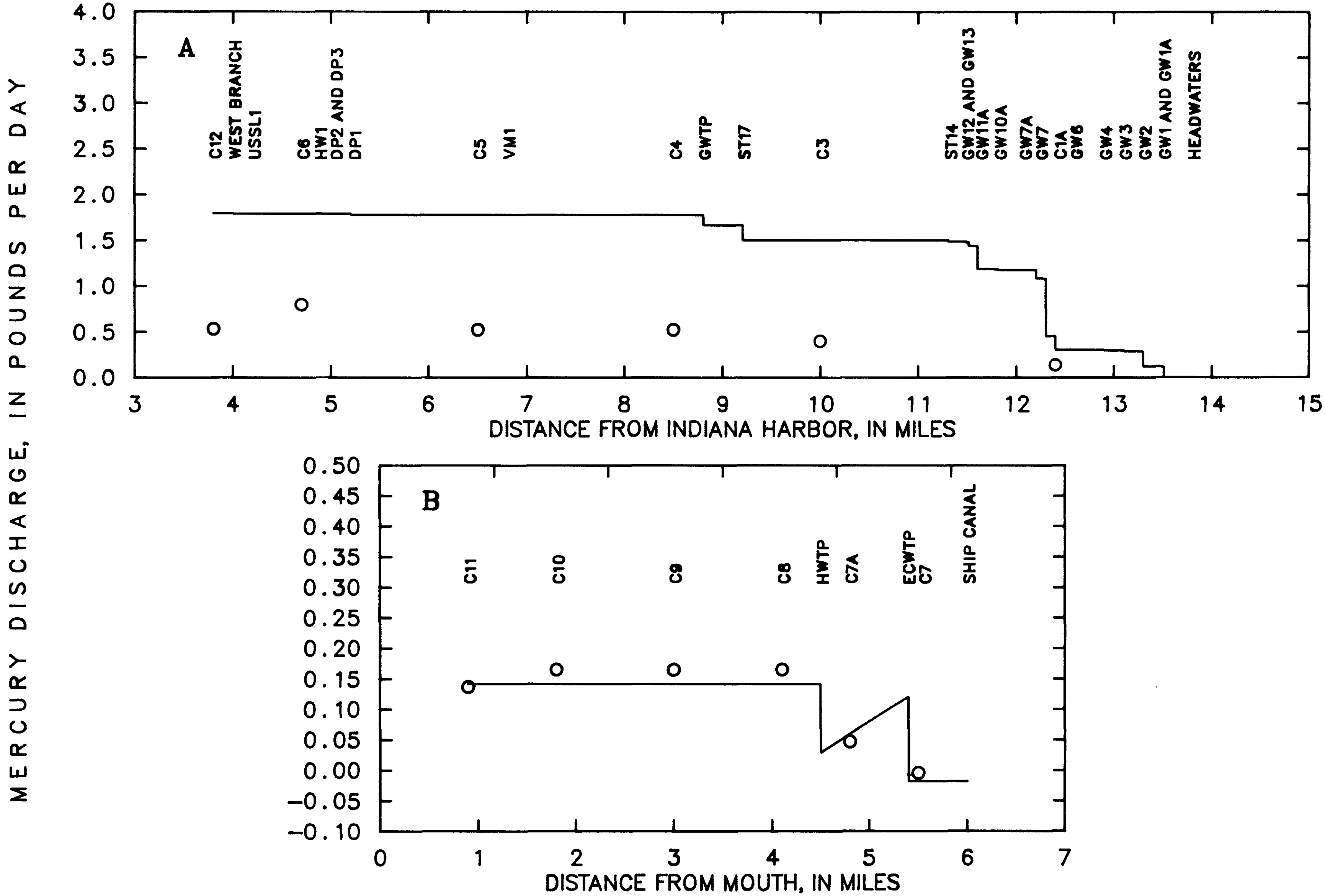


Figure 62.--Relation of cumulative effluent to instream discharge of mercury, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

