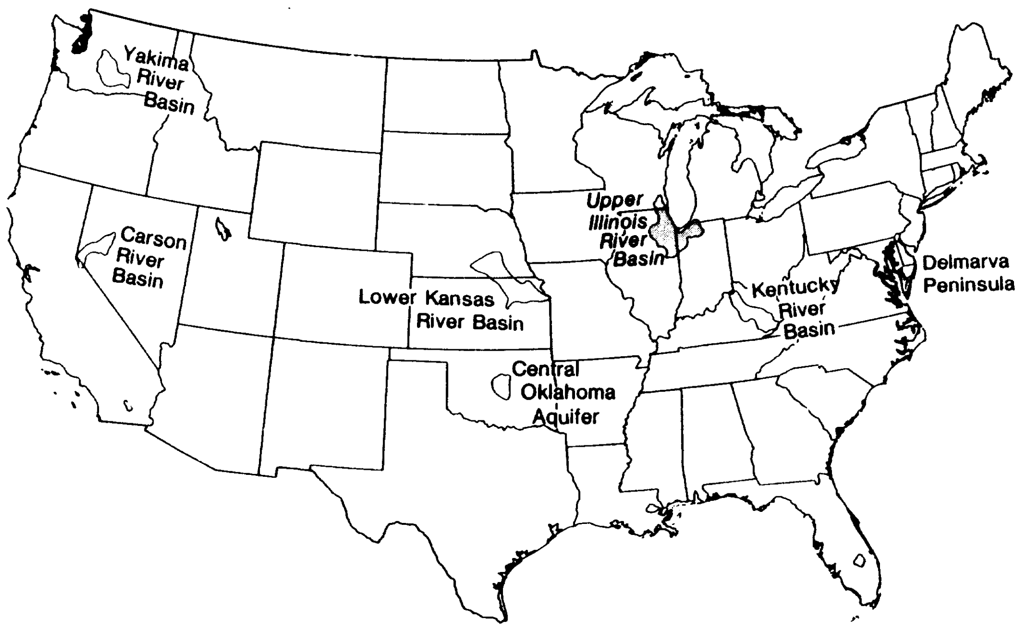
RELATIONS OF CHANGES IN WASTEWATER-TREATMENT PRACTICES TO CHANGES IN STREAM-WATER QUALITY DURING 1978-88 IN THE CHICAGO AREA, ILLINOIS, AND IMPLICATIONS FOR REGIONAL AND NATIONAL WATER-QUALITY ASSESSMENTS

by Paul J. Terrio



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CONTENTS

Abstract 1
Introduction 2
  Purpose and Scope 3
  Description of Wastewater-Treatment Plants 3
  Acknowledgments 3
Data Used in Analysis 7
  Documentation of Changes at Wastewater-Treatment Plants 7
  Wastewater-Quality Data 7
  Stream-Water-Quality Data 7
  Stream-Biology Data 9
Statistical Methods of Data Analysis 10
Description of Changes at Wastewater-Treatment Plants 11
Relation of Changes in Wastewater-Treatment Practices to Changes in Stream-Water Quality 12
  Calumet Water Reclamation Plant 14
    Major Changes in Wastewater-Treatment Practices 15
    Streamflow and Precipitation 17
    Cessation of Chlorination 17
    Expansion of the Treatment Plant 21
    Implementation of the Tunnel and Reservoir Plan and Improvements in Aeration 23
    Changes in Biotic Integrity 31
    Observations from the Analysis of Changes at the Calumet Water Reclamation Plant 36
  Stickney Water Reclamation Plant 36
  North Side Water Reclamation Plant 38
  James C. Kirie Water Reclamation Plant 43
  John E. Egan Water Reclamation Plant 44
Implications of Study Results for Regional and National Water-Quality Assessments 48
Summary 52
References 54
Glossary 56

FIGURES

1-5. Maps showing:
  1. Location of the upper Illinois River Basin and Cook County, Ill. 4
  2. Locations of the five wastewater-treatment plants described in this report 5
  3. Locations of wastewater-treatment plants operated by the Metropolitan Water Reclamation District of Greater Chicago and associated stream-monitoring sites 8
  4. Approximate locations of completed systems of the Tunnel and Reservoir Plan 13
  5. Locations of the Calumet Water Reclamation Plant and associated stream-monitoring sites 16
6-14. Graphs showing:
  6. Annual precipitation totals at Midway Airport, 1978-88, and treatment periods at the Calumet Water Reclamation Plant used for this study 18
  7. Annual mean discharges for the Little Calumet River at South Holland, Ill., calendar years 1978-88, and treatment periods at the Calumet Water Reclamation Plant used for this study 18
  8. Distribution of densities of fecal coliform bacteria in effluent from the Calumet Water Reclamation Plant and at associated stream-monitoring sites for treatment periods before and after the cessation of chlorination in August 1983 20
  9. Concentrations of total ammonia nitrogen in effluent from the Calumet Water Reclamation Plant and at associated stream-monitoring sites for treatment periods before and after the expansion of the treatment plant in September 1984 22
  10. Cumulative relative frequency distribution of concentrations of selected constituents in effluent from the Calumet Water Reclamation Plant, 1985-88 25

11. Seasonal variations of smoothed concentrations for selected constituents in effluent from the Calumet Water Reclamation Plant for treatment periods before and after the implementation of the Tunnel and Reservoir Plan 26
12. Quantile-quantile plots of concentrations of selected constituents in effluent from the Calumet Water Reclamation Plant for treatment periods before and after the implementation of the Tunnel and Reservoir Plan 27
13. Quantile-quantile plots of concentrations of selected constituents in influent to the Calumet Water Reclamation Plant for treatment periods before and after the implementation of the Tunnel and Reservoir Plan 32
14. Cumulative relative frequency distribution of concentrations of selected constituents at stream-monitoring site S-2 for treatment periods before and after the implementation of the Tunnel and Reservoir Plan 33
15. Map showing the locations of the Calumet Water Reclamation Plant and associated fish-sampling sites 34
16-19. Graphs showing:
16. Index of Biotic Integrity scores for fish-sampling sites associated with the Calumet Water Reclamation Plant for treatment periods before the cessation of chlorination and before and after the implementation of the Tunnel and Reservoir Plan 35
17. Cumulative relative frequency distribution for selected constituents in effluent from the Stickney Water Reclamation Plant for treatment periods before and after the implementation of the Tunnel and Reservoir Plan 39
18. Cumulative relative frequency distribution of ammonia nitrogen and suspended solids concentrations at stream-monitoring site S-7 for treatment periods before and after the implementation of the Tunnel and Reservoir Plan 40
19. Cumulative relative frequency distribution of ammonia nitrogen and suspended solids concentrations at stream-monitoring site S-8 for treatment periods before and after the implementation of the Tunnel and Reservoir Plan 41

TABLES

1. Background information for five wastewater-treatment plants operated by the Metropolitan Water Reclamation District of Greater Chicago 6
2. Typical concentrations of selected constituents in wastewater after various levels of treatment 6
3. Selected water-quality properties and constituents monitored in effluents and streams by the Metropolitan Water Reclamation District of Greater Chicago and the Illinois Environmental Protection Agency 9
4. Location of stream-monitoring sites in the greater Chicago area 10
5. Major changes in wastewater-treatment practices at wastewater-treatment plants operated by the Metropolitan Water Reclamation District of Greater Chicago, 1978-88 14
6. Selected information from National Pollutant Discharge Elimination System permits for the Calumet Water Reclamation Plant, 1978-88 15
7. Summary statistics for densities of fecal coliform bacteria in effluent from the Calumet Water Reclamation Plant and at associated stream-monitoring sites during treatment periods before and after the cessation of chlorination in August 1983 19
8. Results of the Wilcoxon-Mann-Whitney rank-sum test for densities of fecal coliform bacteria in effluent from the Calumet Water Reclamation Plant and at associated stream-monitoring sites for treatment periods before and after the cessation of chlorination in August 1983 19
9. Summary statistics for concentrations of total ammonia nitrogen in effluent from the Calumet Water Reclamation Plant and at associated stream-monitoring sites during treatment periods before and after expansion of the treatment plant in September 1984 23
10. Results of the Wilcoxon-Mann-Whitney rank-sum test for concentrations of total ammonia nitrogen in effluent from the Calumet Water Reclamation Plant and at associated stream-monitoring sites for treatment periods before and after expansion of the treatment plant in September 1984 23
11. Availability of and potential improvements to wastewater-treatment information for the Calumet Water Reclamation Plant and associated stream-monitoring sites 37