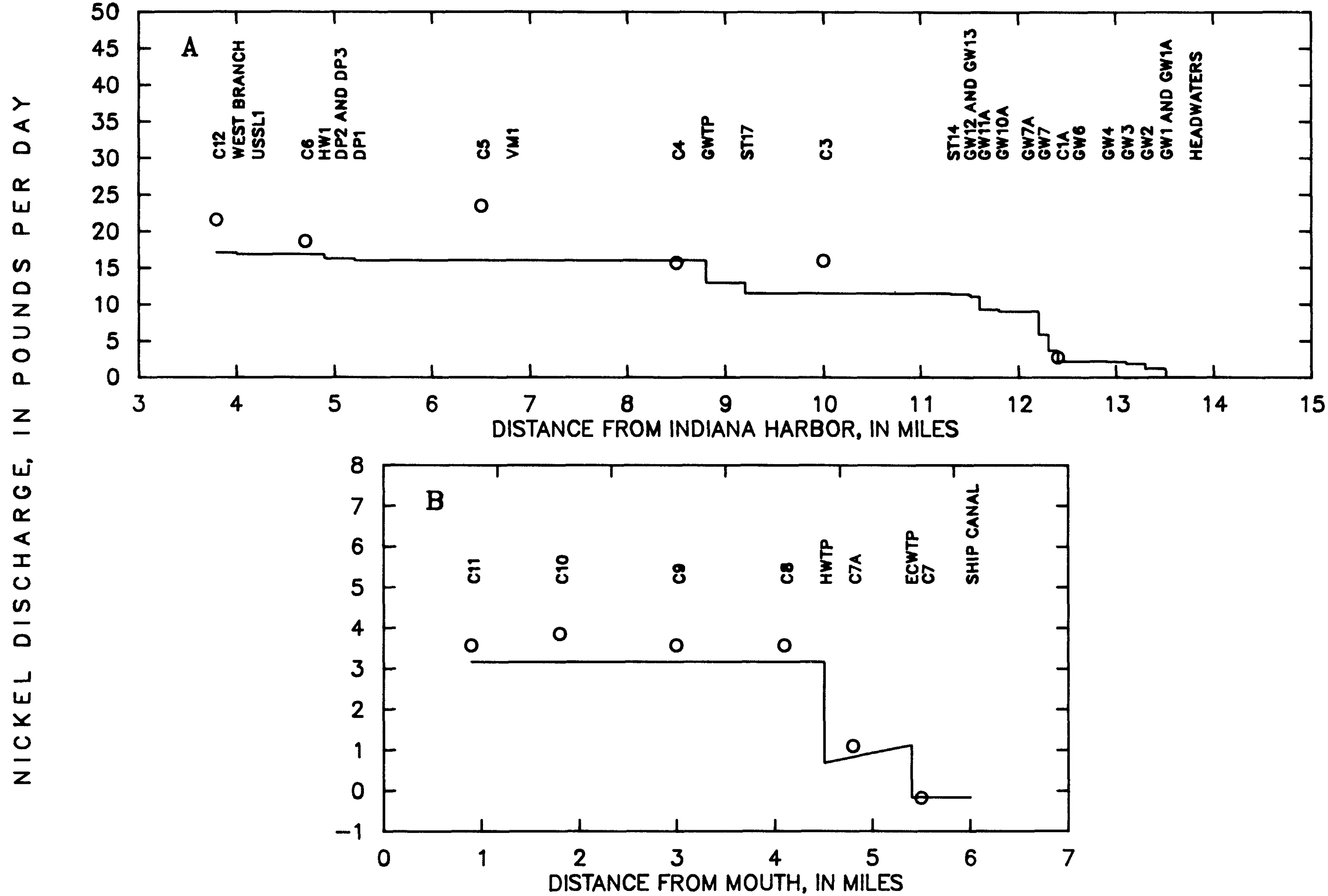


Figure 63.--Relation of cumulative effluent to instream discharge of nickel, (A) East Branch and (B) West Branch Grand Calumet River, October 3–4, 1984. (Station identifiers refer to locations shown in figure 1).

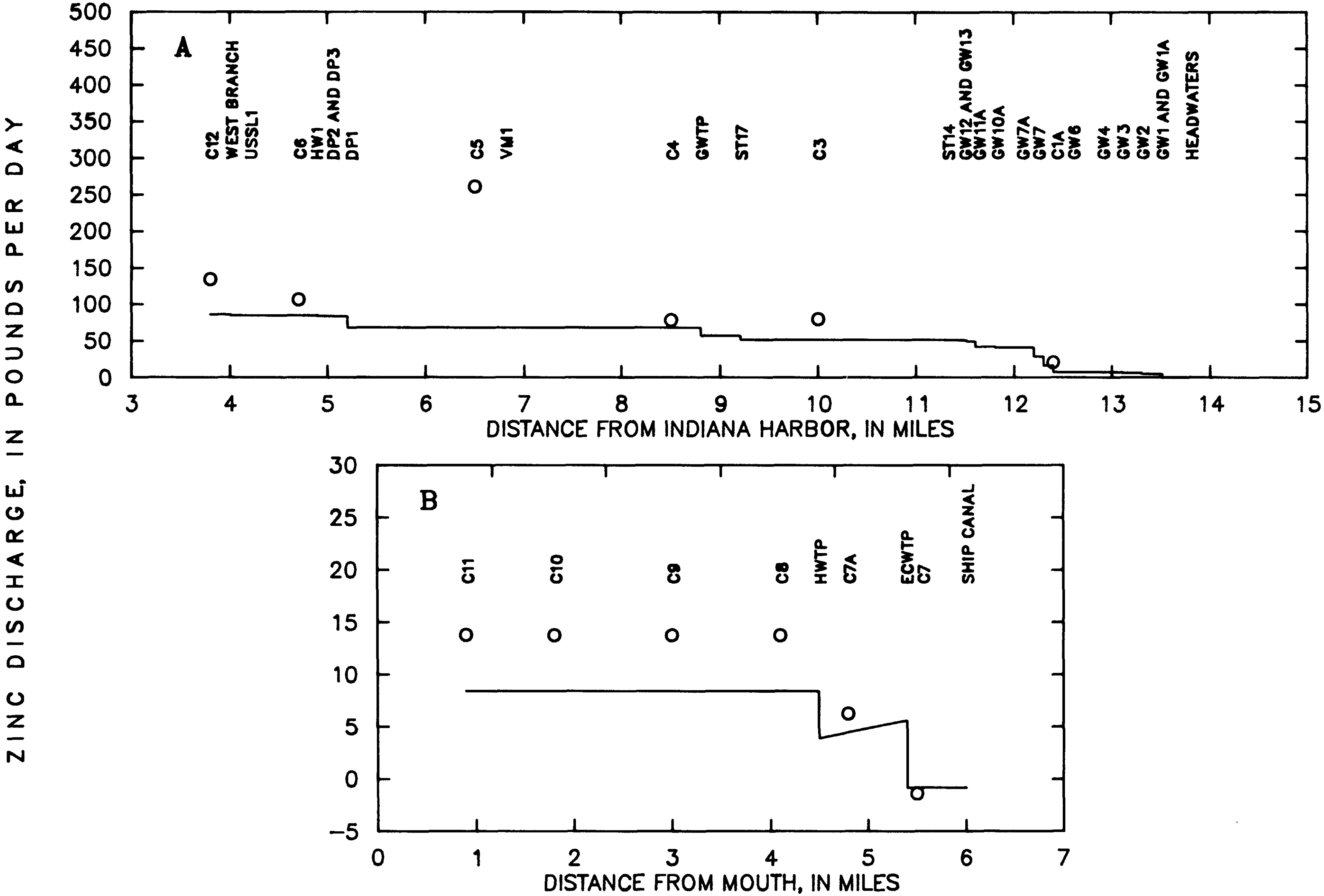


Figure 64.--Relation of cumulative effluent to instream discharge of zinc, (A) East Branch and (B) West Branch Grand Calumet River, October 3-4, 1984. (Station identifiers refer to locations shown in figure 1).

During the October 1984 survey, industrial and municipal effluents discharged an average 467 ft^3/s into the East Branch. Along with this water were 100,000 lb/d (pound per day) of chloride, 120,000 lb/d of sulfate, 620,000 lb/d of dissolved solids, 16,500 lb/d of ultimate CBOD, 57 lb/d of phenols, 69 lb/d of cyanide, 1,160 lb/d of ammonia, 2,900 lb/d of nitrate, 135 lb/d of total phosphorus, 2 lb/d of chromium, 5.5 lb/d of copper, 1,600 lb/d of iron, 5.6 lb/d of lead, 2 lb/d of mercury, 16.5 lb/d of nickel, and 85 lb/d of zinc.

Most water used by dischargers to the Grand Calumet River is obtained from Lake Michigan. For comparison, chemical-mass discharges were calculated on the basis of effluent flows measured during the survey and Lake Michigan water quality reported by the Indiana State Board of Health. The median value for data collected at four locations (the ECWTP, GWTP, HWTP, and Whiting water-treatment plant raw water intakes) in 1983 were used (Indiana State Board of Health, 1984, p. 57, 58, 59, and 61).

Comparable data were available for chloride, sulfate, fluoride, phenol, cyanide, ammonia, and nitrite plus nitrate. This analysis indicates that water discharged to the river has been enriched considerably compared to raw Lake Michigan water with respect to those constituents. In the East Branch, 3 times the chloride, 2 times the sulfate, 3 times the fluoride, 9 times the phenol, 11 times the cyanide, 9 times the ammonia, and 4 times the nitrite plus nitrate were discharged than would have been if concentrations of these constituents in the effluents had been similar to concentrations in Lake Michigan.

There are several differences between the chemical-mass discharges from industrial and municipal outfalls and those measured at the river stations in the East Branch. For example, only 76 percent of the chloride, 88 percent of the sulfate, and 89 percent of the dissolved solids discharges measured in the East Branch at 151st Street (station C12) can be accounted for by the known point sources. These two constituents and dissolved solids are generally stable in rivers. Thus the differences in chloride, sulfate, and dissolved solids discharges are an indication that additional sources contribute chemical discharges to the river. Differences between cumulative effluent and instream chemical-mass discharges were observed at one or more stations in the discharges of chloride, sulfate, dissolved solids, ammonia, nitrate, CBOD, chromium, copper, iron, lead, nickel, and zinc.

Significant differences between cumulative effluent and instream chemical-mass discharges were observed at three of the six stations sampled in the East Branch. The first significant difference in the discharges was observed at Virginia Avenue (station C1A). At this station, the known sources can only account for about 74 percent of the chloride, 80 percent of the sulfate, 87 percent of the dissolved solids, 43 percent of the ammonia, 62 percent of the CBOD, 18 percent of the chromium, 7 percent of the copper, 21 percent of the iron, 11 percent of the lead, and 80 percent of the zinc.

A second significant difference was observed at Industrial Highway (station C4). At this station, the known sources plus additional chemical loads from unknown sources observed at Virginia Avenue (station C1A) can only account for 90 percent of the chloride, 86 percent of the sulfate, 83 percent of the nitrate, 51 percent of the chromium, 89 percent of the iron, and 87 percent of the lead.

The third significant difference was observed at Cline Avenue (station C5). The differences observed at this station were primarily in the metals discharges. At this station, the known sources plus additional chemical loads from unknown sources observed at Virginia Avenue (station C1A) and Industrial Highway (station C4) can only account for 76 percent of the dissolved solids discharge, 87 percent of the nitrate, 22 percent of the copper, 28 percent of the iron, 10 percent of the lead, 68 percent of the nickel, and 30 percent of the zinc. As seen in figures 59, 60, 61, 63 and 64, the discharges of copper, iron, lead, nickel, and zinc jump significantly at Cline Avenue (station C5). All but nickel drop back to levels similar to those observed upstream at Industrial Highway (station C4) by the next sampling location downstream at Kennedy Avenue (station C6).

The reasons for the differences between the effluent chemical-mass discharges and those measured instream in the East Branch are not known. Possible explanations for the differences are sampling or measurement error or additional sources of chemical-mass discharges not monitored such as combined sewer overflows, subsurface drainage from landfills, leakage from wastewater-treatment lagoons, effluent from non-permitted outfalls or ground-water inflow. It is unlikely that sampling or measurement error is solely responsible for the observed differences. To allow for this type of error, chemical discharges that balanced within 90 percent were considered to be within an acceptable level of agreement. Some differences between cumulative effluent discharge and instream discharges also were as great as one order of magnitude. Measurement errors in either streamflow or analytical determination of chemical concentrations are unlikely to be of this magnitude.

West Branch Grand Calumet River

Chemical-mass discharges to the West Branch generally were substantially less than to the East Branch because of the much lower effluent flow (about 63 ft^3/s). A total of 74,000 lb/d of chloride, 44,000 lb/d of sulfate, 250,000 lb/d of dissolved solids, 6,200 lb/d of ultimate CBOD, 0.5 lb/d of phenols, 29 lb/d of cyanide, 1,050 lb/d of ammonia, 1,400 lb/d of nitrate, 140 lb/d of phosphorus, 150 lb/d of iron, 4 lb/d of nickel, and 11 lb/d of zinc were discharged to the West Branch during the water-quality survey. Less than 1 lb/d of chromium, copper, lead and mercury were discharged into the West Branch.

Proportionally, several constituents were discharged in much greater quantities into the West Branch than into the East Branch. Even though effluent flow in the West Branch was only about 13 percent of that in the East Branch, 75 percent as much chloride, 37 percent as much sulfate, 40 percent as much dissolved solids, 38 percent as much CBOD, 42 percent as much cyanide, 90 percent as much ammonia, 205 percent as much nitrate, and 105 percent as much total phosphorus were discharged to the West Branch as to the East Branch.

An analysis of estimated chemical-mass discharges into the West Branch based on chemical analysis of Lake Michigan water also indicated substantial enrichment of several constituents. In the West Branch, 20 times as much chloride, 5.5 times as much sulfate, 8 times as much fluoride, 36 times as much cyanide, 62 times as much ammonia, and 16 times as much nitrite plus nitrate were discharged than would have been if concentrations of these constituents in the effluents had been similar to concentrations in Lake Michigan. Less phenol was discharged into the West Branch than if Lake Michigan water had been discharged unaltered.

Differences in the chemical-mass discharges in the West Branch are not as evident as those in the East Branch because of problems regarding the streamflow balance previously discussed in the section, "Streamflow." Chemical-mass discharges were calculated from chemical data and flow data adjusted to account for differences in the flow balance. Determining differences in the reaches of the West Branch predominantly controlled by the effluent from the ECWTP is not possible with available data. The apparent loss of streamflow in these reaches has too substantial an effect on the instream discharges to draw any firm conclusions. As previously discussed, concentrations of several constituents were found to be higher in the river than in the known point sources. The differences were not large and the difference may have been due to measurement and sampling error. However, several problems are apparent in the reaches of the West Branch downstream of the HWTP.