12. Summary statistics for densities of fecal coliform bacteria in effluent from the Stickney Water Reclamation Plant and at associated stream-monitoring sites during treatment periods before and after the cessation of chlorination in April 1984 38
13. Summary statistics for densities of fecal coliform bacteria in effluent from the North Side Water Reclamation Plant and at associated stream-monitoring sites during treatment periods before and after the cessation of chlorination in March 1984 42
14. Results of the seasonal Kendall trend test for measurements of selected properties and concentrations of selected constituents in effluent from the North Side Water Reclamation Plant and at associated stream-monitoring sites, 1978-88 43
15. Summary statistics for measurements of selected properties and concentrations of selected constituents in effluent from the James C. Kirie Water Reclamation Plant and at associated stream-monitoring sites during treatment periods before and after the construction of the treatment plant 45
16. Results of the Wilcoxon-Mann-Whitney rank-sum test for measurements of selected properties and concentrations of selected constituents at stream-monitoring sites associated with the James C. Kirie Water Reclamation Plant for treatment periods before and after the construction of the treatment plant 48
17. Summary statistics for measurements of selected properties and concentrations of selected constituents in effluent from the John E. Egan Water Reclamation Plant and at associated stream-monitoring sites, 1978-88 49
18. Results of the seasonal Kendall trend test for measurements of selected properties and concentrations of selected constituents in effluent from the John E. Egan Water Reclamation Plant and at associated stream-monitoring sites, 1978-88 50

CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
inch (in.)	0.0254	meter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per second (ft/s)	0.3048	meter per second
gallon (gal)	3.785	liter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	3,785	cubic meter per day

Abbreviated water-quality units used in this report:

colonies per 100 milliliters (col/100 mL)
milligrams per liter (mg/L)

Relations of Changes in Wastewater-Treatment Practices to Changes in Stream-Water Quality During 1978-88 in the Chicago Area, Illinois, and Implications for Regional and National Water-Quality Assessments

By Paul J. Terrio

Abstract

A study was performed in the upper Illinois River Basin to determine (1) relations among changes in wastewater-treatment practices and stream-water quality on the basis of available information and (2) the limitations of available information for this purpose. Five large wastewater-treatment plants operated by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) were studied because of the potential effect of these treatment plants on stream-water quality and because of the availability of extensive computerized wastewater-quality and stream-water-quality data for 1978-88. Major changes in treatment practices were identified, and statistical tests were used to determine significant differences in effluent quality and stream-water quality from periods before and after the changes were implemented.

Two major changes in wastewater-treatment practices–the cessation of chlorination and the implementation of MWRDGC's Tunnel and Reservoir Plan–were identified at the three largest treatment plants. Chlorination was discontinued at these three treatment plants because the receiving streams are designated as secondary-contact waters and the benefits of chlorination were limited. The Tunnel and Reservoir Plan was designed to capture and route overflows from combined sewers through the treatment plants, thereby decreasing the quantity of untreated overflows discharged to streams. Other changes and upgrades, such as improved aeration and the construction of additional treatment units, also were made at some of these treatment plants.

After the cessation of chlorination, increases in densities of fecal coliform bacteria were found in the effluents and at stream-monitoring sites as far as 6.8 miles downstream. At the Calumet Water Reclamation Plant, median densities of fecal coliform bacteria increased from 3,100 to 1,200,000 colonies per 100 milliliters.

After the implementation of the Tunnel and Reservoir Plan, various changes in effluent and stream-water quality were noted, but few similarities were found between treatment plants. For example, at the Calumet Water Reclamation Plant, decreases in concentrations of most constituents were identified. At the Stickney Water Reclamation Plant, however, increases in concentrations of biochemical oxygen demand, ammonia, and cyanide and decreases in concentrations of dissolved oxygen were observed.

Effects from other types of changes were analyzed at two of the treatment plants. The James C. Kirie Water Reclamation Plant, which began operation after stream-water-quality data had been collected for several years, provided an opportunity to evaluate the effects of the addition of effluent on the water quality of the receiving stream. No major changes in treatment practices were made at the John E. Egan Water

Reclamation Plant, but a trend test was used to determine relations between trends in effluent and stream-water quality.

The available water-quality data were generally suitable for this study and were more comprehensive than data from most monitoring programs. The results of this study, however, identified some needed enhancements to increase the usefulness of the monitoring data for additional purposes. Paramount is the need to identify the evaluation of changes in wastewater-treatment practices on stream-water quality as a clearly defined monitoring goal. Useful enhancements identified from this study apply to monitoring programs nationwide and include collecting streamflow data at all stream-monitoring sites, improving records of changes in wastewater-treatment practices, establishing comparable sample-collection and analytical methods at all monitoring sites and between monitoring agencies, and designing monitoring programs to specifically evaluate effects of wastewater-treatment practices on stream-water quality. Streamflow data associated with stream-water-quality data would facilitate mass-loading analyses, which is required for understanding causal relations and for identifying contributions from point and nonpoint sources. Designing applicable monitoring programs may involve converting from time-composited effluent monitoring to discharge-composited effluent monitoring, collecting influent-quality data, and implementing a more appropriate and (or) efficient list of constituents to be sampled.

INTRODUCTION

Concern over the effects of effluents discharged to the Nation's streams from wastewater-treatment plants has been expressed since the early 1900's. In an effort to curtail the degradation of receiving waters and to restore water quality to acceptable levels, the Federal Water Pollution Control Act (subsequently titled the Clean Water Act) (U.S. Environmental Protection Agency, 1979) required the reduction of municipal and industrial pollution. To assist this effort, the U.S. Environmental Protection Agency (USEPA) initiated the Construction Grant Program to help finance improvements to municipal sewer systems and wastewater-treatment plants. Federal, State, and local governments and industry have contributed significant resources to construct and upgrade treatment plants nationwide. The USEPA indicated that 6,248 municipal treatment plants in the United States (40.1 percent of the total number) continued to cause water-quality or public-health problems (U.S. Environmental Protection Agency, 1989). Expenditures are expected to continue into the future as efforts are made to address these concerns. An estimated $83.5 billion will be required to meet the needs of the population for the year 2008 (U.S. Environmental Protection Agency, 1989). Recent Federal stormwater-management regulations will necessitate additional pollution-abatement projects requiring additional financial resources.

Improvements to treatment plants typically are evaluated on the basis of the ability to meet effluent water-quality limits mandated in regulatory permits. Relatively little effort has been made to evaluate changes in wastewater-treatment practices in terms of the water quality of the receiving streams using available data. Several studies have examined relations between changes in wastewater-treatment practices and streamwater quality (Crawford and Wangsness, 1991, 1992) or biological community (Trauben and Olive, 1983; Rabeni and others, 1985; and Thornley, 1985). Studies that have not included additional monitoring or data-collection components have commonly had limited success in determining and quantifying relations. In light of the prospect for future changes in wastewater-treatment practices, it is important to evaluate the effects of past efforts, whether beneficial or detrimental, in terms of changes in stream-water quality. Unfortunately, few existing ambient monitoring programs provide all the data needed for a complete retrospective assessment that quantifies changes in stream-water quality resulting from changes in wastewater-treatment practices. Such assessments, however, are of local and national importance.

In 1986, the U.S. Geological Survey (USGS) began the National Water-Quality Assessment (NAWQA) program. The goals of the NAWQA program are as follows:

1. Provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources.

2. Define long-term trends (or lack of trends) in water quality.
3. Identify, describe, and explain, as possible, the major factors that affect observed water-quality conditions and trends.

Because treatment plants are located throughout the United States, it is necessary for the NAWQA program to determine the effects of treatment-plant effluents on stream-water quality and ecosystem health. To this end, a strategy to evaluate the effects of treatment-plant effluents on stream-water quality in the NAWQA study units has been designed. In the development of this strategy, studies were done in the upper Illinois River Basin to (1) evaluate the availability and suitability of municipal wastewater information for use in a national water-quality assessment, (2) use available information to determine changes in wastewater and stream-water quality that resulted from changes in wastewater-treatment practices, and (3) determine the suitability of available monitoring data to evaluate the effects of changes in wastewater-treatment practices on stream-water quality.

The upper Illinois River Basin served as a pilot-project study area for the NAWQA program and included the study area for this report. The upper Illinois River Basin encompasses 10,949 mi^2 and envelops the greater Chicago metropolitan area (fig. 1). Approximately 13 percent of the land use in the upper Illinois River Basin is urban. Cook County, Ill. (shaded in fig. 1), is extensively urbanized. All wastewaters generated in Cook County are treated by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC), which operates seven large treatment plants. Five of these treatment plants were chosen for this study because of (1) the potential effects of these treatment plants on the water quality of the receiving streams, (2) the availability of computerized wastewater and stream-monitoring data for 1978-88, and (3) the quality and comprehensiveness of the monitoring data.

Purpose and Scope

This report (1) describes the relations among changes in wastewater-treatment practices and changes in stream-water quality on the basis of available information, (2) discusses the limitations of the available information for this purpose, and (3) discusses the implications of the findings from this study to regional and national water-quality assessments.