Differences between effluent and instream chemical-mass discharges were observed at Columbia Avenue (station C8) in the discharge of suspended solids, CBOD, ammonia, total phosphorus, copper, iron, lead, and zinc. Downstream of Columbia Avenue, chemical-mass discharges are rather constant and do not indicate the presence of any additional sources. At Columbia Avenue, known sources only account for about 30 percent of suspended solids, 70 percent of the CBOD, 70 percent of the ammonia, 75 percent of the total phosphorus, 20 percent of the copper, 35 percent of the iron, 15 percent of the lead, and 60 percent of the zinc.

SUMMARY AND CONCLUSIONS

A diel water-quality survey was done October 3-4, 1984, on the Grand Calumet River, Lake County, Indiana, and Cook County, Illinois. The study was designed to (1) investigate the sources of dry-weather waste inputs not attributable to permitted point-source effluent discharges and (2) provide information for evaluating the waste-load assimilative capacity of the river. Five sampling stations were selected in the East Branch Grand Calumet River, six in the West Branch, and one in the Indiana Harbor Ship Canal.

The Grand Calumet River system extends along the southern shoreline of Lake Michigan in northwest Indiana and consists of three parts: The East Branch, the West Branch, and the Indiana Harbor Ship Canal and Indiana Harbor. The West Branch Grand Calumet River flows from its confluence with the Indiana Harbor Ship Canal to its confluence with the Little Calumet River in Illinois. West of Columbia Avenue in Hammond (fig. 1), the river flows to the west. East of Columbia Avenue, the river flows east or west depending on the water level in Lake Michigan, effluent flow in the two branches of the river and the ship canal, and the influence of wind direction and velocity. The Indiana Harbor Ship Canal flows north from its confluence with the Grand Calumet River and discharges into Lake Michigan. The ship canal is virtually an extension of the East Branch.

Flow in the Grand Calumet River is almost entirely municipal and industrial effluents. Over 90 percent of the 500 ft^3/s flow observed at the confluence of the East Branch and the ship canal was due to these effluents. The remaining flow in the East Branch was attributed to ground water or seepage from adjacent wetlands. Diel variation in streamflow of as much as 300 ft^3/s was observed in the East Branch near the Indiana Harbor Ship Canal. The diel variation diminished at the upstream sampling stations. Virtually all the flow in the West Branch was municipal wastewater effluent. During the water-quality survey, approximately 15 percent of the effluent from the ECWTP was measured flowing east into the Indiana Harbor Ship Canal. The remaining effluent from this WTP flowed west into the West Branch. Flow measured in the West Branch at locations west of the HWTP and ECWTP indicates that about 25 percent of the effluent flow reported by these plants was not being measured at downstream sampling stations. This apparent difference was attributed to (1) error in assuming that the effluent flow from the HWTP was equivalent to the flow measured entering the plant, and (2) evaporation, seepage, and storage of water in a large marshy area near the ECWTP. The effluent flow at the HWTP was estimated to be 80 percent of the influent wastewater flow. In the West Branch, flow reversals were observed at sampling stations near the ship canal.

Water quality in the East Branch is generally much better than in the West Branch. For example, average DO concentrations in the East Branch ranged from 5.7 to 8.2 mg/L. In the West Branch, average DO concentrations ranged from 0.8 to 6.6 mg/L. Dissolved solids concentrations were two to three times higher in the West Branch (660 to 1,000 mg/L) than in the East Branch (185 to 325 mg/L). Concentrations of suspended solids, BOD, ammonia, nitrite, nitrate, and phosphorus also were substantially higher in the West Branch than in the East Branch. In the East Branch, only the water-quality standards for phenol and total phosphorus were exceeded, whereas in the West Branch, water-quality standards for chloride, fluoride, dissolved solids, ammonia, total phosphorus, cyanide, phenol, and mercury were exceeded. Dissolved oxygen was less than the minimum allowable at four of the six sampling stations in the West Branch.

Chemical-mass discharges in the Grand Calumet River could not all be accounted for by known effluent discharges. Three areas of significant differences between cumulative effluent and instream chemical-mass discharges were identified in the East Branch and one in the West Branch. In the East Branch, differences observed at Virginia Avenue (station C1A), Industrial Highway (station C4), and Cline Avenue (station C5), were an indication of the presence of unidentified waste inputs upstream of these sites. In the West Branch, differences in chemical-mass discharge were more difficult to define because of the imbalance between effluent flow and streamflow. Elevated suspended-solids, BOD, and ammonia discharges are indicative of a source of what may be raw sewage located between the HWTP and Columbia Avenue (station C8). Substantial sludge deposits more than 7 ft deep were observed in this reach of the West Branch.

REFERENCES CITED

Combinatorics, Inc., 1974, Load allocation study of the Grand Calumet River and Indiana Harbor Ship Canal: Lafayette, Indiana, 100 p.

Cook, S. G., and Jackson, R. S., 1978, The Bailly area of Porter County, Indiana: Evanston, Illinois, Robert Jackson and Associates, 110 p.

Dunn, J. P., 1919, Indiana and Indianans, v. I: Chicago, Ill., American Historical Society, 568 p.

Durfor, C. N., and Becker, Edith, 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geological Survey Water-Supply Paper 1812, 364 p.

Federal Water Pollution Control Administration, 1967, Report on the water quality of lower Lake Michigan, Calumet River, and Wolf Lake: U.S. Department of the Interior, 79 p.

Friedman, L. C., and Erdmann, D. E., 1982, Quality assurance practices for the chemical and biological analyses of water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A6, 181 p.

Goerlitz, D. F., and Brown, Eugene, 1972, Methods for analysis of organic substances in water: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A3, 40 p.

Harris, R. A., 1907, Tides in lakes and wells--Manual of tides: U.S. Coast and Geodetic Survey Report, appendix 6, 487 p.

Harrison, W., McCown, D. L., Saunders, K. D., and Ditmars, J. D., 1979, Wintertime raw-water contamination at Chicago's South Water Filtration Plant: Water Pollution Control Federation Journal, v. 51, no. 10, p. 2432-2446.

Hem, J. D., 1985, Study and Interpretation of the Chemical Characteristics of Natural Water (3rd ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Heyford, J. F., 1922, Effects of wind and barometric pressure on the Great Lakes: Washington, Carnegie Institute of Washington Report 317, 133 p.

HydroQual, Inc., 1984, Grand Calumet River Wasteload Allocation Study: Mahwah, New Jersey, 262 p.

Indiana State Board of Health, 1984, 1983 Water quality monitoring-Rivers and streams: Indianapolis, Indiana State Board of Health, Division of Water Pollution Control, 140 p.