This report includes analyses of available wastewater-monitoring data for 5 large wastewater-treatment plants operated by the MWRDGC and 16 associated stream-monitoring sites for 1978-88. The wastewater-treatment plants discussed in this report are the Calumet, Stickney, North Side, James C. Kirie, and John E. Egan Water Reclamation Plants (fig. 2). A detailed discussion is presented for the Calumet Water Reclamation Plant. Differences in wastewater quality and stream-water quality from periods before and after changes in wastewater-treatment practices were evaluated by means of statistical analyses. To the extent possible, relations among changes in wastewater quality and changes in stream-water quality were determined.

Description of Wastewater-Treatment Plants

The MWRDGC operates seven large wastewater-treatment plants in Cook County, Ill., that serve the greater Chicago area. These treatment plants receive wastewater from 5.1 million residents and industrial discharges with a population equivalent of 4.5 million people (Metropolitan Sanitary District of Greater Chicago, [1985?]). This report focuses on five of the treatment plants–the Calumet, Stickney, North Side, James C. Kirie, and John E. Egan Water Reclamation Plants (fig. 2). The design maximum discharges for the five treatment plants range from 50 Mgal/d for the John E. Egan Water Reclamation Plant to 1,440 Mgal/d for the Stickney Water Reclamation Plant. All five treatment plants discharge effluent to streams that eventually contribute to the flow of the Des Plaines River. The Stickney, Calumet, and North Side plants provide secondary treatment, whereas the James C. Kirie and John E. Egan plants provide tertiary treatment. Background information for the five treatment plants is presented in table 1. Detailed descriptions of the individual treatment plants are given in subsequent sections. A glossary of wastewater-treatment terminology is included at the back of this report. Typical concentrations of selected constituents in wastewater after various levels of treatment are presented in table 2.

Acknowledgments

The author thanks the staff of the Metropolitan Water Reclamation District of Greater Chicago for

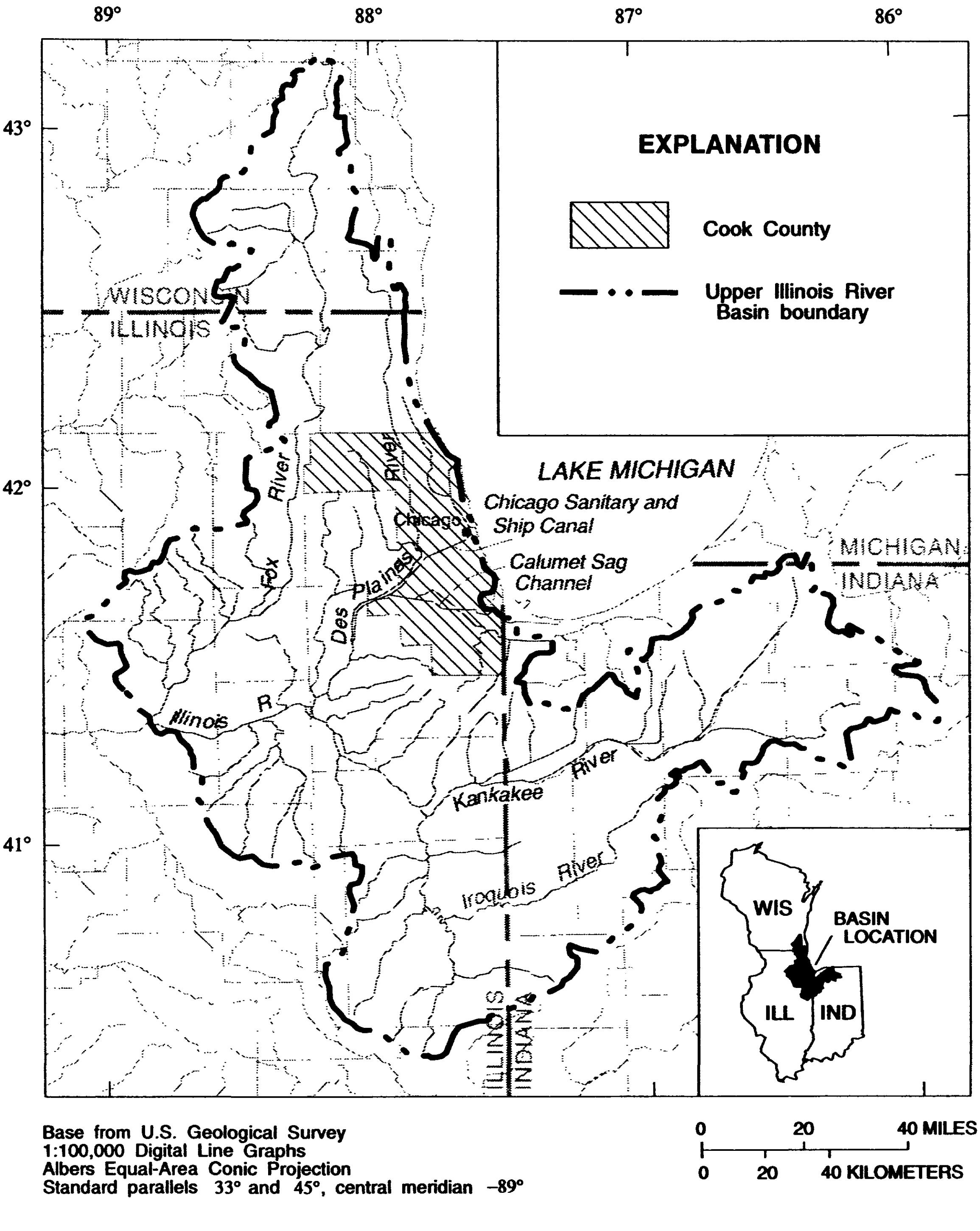


Figure 1. Location of the upper Illinois River Basin and Cook County, Ill.

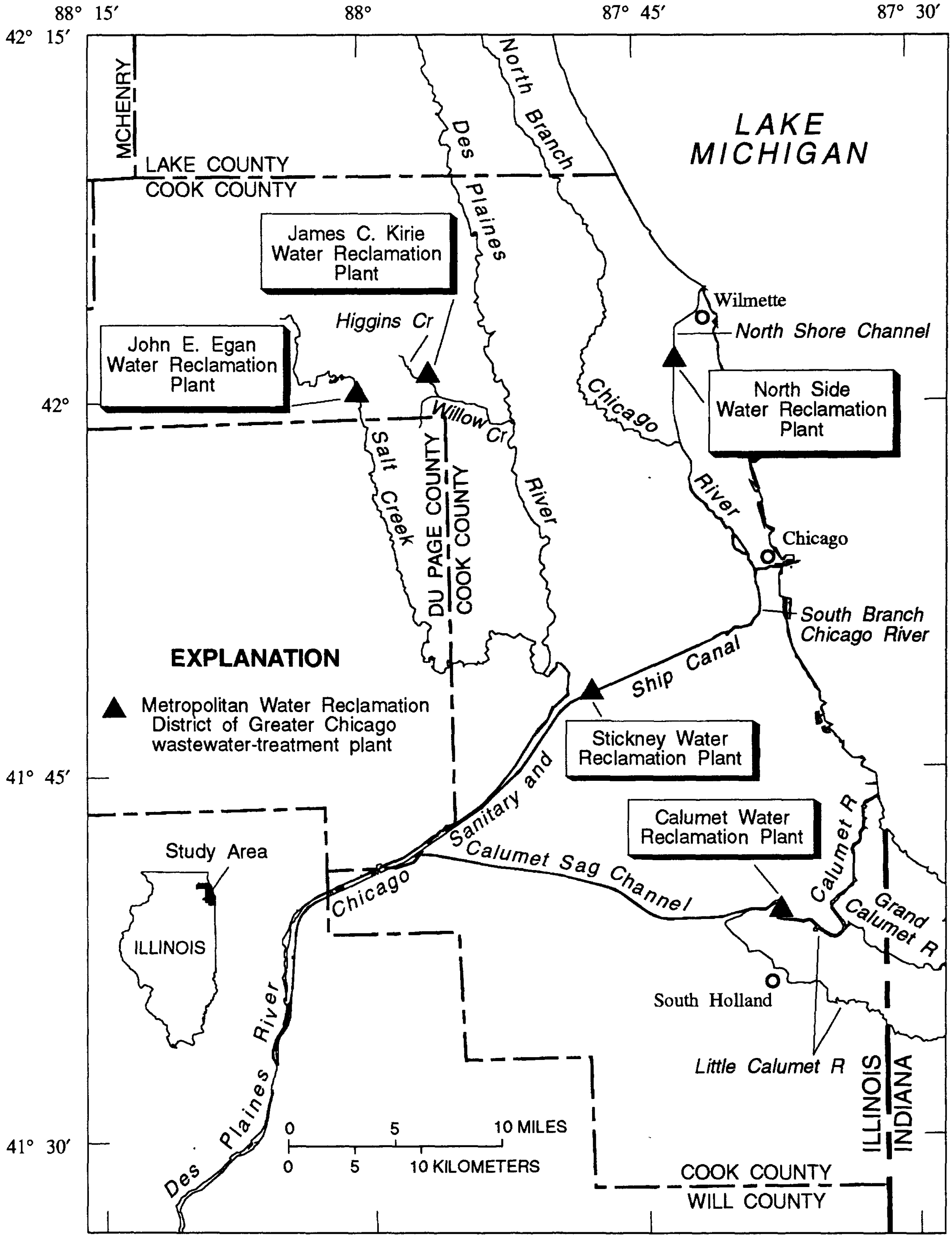


Figure 2. Locations of the five wastewater-treatment plants described in this report.

Table 1. Background information for five wastewater-treatment plants operated by the Metropolitan Water Reclamation District of Greater Chicago
[Mgal/d, million gallons per day]

Wastewater-treatment plant	Period of water-quality record[1]	Design average discharge (Mgal/d)	Design maximum discharge (Mgal/d)	Mean discharge, 1978-88 (Mgal/d)	Receiving water and (classification[2])	Level of treatment
Stickney	1978-88	1,200	1,440	812	Chicago Sanitary and Ship Canal (secondary contact)	Secondary
Calumet	1978-88	354	430	234	Little Calumet River (secondary contact)	Secondary
North Side	1978-88	333	450	287	North Shore Channel (secondary contact)	Secondary
James C. Kirie	1980-88	72	110	34	Higgins Creek (general use)	Tertiary
John E. Egan	1978-88	30	50	21	Salt Creek (general use)	Tertiary

[1]Period of record used for this report.

[2]Secondary contact, incidental or accidental contact with the water with minimal risk of ingestion of appreciable quantities; general use, suitable for aquatic life, agricultural, industrial and recreational uses in which there is prolonged and intimate contact with the water involving considerable risk of ingesting water in quantities sufficient to pose a significant health hazard.

Table 2. Typical concentrations of selected constituents in wastewater after various levels of treatment
[mg/L, milligrams per liter; <, less than. Adapted from Gianessi and Peskin (1984), Viessman and Hammer (1985), and Metcalf and Eddy (1991)]

Level of treatment	Biochemical oxygen demand (mg/L)	Suspended solids (mg/L)	Chemical oxygen demand (mg/L)	Total nitrogen as N (mg/L)	Ammonia nitrogen as N (mg/L)	Phosphorus as P (mg/L)
Untreated domestic wastewater	100-400	100-350	250-1,000	20-85	12-50	4-15
Primary treatment	50-200	50-150	100- 400	20-60	15-25	6-15
Secondary treatment	15- 25	20- 30	40- 80	20-60	15-25	6-15
Tertiary treatment	4- 10	<5- 10	30- 70	3-35	<1-25	<1-12

providing data and information necessary for this assessment. Individuals whose input was vital to the study include Richard Lanyon, Irwin Polls, Eugene Bogusch, and Samuel Dennison.

DATA USED IN ANALYSIS

Four types of data and information were required to relate changes in wastewater-treatment practices to changes in stream-water quality.

1. Documentation of operational changes at the treatment plants was needed to establish a chronology of changes in wastewater-treatment practices.
2. Time-series discharge and water-quality data for treatment-plant influents and effluents were needed to determine changes in wastewater quality.
3. Time-series streamflow and water-quality data for sites upstream and downstream from treatment plants were required to identify changes in stream-water quality.
4. Biological data for sites upstream and downstream from the treatment plants were needed to evaluate changes in aquatic biological communities related to changes in wastewater-treatment practices.

Documentation of Changes at Wastewater-Treatment Plants

The MWRDGC provided annual summary reports that documented operational changes at the five treatment plants. In addition, communication with MWRDGC personnel provided information regarding specific operational changes, equipment upgrades, and pertinent dates. Between 1978 and 1988, several changes and upgrades were made at the treatment plants. Some of these changes required extended periods to complete, and a few changes were implemented simultaneously.

Wastewater-Quality Data

With the exception of the James C. Kirie plant, computerized influent- and effluent-quality and effluent-discharge data were available for all five treatment plants for 1978-88. Records for the James C. Kirie plant began in 1980, the year the treatment plant began operation. Data included monthly mean values for 1978-81 and daily values for 1982-88. The daily data were converted to monthly mean data and appended to the 1978-81 data to form a complete 1978-88 data set of monthly mean values.

The MWRDGC did comprehensive analyses to monitor the quality of influent and effluent for the five treatment plants. The major water-quality categories monitored included physical properties, nutrients, trace metals, solids, and major ions. Samples also were analyzed for fecal coliform bacteria, oxygen demand, cyanide, phenol, and oil and grease. Some of the specific constituents monitored by the MWRDGC are listed in table 3. Because concentrations of trace elements and major ions in effluent typically met applicable water-quality standards, and because municipal wastewater-treatment processes are not designed to remove such constituents, this assessment was limited to constituents typically associated with effluents from wastewater-treatment plants. Unless otherwise indicated, concentrations in this report refer to the total amount of the constituent present in all phases (solid, dissolved, or suspended; elemental or combined) including all oxidation states. In this report, concentrations of nitrogen species are expressed as elemental nitrogen, and concentrations of phosphorus are expressed as elemental phosphorus. All of the analytical tests for the wastewater-monitoring program were done at the MWRDGC laboratory according to methods documented by the American Public Health Association and others (1985).

Stream-Water-Quality Data

Stream-water-quality data were collected by the MWRDGC and the Illinois Environmental Protection Agency (IEPA). These monitoring programs provided water-quality data for sites upstream and downstream from the effluent-discharge points of the treatment plant. In some instances, several sites were located at various distances downstream from the treatment plants. The stream-monitoring sites used for this analysis are listed in table 4, and their locations and proximities to the treatment plants are shown in figure 3.

Monitoring sites upstream from effluent-discharge points provided data on ambient stream-water-quality conditions. Monitoring sites downstream