McCutcheon, S. C., and others, 1985, Water quality and streamflow data for the West Fork Trinity River in Fort Worth, Texas: U.S. Geological Survey Water-Resources Investigations Report 84-4330, 101 p.

Rantz, S. E., and others, 1982, Measurement and computation of streamflow: Volume 1. Measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, 284 p.

Robertson, N. A., and Riker, Dorothy, eds., 1942, The John Tipton Papers, v. I, 1809-1827: Indianapolis, Indiana Historical Bureau, 909 p.

Romano, R. R., 1976, A study of selected heavy metals in the Grand Calumet River-Indiana Harbor Canal System: Purdue University, Ph.D. thesis, 202 p.

Romano, R. R., McIntosh, A. W., Kessler, W. V., Anderson, V. L., and Bell, J. M., 1977, Trace metal discharges of the Grand Calumet River: Journal of Great Lakes Research, v. 3, no. 1/2, p. 144-147.

Skougstad, M. W., and others, 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A1, 626 p.

Smart, P. L., and Laidlaw, I. M. S., 1977, An evaluation of some fluorescent dyes for water tracing: Water Resources Research, v. 13, no. 1, p. 15-33.

U.S. Army Corps of Engineers, 1985, Great Lakes water level facts: U.S. Army Corps of Engineers, Detroit District, 15 p.

U.S. Department of Commerce, 1982, 1980 Census of population, volume 1, Characteristics of population, Chapter B, General population characteristics, Part 16, Indiana: U.S. Department of Commerce, Bureau of the Census, 329 p.

U.S. Department of Health, Education, and Welfare, 1970, Water quality in the Calumet Area - Conference on pollution of lower Lake Michigan, Calumet River, Grand Calumet River, Little Calumet River, and Wolf Lake, Illinois and Indiana: U.S. Department of Health, Education and Welfare, Technical Committee on Water Quality, 140 p.

Wezernak, C. T., and Gannon, J. J., 1967, Oxygen nitrogen relationships in autotrophic nitrification: Applied Microbiology, v. 15, p. 1211-1215.

Wilson, J. F., Cobb, E. D., and Kilpatrick, F. A., 1984, Fluorometric procedures for dye tracing: U.S. Geological Survey Open-File Report 84-234, 53 p.

APPENDIX: Streamflow in the West Branch Grand Calumet River, September 18-19, 1985

As a result of the differences observed in the West Branch Grand Calumet River during the October 1984 survey, a small follow-up study was done on September 18-19, 1985. The study was designed to determine the flow balance in the West Branch near the HWTP and included the following:

1. Recording water-level gages were installed at three stations on the river near the HWTP (C7A, C8, and a new station located upstream from the HWTP at RM 4.6 designated C7B), in the center of the small lake located near the Indiana East-West Toll Road (designated station C7C) and in the HWTP effluent channel just before the channel discharges to the West Branch. The gages recorded water levels at 5-minute intervals.

2. Streamflow at the three river stations was measured at 90-minute intervals for a 24-hour period beginning at 1000 on September 18, 1985. Procedures for measuring streamflow used in the October 1984 survey previously described in the section, "Data Collection Procedures," were also used during this study. Flow was also measured twice at Hohman Avenue (station C9) and once at Bridge Street (station C3) and Industrial Highway (station C4).

3. Forty-seven flow measurements were made in the HWTP effluent channel during the 24-hour period. Measurements were made over a sufficient range in water level and flow to obtain a relation between the two so that a detailed estimate of the total flow for the 24-hour period could be obtained. The gage height was recorded at the time when individual velocity and depth measurements were made in the cross section so that the variability in gage height during the measurement could be obtained.

4. Samples for determining concentrations of chloride, sulfate, and dissolved solids were obtained by the procedures used for the October 1984 survey.

5. Rhodamine WT dye (as rhodamine WT, 20-percent solution) and lithium (as lithium chloride, 35-percent solution) tracers were released from Indianapolis Boulevard in a single slug at the start of the 24-hour period. The tracers were used in this study to determine if water was being lost from the stream channel, either as storage in the small lake near the Indiana East-West Toll Road or as ground-water infiltration. Rhodamine WT was used because it is easily measured in the field. Rhodamine WT is not totally stable in the environment, being particularly susceptible to adsorption onto sediments (Smart and Laidlaw, 1977). Lithium is much more stable than rhodamine WT and was used to estimate losses of water from the stream channel. Loss of lithium was assumed to be proportional to the loss of water from the channel. Water samples for the determination of rhodamine WT and lithium concentrations were collected at the two stations near the Indiana East-West Toll Road (stations C7A and C7B) and Columbia Avenue (station C8). Samples were collected during passage of the tracers at each river station until the concentration of rhodamine WT dropped below 1 percent of the maximum concentration. The procedures of Wilson and others (1984) were used to determine the concentration of

rhodamine WT. Samples for determination of lithium were analyzed at the U.S. Geological Survey laboratory, Doraville, Georgia, by the methods of Skougstad and others (1979).

Linear regression methods were used to develop a stage-discharge relation for the HWTP effluent channel. Data used to develop this relation are given in table 10. Gage height did not always remain constant during the flow measurements in the effluent channel. Therefore, the measurements were weighted in the regression calculations on the basis of the inverse of the standard deviation of the average stage during the measurement. Thus, measurements where stage varied little were given more weight than measurements where the stage varied substantially. The following equation best described the observed data:

$$Q = 69733.941 \times \ln(GHT) + 43.095 \times (GRAD) - 192842$$

where Q is the predicted flow at the HWTP effluent channel, in cubic feet per second,

ln(GHT) is the natural logarithm of the water-surface elevation at the HWTP effluent channel, in feet above the NGVD of 1929,

and GRAD is the gradient between the water-surface elevation in the HWTP effluent channel and the water-surface elevation in the stream channel near the Indiana East-West Toll Road (station C7B), in feet.

This equation reliably predicts effluent flow from water-surface elevation for the HWTP. The equation accounts for over 97 percent of the variability observed in the data. The standard deviation of the residuals is 1.8 ft^3/s, and the average absolute prediction error for the 47 observed data points is 1.2 ft^3/s.