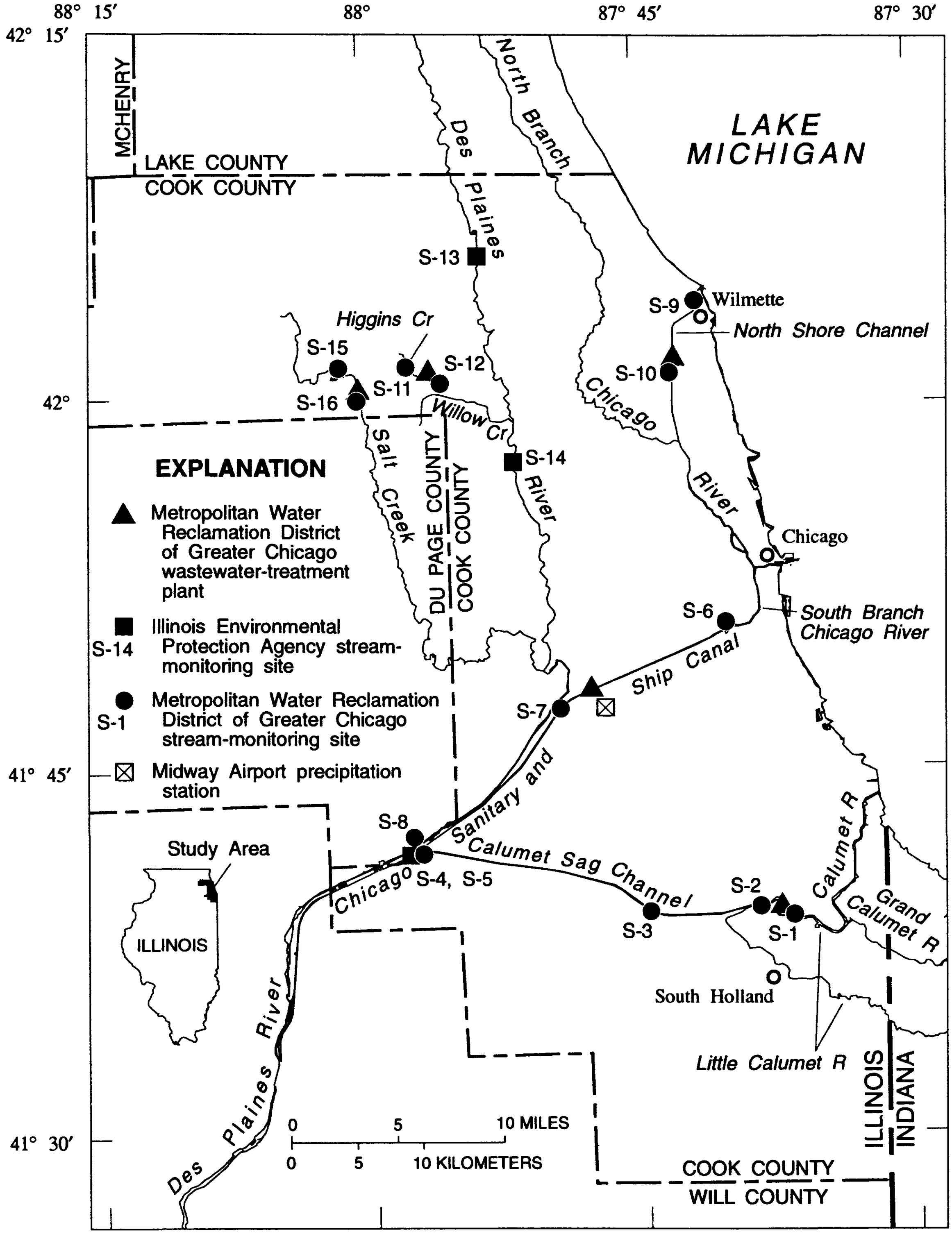


Figure 3. Locations of wastewater-treatment plants operated by the Metropolitan Water Reclamation District of Greater Chicago and associated stream-monitoring sites.

Table 3. Selected water-quality properties and constituents monitored in effluents and streams by the Metropolitan Water Reclamation District of Greater Chicago and the Illinois Environmental Protection Agency
[MWRDGC, Metropolitan Water Reclamation District of Greater Chicago; IEPA, Illinois Environmental Protection Agency; X, property or constituent is included in the agency's monitoring program; --, not monitored]

Property or constituent[1]	MWRDGC Effluent	MWRDGC Stream	IEPA stream only
Physical, chemical, and biological properties			
Discharge	X	--	X
Specific conductance	X	--	X
pH	X	X	X
Temperature	--	X	X
Turbidity	--	X	X
Dissolved oxygen	X	X	X
Fecal coliform bacteria	X	X	X
Alkalinity	--	X	X
Oxygen demand			
Chemical oxygen demand	X	X	X
Biochemical oxygen demand	X	X	--
Major ions			
Calcium	--	X	X
Magnesium	--	X	X
Sulfite	X	--	--
Sulfate	X	X	X
Chloride	X	X	X
Fluoride	X	X	X
Solids			
Total dissolved solids	--	X	--
Total solids	X	X	--
Suspended solids	X	X	X
Volatile suspended solids	X	--	X
Nutrients			
Nitrite plus nitrate nitrogen	--	X	X
Ammonia nitrogen	X	X	X
Kjeldahl nitrogen	X	X	X
Organic nitrogen	--	X	X
Phosphorus	X	X	X
Trace metals			
Barium	X	X	X
Beryllium	X	--	X
Cadmium	X	X	X
Chromium	X	X	X
Copper	X	X	X
Iron	X	X	X
Lead	X	X	X
Manganese	X	X	X
Mercury	X	X	X
Nickel	X	X	X
Silver	X	X	X
Zinc	X	X	X
Other			
Arsenic	X	X	X
Cyanide	X	X	X
Oil and grease	X	X	X
Phenol	X	X	X
Selenium	X	X	--

[1]Analyses may determine total, total recoverable, suspended, or dissolved concentrations.

from effluent-discharge points provided data used to describe the effects of the treatment-plant effluents on stream-water quality and the persistence of these effects downstream.

Stream-water-quality samples were collected monthly by the MWRDGC in a stainless-steel bucket lowered 3 ft below the surface at midchannel. Some of the specific constituents analyzed for in the MWRDGC stream-monitoring program also are listed in table 3. As with the effluent data, all stream-water-quality samples collected by the MWRDGC were analyzed in accordance with methods documented by the American Public Health Association and others (1985).

The IEPA operates a network of water-quality-monitoring stations throughout the State. Water-quality data collected at the IEPA station on the Calumet Sag Channel were used in the assessment of the Calumet Water Reclamation Plant. Data from two of the IEPA sites were used in evaluating the effect of the effluent from the James C. Kirie plant on stream-water quality of the Des Plaines River.

The sample-collection methods used by the IEPA differed significantly from those practiced by the MWRDGC. The IEPA used depth-, width-, and flow-integrating techniques to collect most samples. The resulting composite samples were considered representative of water-quality conditions of the entire stream. More specific information regarding the field methods used by the IEPA can be found in IEPA (1987b).

IEPA samples were collected approximately every 6 weeks. Samples were analyzed at IEPA laboratories for the constituents listed in table 3, although some sites were sampled for additional constituents. (See IEPA (1987a) for descriptions of the analytical methodologies used at the IEPA laboratories.)

Stream-Biology Data

Numerous biological sampling programs have been done in the upper Illinois River Basin during the last two decades. Unfortunately, data collected through these programs were intended for specific purposes, and individual sites generally were not sampled for more than 3 consecutive years. Disparate sampling strategies and methods were used, and these differences limited the usefulness of data collected from various sites or by different agencies. Consequently, it could not be determined whether indicated

Table 4. Location of stream-monitoring sites in the greater Chicago area
[MWRDGC, Metropolitan Water Reclamation District of Greater Chicago; IEPA, Illinois Environmental Protection Agency]

Map reference number (fig. 3)	Location	Monitoring agency
S- 1	Little Calumet River at Indiana Avenue	MWRDGC
S- 2	Little Calumet River at Halsted Street	MWRDGC
S- 3	Calumet Sag Channel at Cicero Avenue	MWRDGC
S- 4	Calumet Sag Channel at State Highway 83	MWRDGC
S- 5	Calumet Sag Channel at Sag Bridge, Ill.	IEPA
S- 6	South Branch Chicago River at Damen Avenue	MWRDGC
S- 7	Chicago Sanitary and Ship Canal at Harlem Avenue	MWRDGC
S- 8	Chicago Sanitary and Ship Canal at State Highway 83	MWRDGC
S- 9	North Shore Channel at Central Road	MWRDGC
S-10	North Shore Channel at Touhy Avenue	MWRDGC
S-11	Higgins Creek at Elmhurst Road	MWRDGC
S-12	Higgins Creek at Wille Road	MWRDGC
S-13	Des Plaines River at Des Plaines, Ill.	IEPA
S-14	Des Plaines River at Schiller Park, Ill.	IEPA
S-15	Salt Creek at Higgins Road	MWRDGC
S-16	Salt Creek at Arlington Heights Road	MWRDGC

changes in the data actually were due to changes in the aquatic biological community or due to changes in methods, strategy, or location.

Fish-community-assemblage data for 1974-88 were available from the MWRDGC. The strategy used by the MWRDGC for monitoring stream biological conditions changed during 1974-88, and the number and locations of sampling sites also changed; however, the data could be used for some analyses. The Index of Biotic Integrity (IBI) was developed to characterize the biological integrity of midwestern streams (Karr and others, 1986). IBI scores, which were computed by the MWRDGC for samples collected as part of their program, provided a method to assess changes upstream and downstream from the treatment plants.

STATISTICAL METHODS OF DATA ANALYSIS

The initial step on this assessment was to examine documentation of operational changes and upgrades at the treatment plants and to identify major changes in wastewater-treatment practices. On the basis of these changes, periods of consistent treatment practices (hereafter referred to as "treatment periods") were identified. Effluent-quality data from chronologically adjacent treatment periods were analyzed for significant differences. If any significant changes in effluent quality were found, stream-water-quality data were analyzed to determine whether there were any corresponding changes. Finally, relations between changes in wastewater quality and changes in stream-water quality were evaluated.

Several statistical methods were used in the assessments to determine changes in effluent and stream-water quality. For 1982-88, monthly median values were calculated from daily values for use in the statistical tests. Summary statistics (percentiles) were calculated for the data from each treatment period. These percentiles provided a means to show the general magnitude of constituent concentrations, evaluate the relative magnitude of observed changes, and verify changes indicated by other statistical and graphical analyses. Concentrations reported as less than the detection limit were set to a value of zero in calculating the percentiles, but percentile values of zero are reported as less than the respective detection limits for the particular constituents.

The Wilcoxon-Mann-Whitney rank-sum test was used to determine significant differences in effluent concentrations and stream concentrations between different treatment periods. The Wilcoxon-Mann-Whitney rank-sum test is a nonparametric test that calculates the probability that two independent samples are from the same population. The test uses the ranks of the values rather than the actual values. A level of significance of 0.10 was used to determine if a change was statistically significant. A complete description of the Wilcoxon-Mann-Whitney rank-sum test is provided by Iman and Conover (1983).

Boxplots were used to graphically summarize and display data characteristics and to provide a visual means of comparing data from different periods or locations. Boxplots show the magnitude of the data set, the variation or spread of the data set, the skewness of the data set, and the presence of outlying values. The center line of a boxplot is drawn at the median value of the data set. The upper and lower ends of the box represent the upper and lower quartiles, or 75th and 25th percentiles, respectively. Fifty percent of the data fall between these quartiles, and this range is known as the interquartile range. Whiskers extend to the smallest and largest data values within one step (a distance of 1.5 times the interquartile range) from the ends of the box. Data greater than one step but less than two steps beyond the box are labeled as outside values and are plotted as asterisks; data farther than two steps beyond the box are called detached values and are plotted as open circles.

Quantile-quantile (Q-Q) plots compare the distributions and attributes of two data sets. Comparisons can be made between quantiles from a data set and the normal distribution quantiles or between quantiles of two data sets. In this report, Q-Q plots were used to compare two data sets with an equal number of data, and the Q-Q plots are simply plots of matched pairs of ranked data from each data set. Although the data were paired using ranks, the actual data values are plotted.

The solid diagonal line in the Q-Q plots represents the x=y line. If the data from the two data sets were identical, the plotted data would lie along the x=y line. Data plotted to one side of the x=y line show that values from one data set were larger than values from the second data set. How the plotted data deviates from the x=y line indicates how the data sets differ. If the data lie parallel to the x=y line, the data sets differ additively–there is a constant difference between the data from the two data sets, but the data sets have similar distributions. Data that diverge from or converge on the x=y line in a curve or at an angle differ multiplicatively–there is not a constant difference between the data sets, and the distributions of the data sets are dissimilar.

Plots of the cumulative frequency distribution of concentrations (probability plots) are used in this report to compare data to the normal distribution and to compare data from periods before and after changes in treatment practices when there are unequal numbers of data. Probability plots are graphs of data values versus the fraction of data less than that value. The Cunnane formula (Cunnane, 1978) was used to calculate the plotting position (cumulative relative frequency) associated with each data value. The Cunnane formula is

$$p = (i - 0.4) / (n + 0.2) ,$$

where

p = plotting position (cumulative relative frequency),
i = rank of the data value, and
n = number of data.

The seasonal Kendall trend test was used to determine trends in effluent quality and stream-water quality associated with the James C. Kirie and John E. Egan plants. The test is a nonparametric test that determines chronological increases or decreases of values within a data set. The seasonal Kendall trend test generally is defined as Kendall's Tau test restricted to pairs of data that are 12 months (seasons) apart, thereby eliminating comparisons of data from different seasons (Smith and others, 1982). Other seasonal designations, such as four seasons per year, can also be used. A description of the seasonal Kendall trend test is given by Hirsch and others (1982).

DESCRIPTION OF CHANGES AT WASTEWATER-TREATMENT PLANTS

Two major changes in wastewater-treatment practices were made at the Calumet, Stickney, and North Side plants. These treatment plants discharge effluent to secondary-contact waters where body contact with the water is either accidental or incidental and the probability of ingesting appreciable amounts of water is minimal (Illinois Pollution Control Board, 1984). These secondary-contact streams, however, eventually flow into general-use waters. General-use waters are designated as suitable for aquatic life, full-body-contact recreation, and agricultural and industrial uses, and they are regulated by use of more stringent water-quality standards. Because chlorination of the effluents from the treatment plants resulted in limited benefits to the receiving streams, and because of possible adverse affects to aquatic life, the Illinois Pollution Control Board ruled in favor of stopping the chlorination of effluents at these three treatment plants. Chlorination and disinfection of any type was discontinued in either 1983 or 1984, depending on the particular plant.

Chlorination is incorpcrated into the wastewater-treatment process for disinfection–the killing of disease-causing microorganisms (bacteria, viruses, and so forth). The major change in water quality anticipated from the cessation of chlorination was an increase in densities of fecal coliform bacteria, the bacteria typically used to indicate the presence of pathogenic organisms. In this report, the term "bacteria" refers to fecal coliform bacteria except where specific mention of other bacteriological organisms is made.

The second major operational change in wastewater-treatment practices at these three treatment plants was the implementation of MWRDGC's Tunnel and Reservoir Plan (TARP). Historically, the capacities of combined-sewer systems in the study area often were exceeded during rainfall or runoff, resulting in the release of untreated sewage to local streams. TARP is a system of dropshafts, tunnels, and reservoirs designed to capture overflows from combined sewers, convey the water to a treatment plant, and store the water until it can be treated at the treatment plant. Through 1989, an estimated 126.5 billion gallons of water had been treated through the TARP system (Metropolitan Water Reclamation District of Greater Chicago, 1990). The TARP systems are shown in figure 4. Different TARP systems were completed and placed in service at various times. The O'Hare TARP system began operation in 1980, the Mainstem system began operation in 1985, and full operation of the Calumet system began in 1986. Influents to the Calumet, Stickney, North Side, and James C. Kirie plants were affected by TARP.

TARP functions as a flood-control mechanism and as a means of improving stream-water quality by (1) reducing the amount of untreated wastewater and stormwater entering the streams, (2) increasing the amount of wastewater processed by the treatment plants, and (3) possibly affecting the discharge and quality of the effluent and of the stream upstream and downstream from the treatment plants.

TARP can affect water quality by several processes and mechanisms. TARP collects stormwater runoff that typically has passed over infrequently washed surfaces, such as streets, commercial and industrial developments, and residential areas. This runoff can contain large concentrations of constituents, especially during the early phase of runoff. Conversely, the increased volume of water can decrease the concentrations of some constituents through dilution. Correspondingly, resulting concentrations and loads in the treatment-plant effluent may be large or small, depending on the quality of the stormwater or the combined-sewer-overflow water captured by TARP. In addition, TARP also increases the amount of time the wastewater is stored before treatment, thus creating an opportunity for changes in physical, biological, and chemical characteristics of the wastewater. The chemical quality and quantity of runoff produced by individual storms can vary. Typically, the largest concentrations in runoff will be associated with the initial washing of surfaces. A relatively small intense storm theoretically can yield concentrations equal to or larger than longer duration storms that produce more precipitation.

Several other changes specific to individual treatment plants could have affected effluent quality. These changes are described in the sections discussing the analyses of the individual plants. Major changes identified for each treatment plant are listed in table 5.

RELATION OF CHANGES IN WASTEWATER-TREATMENT PRACTICES TO CHANGES IN STREAM-WATER QUALITY

This section presents results of the analyses for each of the five MWRDGC treatment plants assessed in this study. Significant changes in effluent and stream-water quality that occurred after changes in wastewater-treatment practices are identified. Conclusions and implications from each of the analyses also are presented. As previously mentioned, a more detailed analysis was done for the Calumet plant. This detailed analysis was done to determine (1) possible causative factors for changes in water quality other than changes in wastewater-treatment practices,