Estimates of flow for each of the water-surface elevations that were recorded every 5 minutes during the study were obtained from the stage-discharge equation. By use of this equation the mean effluent flow from the HWTP for the 24-hour period beginning at 1000 September 18, 1985, was determined to be 38.6 ft^3/s. For the same period, the HWTP reported a flow of 50.1 ft^3/s. The measured effluent flow was 77 percent of the influent flow reported by the HWTP. This percentage compares favorably with the 81 percent obtained by comparing the influent flow and effluent flow estimated by the mass-balance technique for the October 1984 survey. It is unlikely that the difference between the average 24-hour influent and effluent flows is due to the time lag between influent and effluent flow as a consequence of the detention of water in the plant. The range in average 24-hour flow for the twenty-five 24-hour periods beginning at 1000 September 17 and ending 1000 September 19 (moving average, incremented hourly) was only 1.7 ft^3/s. Use of the minimum average 24-hour influent flow during this period still results in an influent/effluent ratio of 0.78, not significantly different from the ratio calculated previously.

Table 10.--Measurements of effluent discharge and stage data used to develop stage-discharge relation for the Hammond wastewater-treatment plant, September 18-19, 1985

[All measurements by U.S. Geological Survey]

[ft^3/s, cubic foot per second]

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)	Average stage at HWTP outfall (feet above NGVD of 1929)	Average stage at site C7B (feet above NGVD of 1929)	Standard deviation of stage at HWTP during measurement
HWTP	1	1040	1050	27.3	580.95	580.82	.13344
HWTP	2	1155	1205	31.7	580.98	580.82	.00522
HWTP	3	1203	1213	39.9	581.08	580.83	.03588
HWTP	4	1239	1244	21.2	580.88	580.84	.05711
HWTP	5	1244	1250	18.1	580.87	580.84	.06630
HWTP	6	1333	1339	41.0	581.15	580.94	.04450
HWTP	7	1339	1345	40.7	581.15	580.96	.03264
HWTP	8	1433	1439	42.3	581.18	581.00	.03668
HWTP	9	1439	1445	42.3	581.17	580.99	.03475
HWTP	10	1533	1539	44.8	581.22	581.03	.00647
HWTP	11	1539	1545	40.2	581.18	581.03	.01695
HWTP	12	1633	1639	42.4	581.20	581.02	.02687
HWTP	13	1639	1645	42.6	581.19	581.01	.02359
HWTP	14	1737	1743	37.2	581.14	581.01	.02115
HWTP	15	1743	1749	45.6	581.22	581.01	.01753
HWTP	16	1837	1843	47.0	581.22	581.03	.02933
HWTP	17	1843	1849	41.1	581.17	581.03	.01578
HWTP	18	1945	1955	43.1	581.21	581.02	.05519
HWTP	19	1955	2005	41.6	581.17	581.02	.04569
HWTP	20	2035	2045	43.0	581.18	581.02	.03289
HWTP	21	2045	2055	42.2	581.18	581.02	.04225
HWTP	22	2110	2120	18.1	580.96	580.98	.05833
HWTP	23	2120	2126	28.0	580.98	580.97	.03477
HWTP	24	2145	2150	39.1	581.12	580.94	.08000
HWTP	25	2150	2155	47.1	581.20	580.96	.03488
HWTP	26	2155	2200	39.8	581.11	580.96	.02508
HWTP	27	2200	2206	46.4	581.22	580.97	.01912
HWTP	28	2245	2252	40.7	581.17	580.98	.05921
HWTP	29	2300	2306	43.9	581.18	580.99	.04277
HWTP	30	2335	2345	42.2	581.16	581.02	.03092
HWTP	31	2345	2351	43.8	581.19	581.02	.04388
HWTP	32	0010	0020	22.3	580.99	581.00	.04519
HWTP	33	0020	0026	31.1	581.05	581.00	.01095
HWTP	34	0035	0045	37.7	581.13	581.01	.05608
HWTP	35	0135	0145	44.1	581.21	581.01	.03488
HWTP	36	0215	0225	23.4	580.96	580.95	.02386
HWTP	37	0225	0235	25.4	580.97	580.92	.04020
HWTP	38	0340	0350	41.9	581.15	580.93	.03045
HWTP	39	0435	0442	38.5	581.12	580.96	.04191
HWTP	40	0535	0545	36.6	581.09	580.95	.03297
HWTP	41	0635	0645	36.8	581.07	580.93	.02089
HWTP	42	0735	0745	40.5	581.12	580.90	.03171
HWTP	43	0745	0755	36.5	581.05	580.89	.02601
HWTP	44	0835	0845	41.1	581.13	580.91	.04740
HWTP	45	0935	0945	40.3	581.14	580.95	.03459
HWTP	46	1030	1040	28.8	581.00	580.90	.08765
HWTP	47	1040	1050	14.7	580.92	580.89	.08837
			Average	37.1	581.11	580.96	

 (PAGE 131 FOLLOWS)

Flow measurements made in the Grand Calumet River on September 18-19, 1985, are listed in table 11. Flow in the Grand Calumet River during the September 18-19, 1985, study were considerably different than that during the October 3-4, 1984, study. Flow in the East Branch was approximately 10 to 20 percent more than that measured during the previous study. More importantly, the flow in the West Branch was considerably greater than it had been during the October 1984 study (table 12), and there was no evidence of the flow reversals that had been observed during the October 1984 study. The amount of rainfall in the days preceding the September 1985 study was similar to that preceding the October 1984 study, however. The National Weather Service station at Hobart, Ind., reported no rainfall in the 7 days prior to the September 1985 study. (No data were reported for the weather station at Ogden Dunes for September 1985.)

Stage-discharge relations could not be developed at the three river sampling stations (C7A, C7B, and C8) because the range in stage was too small. Therefore, the average flow for the 24-hour period at these stations was calculated as the average of the 17 flow measurements made at the station. Flow at the stations upstream and downstream from the Indiana East-West Toll Road (C7A and C7B) averaged 59 and 60 ft^3/s, for the 24-hour period. Flow measured at Columbia Avenue (station C8) averaged 106 ft^3/s, about 7 ft^3/s greater than the sum of the HWTP effluent flow and that measured near the Indiana East-West Toll Road. There was no evidence of a source of raw sewage during the September 1985 survey as was found in this reach during the October 1984 survey. No other point source of flow was found in the reach between the HWTP and Columbia Avenue. It is possible that this difference is due entirely to measurement error. The difference is less than 7 percent of the average flow at Columbia Avenue (station C8) and slightly more than 10 percent of the average flow at the two upstream stations near the Indiana East-West Toll Road (C7A and C7B). These differences are within the conceivable range of measurement error given the difficulty of measuring unsteady flow conditions. The mass-balance technique used to estimate the flow balance from chloride, sulfate, and dissolved solids could not be used to verify the estimated 24-hour average flows because the concentrations were too similar at the four stations (table 13).