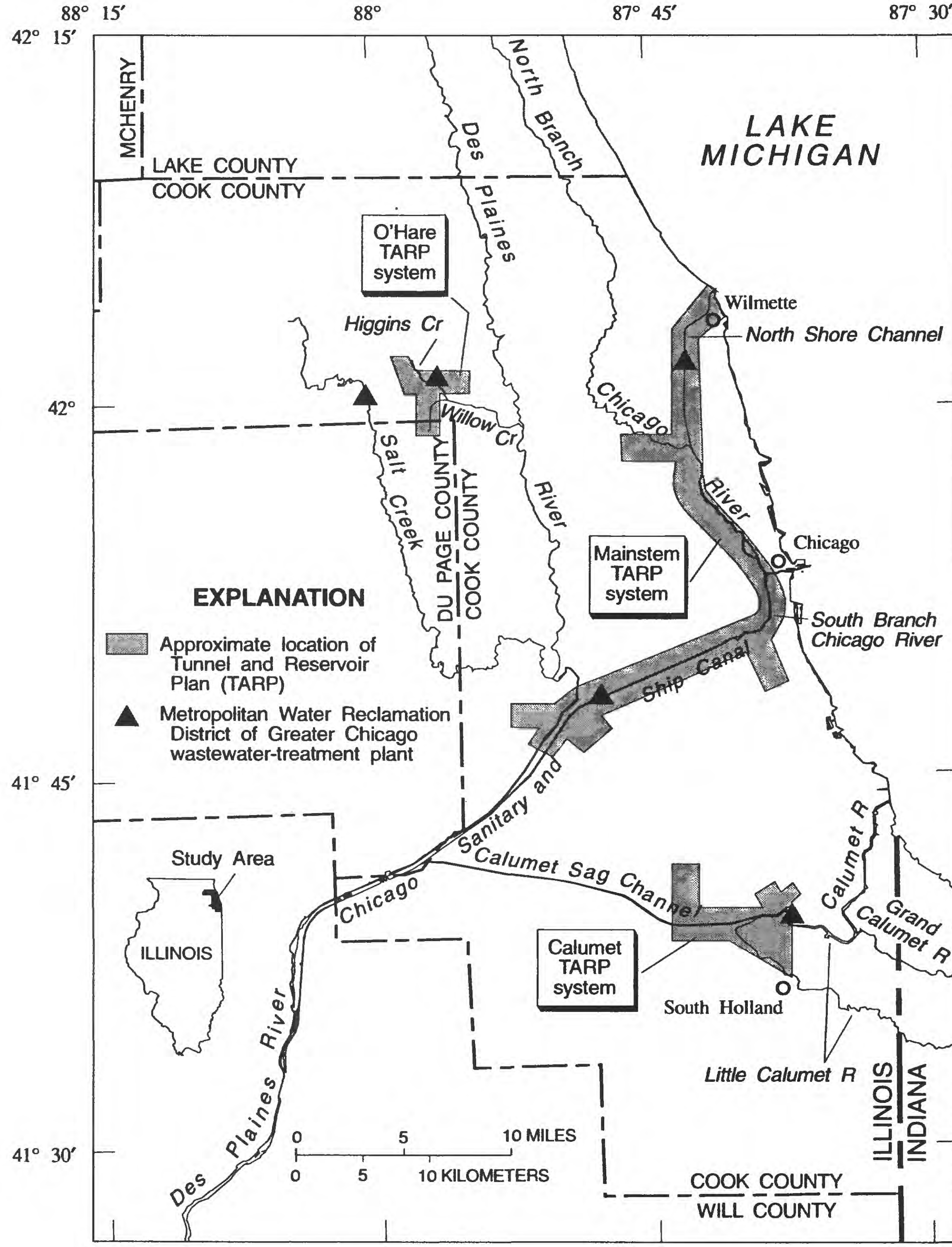


Figure 4. Approximate locations of completed systems of the Tunnel and Reservoir Plan.

Table 5. Major changes in wastewater-treatment practices at wastewater-treatment plants operated by the Metropolitan Water Reclamation District of Greater Chicago, 1978-88

Wastewater-treatment plant	Date of change	Major change
Calumet	August 1983	Cessation of chlorination
	September 1984	Addition of primary- and secondary-treatment units
	September 1986	Implementation of the Tunnel and Reservoir Plan
	November 1987-December 1988	Improvements in aeration
Stickney	April 1984	Cessation of chlorination
	May 1985	Implementation of the Tunnel and Reservoir Plan
North Side	March 1984	Cessation of chlorination
	May 1985	Implementation of the Tunnel and Reservoir Plan
James C. Kirie	May 1980	Commenced operation in conjunction with the Tunnel and Reservoir Plan
John E. Egan	--	No major changes in treatment practices

(2) the ability to ascertain these factors using existing information, and (3) the ability to assess changes in stream-water quality resulting from changes in wastewater-treatment practices when other factors are present.

Calumet Water Reclamation Plant

The Calumet Water Reclamation Plant was built in 1922. Originally, Imhoff tanks were used for treatment of wastewater. In 1935, a conventional activated-sludge plant, with a design capacity of 136 Mgal/d, replaced the original treatment plant (Metropolitan Sanitary District of Greater Chicago, [1985?]). During the 1960's, the Calumet plant was expanded to a capacity of 220 Mgal/d, and additional pretreatment and secondary-treatment units, sludge-thickening facilities, and sludge digesters were incorporated. In the 1980's, additional upgrades were made to the Calumet plant, and the Calumet TARP system began operation.

Three operating permits were issued for the Calumet plant between 1978 and 1988. Major changes in permit requirements in 1988 included less stringent concentration limits and the discontinuance of some limits altogether. Selected information from these permits is presented in table 6.

The Calumet Water Reclamation Plant serves an area of approximately 300 mi^2 with a 1980 population of about 1 million (Richard Lanyon, Metropolitan Water Reclamation District of Greater Chicago, oral commun., 1991). The major land uses in the service area are residential and industrial. During the last several decades, much of the land has been converted from agricultural to industrial use. The mean discharge from the Calumet plant for 1978-88 was 234 Mgal/d, and approximately 11 percent of the inflow to the treatment plant (about 25 Mgal/d) was from industrial sources (Richard Lanyon, Metropolitan Water Reclamation District of Greater Chicago, unpub. data, 1991).

For the purpose of this report, the Calumet River system consists of the Calumet Sag Channel and all of its tributaries, including the Little Calumet River, Calumet River, and Grand Calumet River (fig. 5). The hydrology of the Calumet River system is complex. The region receives an average of 32 in. of precipitation each year. The mean annual runoff in the region is 10 in., or approximately 30 percent of the annual precipitation (Calumet-Sag Channel Watershed Steering Committee, 1976). Major inputs to the Calumet River system include surface drainage, point sources, and diversions from Lake Michigan. Historically, the Grand Calumet and Little Calumet Rivers joined to form the Calumet River, a tributary to Lake Michigan. In 1922, the Metropolitan Sanitary District of Greater Chicago constructed the Calumet Sag Channel to alleviate flooding and to eliminate the discharge of raw sewage to Lake Michigan from combined-sewer overflows during storms. Construction of the Calumet Sag Channel reversed the flow of the Calumet River system; the system now discharges to the Chicago Sanitary and Ship Canal, a tributary to the Des Plaines River. The slope of the Calumet Sag Channel is minimal, and flow velocities are typically less than 0.5 ft/s. Flow sometimes reverses within the Calumet River system.

Historically, parts of the service area of the Calumet Water Reclamation Plant experienced frequent and substantial flooding (Calumet-Sag Channel Watershed Steering Committee, 1976).

Table 6. Selected information from National Pollutant Discharge Elimination System permits for the Calumet Water Reclamation Plant, 1978-88

[Mgal/d, million gallons per day; mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; constituent concentrations are based on a 30-day average of 24-hour composite samples, unless otherwise noted; asterisks indicate the sample is collected as a grab sample; dashes indicate that no permit limit was designated for this constituent; unless otherwise indicated, concentrations refer to the total amount of constituent present in all phases (solid, dissolved, or suspended; elemental or combined), including all oxidation states]

Permit component	Effective permit date		
	4/15/78	6/1/81	7/29/88
Design maximum flow (Mgal/d)	460	460	430
Design average flow (Mgal/d)	354	354	354
Constituent concentration limits			
Biochemical oxygen demand, 5-day (mg/L)	10	10	--
Carbonaceous biochemical oxygen demand, 5-day (mg/L)	--	--	24
Total suspended solids (mg/L)	12	12	28
*Fecal coliform bacteria (col/100 mL)	400 (daily maximum)	400 (daily maximum)	--
Ammonia as N (mg/L)			
April through October	2.5 (daily maximum)	2.5 (daily maximum)	13
November through March	4.0 (daily maximum)	4.0 (daily maximum)	13
*Dissolved oxygen (mg/L)	6.0 (daily minimum)	6.0 (daily minimum)	--
Chlorine residual (mg/L)	0.2-0.75	0.2-0.75	--
*pH (standard units)	6.0-9.0	6.0-9.0	6.0-9.0
Cyanide (mg/L)	0.025	0.025	0.11 (daily maximum)
Fluoride (mg/L)	15	15	--
Oil (mg/L)	15	15	--
Phenols (mg/L)	0.3	0.3	0.3 (daily maximum)