A summary of the tracer data is given in tables 14 (rhodamine WT) and 15 (lithium). The mass of lithium recovered at the station upstream from the Indiana East-West Toll Road (C7A) was 78 percent of that released. The tracer loss reflects the portion of flow that entered the lake from the West Branch. Eighty-seven percent of the lithium released was recovered downstream from the Indiana East-West Toll Road (station C7B). The increase in the mass of lithium recovered at this station is an indication that some but not all the lithium-dosed water that entered the small lake reentered the stream channel during the study. Approximately 13 percent of the lithium was retained in the lake. About another 7 percent was lost in the channel of the West Branch between the Indiana East-West Toll Road and Columbia Avenue (station C8) where 80 percent of the mass of the lithium released was recovered. The data for rhodamine WT showed a similar pattern although the percent recovery figures are smaller, probably reflecting adsorptive losses.

Table 11.--Flow measurements at river sampling stations in the Grand Calumet River basin, September 18-19, 1985

[All measurements by U.S. Geological Survey; measurements at station C9 were made in the culverts beneath Hohman Avenue; measurements at all other stations were made in the stream channel; ft^3/s, cubic foot per second; ft, foot; ft^2, square foot; n.a., not applicable]

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)	Average velocity (ft/s)	Average depth (ft)	Width (ft)	Area (ft^2)
C3	1	1150	1300	448	1.1	4.7	88	412
C4	1	1045	1105	540	1.6	4.0	82	332
C7A	1	1030	1055	53.8	0.4	2.1	65	136
C7A	2	1200	1235	60.5	.5	2.1	65	135
C7A	3	1333	1403	69.9	.5	2.2	65	142
C7A	4	1502	1532	72.3	.5	2.3	65	148
C7A	5	1635	1704	45.2	.3	2.2	65	142
C7A	6	1807	1838	56.3	.4	2.2	65	145
C7A	7	1933	2003	45.2	.3	2.1	65	137
C7A	8	2103	2133	48.4	.4	2.1	65	135
C7A	9	2234	2305	67.6	.5	2.2	65	145
C7A	10	0004	0036	58.2	.4	2.3	65	146
C7A	11	0136	0207	34.0	.2	2.2	65	144
C7A	12	0312	0343	61.3	.4	2.2	65	143
C7A	13	0439	0512	59.5	.4	2.2	65	142
C7A	14	0605	0638	63.8	.5	2.2	65	142
C7A	15	0734	0803	72.1	.5	2.2	65	142
C7A	16	0907	0936	67.2	.5	2.2	65	145
C7A	17	1033	1104	69.6	.5	2.2	65	144
			Average	59.1	0.4	2.2	65	142
C7B	1	1040	1140	38.7	0.2	2.1	83	178
C7B	2	1203	1240	60.1	.3	2.2	83	185
C7B	3	1334	1412	61.0	.3	2.4	83	196
C7B	4	1500	1543	66.6	.3	2.5	83	204
C7B	5	1631	1710	52.1	.3	2.4	83	201
C7B	6	1800	1843	61.9	.3	2.5	83	206
C7B	7	1930	2020	55.8	.3	2.6	83	214
C7B	8	2105	2154	58.7	.3	2.5	83	204
C7B	9	2235	2330	65.7	.3	2.5	83	207
C7B	10	0005	0050	63.2	.3	2.5	83	208
C7B	11	0135	0220	43.3	.2	2.5	83	211
C7B	12	0305	0352	57.7	.3	2.5	83	206
C7B	13	0435	0524	68.9	.3	2.5	83	208
C7B	14	0601	0642	66.8	.3	2.5	83	207
C7B	15	0730	0809	72.6	.4	2.5	83	205
C7B	16	0902	0942	67.0	.3	2.5	83	209
C7B	17	1033	1110	66.1	.3	2.5	83	206
			Average	60.4	0.3	2.5	83	203

Table 11.--Flow measurements at river sampling stations in the Grand Calumet River basin, September 18-19, 1985--Continued

Station ID	Measurement number	Beginning time	Ending time	Discharge (ft^3/s)	Average velocity (ft/s)	Average depth (ft)	Width (ft)	Area (ft^2)
C8	1	1005	1030	97.0	1.2	2.3	37	85
C8	2	1133	1201	97.6	1.2	2.3	37	84
C8	3	1258	1329	103	1.2	2.3	37	85
C8	4	1435	1503	109	1.2	2.4	37	88
C8	5	1605	1634	114	1.3	2.4	37	89
C8	6	1731	1802	112	1.3	2.4	37	89
C8	7	1902	1931	114	1.3	2.4	37	89
C8	8	2100	2130	104	1.2	2.3	37	87
C8	9	2230	2305	108	1.2	2.4	37	88
C8	10	0002	0033	110	1.3	2.4	37	88
C8	11	0130	0202	109	1.2	2.4	37	87
C8	12	0300	0329	105	1.2	2.3	37	86
C8	13	0430	0458	108	1.3	2.3	37	85
C8	14	0602	0633	105	1.2	2.3	37	85
C8	15	0733	0800	100	1.2	2.3	37	85
C8	16	0901	0929	107	1.2	2.3	37	86
C8	17	1030	1057	102	1.2	2.4	37	87
			Average	106	1.2	2.4	37	87
C9	1	1515	1615	101	n.a.	n.a.	n.a.	n.a.
C9	2	0930	1015	86.0	n.a.	n.a.	n.a.	n.a.
			Average	94.0	n.a.	n.a.	n.a.	n.a.

Table 12.--Comparison of flow in the Grand Calumet River basin, October 3-4, 1984, and September 18-19, 1985

[ft^3/s, cubic foot per second]

Station ID	River segment	Average flow October 3-4, 1984 (ft^3/s)	Average flow September 18-19, 1985 (ft^3/s)
C3	East	370	450
C4	East	490	540
C7A	West	15	59
C7B	West	--	60
C8	West	53	106
C9	West	47	94

Table 13.--Water-quality analyses for sampling stations in the West Branch Grand Calumet River, September 18-19, 1985

[mg/L, milligram per liter]

Station ID	Chloride (mg/L)	Sulfate (mg/L)	Dissolved solids (mg/L)
C7A	140	99	538
C7B	140	99	541
C8	140	130	615
HWTP	140	170	712

Table 14.--Rhodamine WT dye-tracer data, West Branch Grand Calumet River, September 18-19, 1985

[min, minute; min-μg/L, minutes-microgram per liter; ft^3/s, cubic foot per second; g, gram; 890 grams rhodamine WT dye released at Indianapolis Boulevard, RM 5.35, 0955 September 18, 1985]

Station ID	Elapsed time to leading edge of dye cloud (min)	Elapsed time to maximum dye concentration (min)	Area of time-concentration curve (min-μg/L)	Average streamflow during passage of dye (ft^3/s)	Mass of dye recovered (g)	Percentage of dye recovered
C7A	135	170	4,670	65	510	57
C7B	170	210	6,480	61	670	75
C8	260	320	3,260	112	620	70

Table 15.--Lithium-tracer data, West Branch Grand Calumet River, September 18-19, 1985

[min, minute; min-μg/L, minute-microgram per liter; ft^3/s, cubic foot per second; g, gram; 7900 grams lithium released at Indianapolis Boulevard, RM 5.35, 0955 September 18, 1985]

Station ID	Elapsed time to leading edge of lithium cloud (min)	Elapsed time to maximum lithium concentration (min)	Area of time-concentration curve (min-μg/L)	Average streamflow during passage of lithium (ft^3/s)	Mass of lithium recovered (g)	Percentage of lithium recovered
C7A	135	170	56,050	65	6,150	78
C7B	170	210	66,800	61	6,880	87
C8	260	320	33,550	112	6,350	80

The lack of complete recovery of the tracers does not necessarily conflict with the flow measurement data that indicated an increase and not a decrease in flow in the reach between the Indiana East-West Toll Road and Columbia Avenue (station C8). The difference in the mass of the tracers recovered at the three sampling stations (C7A, C7B, and C8) may be due in part to measurement and sampling errors. However, the data presented suggests that much of the tracer-dosed water was lost from the stream channel into the Lake. Further, stage data suggest that some of the dosed water could have been lost to the ground-water system. If the tracer data are accurate, another possible reason for the disagreement could be the duration of the passage of the tracers. Most of the mass of the tracers had passed each of the three sampling stations within 4 to 10 hours after release of tracers into the stream. The time of passage of the tracer cloud at each sampling station was only a few hours. The tracer data are not representative of the entire 24-hour period as are the flow data. The difference between the conclusions drawn from the tracer and streamflow data may mean that a good connection exists between the stream channel and the shallow ground-water system such that relatively rapid exchanges of water through the streambed are possible. Another possibility would be bank storage and subsequent release of water in relation to the water-level elevation in the river. Water-elevation data collected downstream of the Indiana East-West Toll Road (station C7B) support these possibilities. The river stage was highest near the beginning of the study coinciding with the passage of the tracers (fig. 65). If water was being lost from the channel, it would be associated with higher river stages.

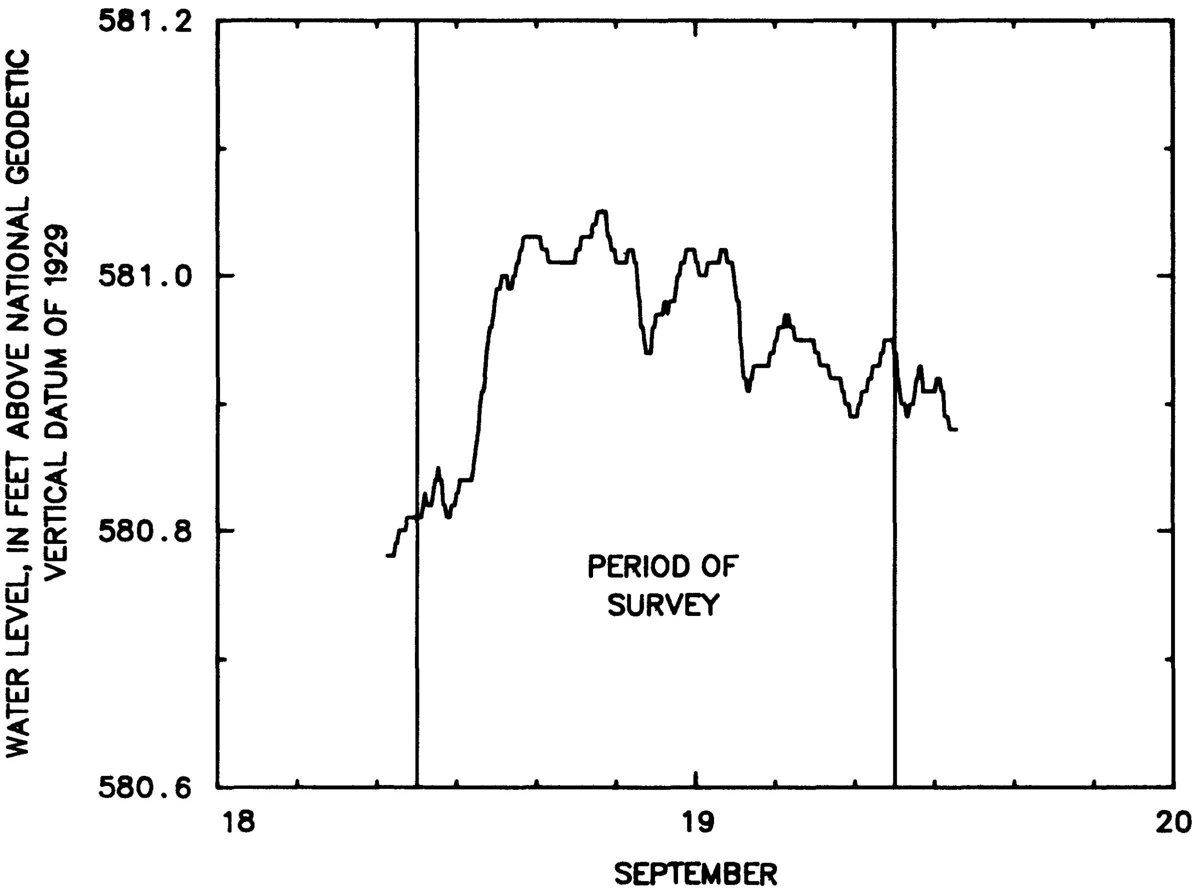


Figure 65.--Water-level elevations near the Indiana East-West Toll Road (station C7B), West Branch Grand Calumet River, September 18-19, 1985.