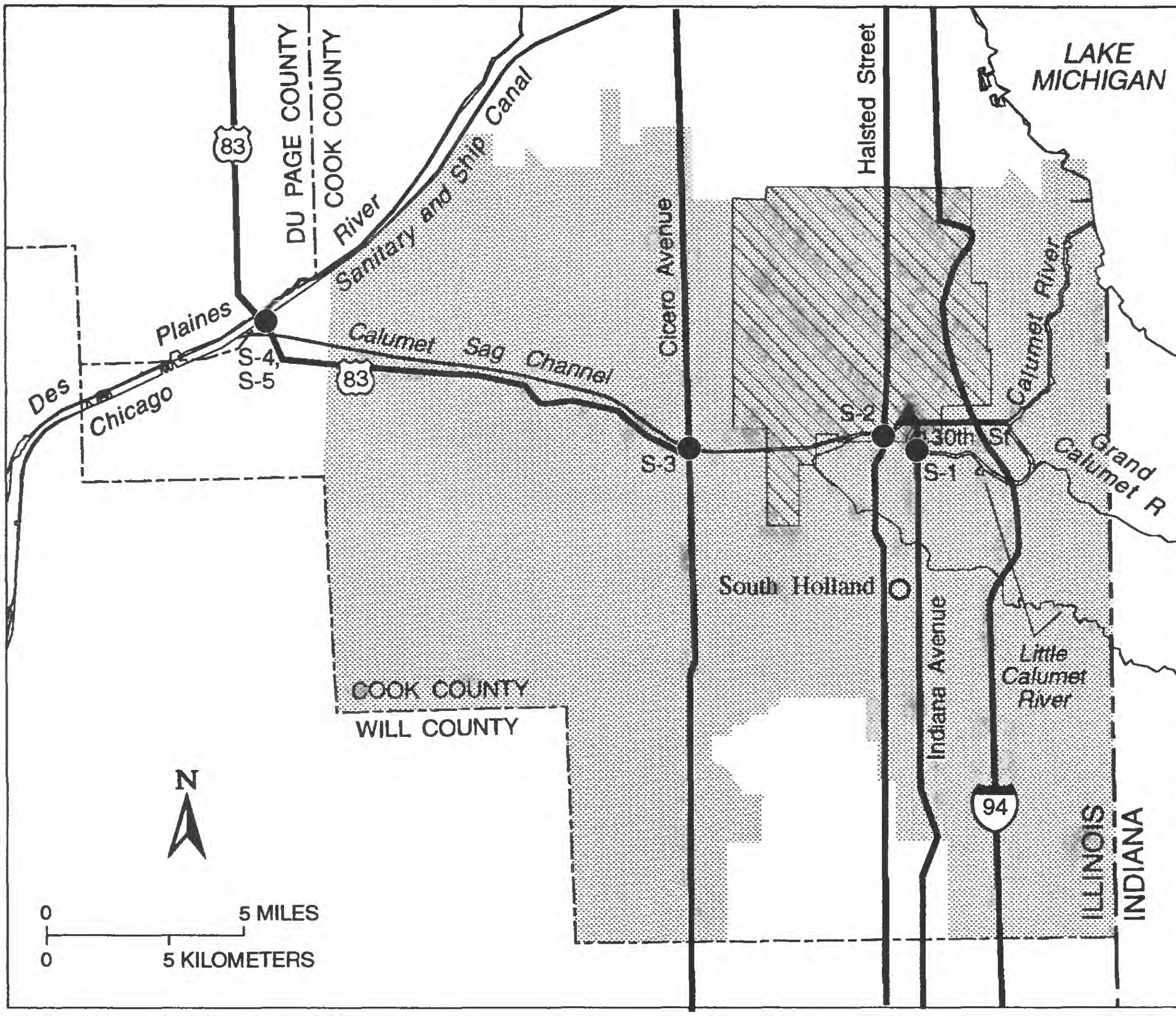
In 1986, the initial phase of the Calumet TARP system was put into operation to alleviate flooding and water-quality problems associated with overflows from combined sewers during storms. The service area for this part of TARP is approximately 41 mi^2.

The IEPA identified the major water-quality concerns of the Calumet River system to be elevated phosphorus concentrations, ammonia toxicity, and low dissolved oxygen concentrations (Illinois Environmental Protection Agency, 1988). Other historical water-quality problems in the area included erosion, sedimentation, and high densities of bacteria.

Effluent from the Calumet Water Reclamation Plant is discharged to the Little Calumet River. The locations of the Calumet Water Reclamation Plant and associated stream-monitoring sites are shown in figure 5. Site S-1 is approximately 0.75 mi upstream from the Calumet plant, and sites S-2 and S-3 are 1.5 and 6.8 mi downstream, respectively, from the effluent discharge point of the treatment plant. Sites S-4 and S-5 are both 17.4 mi downstream from the effluent discharge point at the Calumet plant; site S-4 was sampled by the MWRDGC, and site S-5 was sampled by the IEPA.

Major Changes in Wastewater-Treatment Practices

Several major changes in wastewater-treatment practices were made at the Calumet plant between 1978 and 1988. Chlorination was discontinued at the treatment plant in August 1983. Additional primary- and secondary-treatment units were constructed in 1984. Start-up procedures for TARP began in September 1986, and TARP flows routinely were conveyed to the Calumet plant by January 1987. Additional blowers were added to the treatment plant in 1987, and new diffuser plates were installed in 1988. To the extent possible, the effects of each change in wastewater-treatment practices on water quality were analyzed individually; however, the improvements at the treatment plant in 1987-88 and the implementation of TARP occurred concurrently



EXPLANATION

APPROXIMATE ACTIVE TUNNEL AND RESERVOIR PLAN SERVICE AREA

APPROXIMATE WASTEWATER-TREATMENT PLANT SERVICE AREA

CALUMET WATER RECLAMATION PLANT

S-2 STREAM-MONITORING SITE

Figure 5. Locations of the Calumet Water Reclamation Plant and associated stream-monitoring sites.

and necessarily were analyzed together. The following treatment periods were used for the analysis of the Calumet Water Reclamation Plant:

Treatment period 1 (TP-1): January 1978-July 1983,
Treatment period 2 (TP-2): September 1983-August 1984,
Treatment period 3 (TP-3): January 1985-August 1986, and
Treatment period 4 (TP-4): January 1987-December 1988.

These treatment periods correspond to the changes in wastewater-treatment practices as mentioned above and listed in table 5.

Streamflow and Precipitation

Stream-discharge data upstream and downstream from the Calumet Water Reclamation Plant are few. The MWRDGC does not collect stream-discharge data as part of its stream-monitoring program. Similarly, discharge data were not collected at the IEPA ambient water-quality-monitoring station on the Calumet Sag Channel. The USGS has measured the discharge of the Little Calumet River at South Holland, Ill., since 1947, but discharge data also are needed for the Calumet Sag Channel, the Grand Calumet River, and the part of the Little Calumet River between the Grand Calumet River and the Calumet plant to understand drainage characteristics of the system. A low-flow synoptic study for dissolved oxygen, nutrients, and fecal indicator bacteria was done by the USGS in 1988, and discharge measurements for a few sites along the Little Calumet River and Calumet Sag Channel were made at that time. No discharge-measurement sites upstream or downstream from the Calumet plant were in operation during 1978-88. Channel morphology, diversions from Lake Michigan, and drainage features make discharge measurement difficult. On the basis of limited data, discharge for the Calumet Sag Channel during 1978-88 ranged from 200 to 2,100 ft^3/s; most discharges were between 500 and 800 ft^3/s. The average discharge from the Calumet Water Reclamation Plant during 1978-88 was 234 Mgal/d (363 ft^3/s). Therefore, the effluent from the Calumet plant contributed an estimated 47 to 75 percent of the total discharge in the Calumet Sag Channel downstream from the treatment plant.

Annual precipitation totals at Midway Airport (fig. 3) for 1978-88 are shown in figure 6. Precipitation in 1982 and 1983 was greater than the 1978-88 average, whereas precipitation in 1978 and 1988 was well below the 1978-88 average. Annual mean discharges for calendar years 1978-88 for the Little Calumet River at South Holland (fig. 3) are shown in figure 7. Annual mean discharges for 1979 and 1981-83 were relatively large in comparison to the 1978-88 mean discharge, and annual mean discharges for 1978 and 1986-88 were relatively small. Although these sites may not be representative of the entire region, they provide some insight into regional hydrologic conditions during 1978-88. Because of diversions from Lake Michigan, discharge of the Calumet Sag Channel is assumed to be less variable than discharge of the Little Calumet River.

The treatment periods for the assessment of the Calumet Water Reclamation Plant also are delineated in figures 6 and 7. Total annual precipitation at Midway Airport during TP-1 ranged from 86 to 121 percent of the 1978-88 mean of about 39 in. Annual mean discharge for the Little Calumet River at South Holland during TP-1 ranged from 83 to 139 percent of the 1978-88 mean (206 ft^3/s). Greater than average to average precipitation and discharge characterized TP-2. Annual precipitation during TP-3 averaged 98 percent of the 1978-88 mean, but annual mean discharge during TP-3 averaged only 88 percent of the 1978-88 mean. Annual precipitation totals during TP-4 were among the lowest totals for the 11-year period; the total annual precipitation for 1988 was the smallest during the period. The annual mean discharge for 1988 also was one of the smallest for the 1978-88 period.

Cessation of Chlorination

The first major change in wastewater-treatment practices at the Calumet plant from 1978 to 1988 was the cessation of chlorination in August 1983. Because chlorination is a disinfection process, the primary result expected from the cessation of chlorination was an increase in densities of bacteria in the effluent. TP-1 and TP-2 were used to analyze changes in bacteria concentrations resulting from the cessation of chlorination; TP-1 represented the period when effluents were chlorinated, and TP-2 represented the period after the cessation of chlorination. The median bacteria densities in effluent from the plant for TP-1 and TP-2 were 3,100 and 1,200,000 col/100 mL, respectively (table 7). The results of the

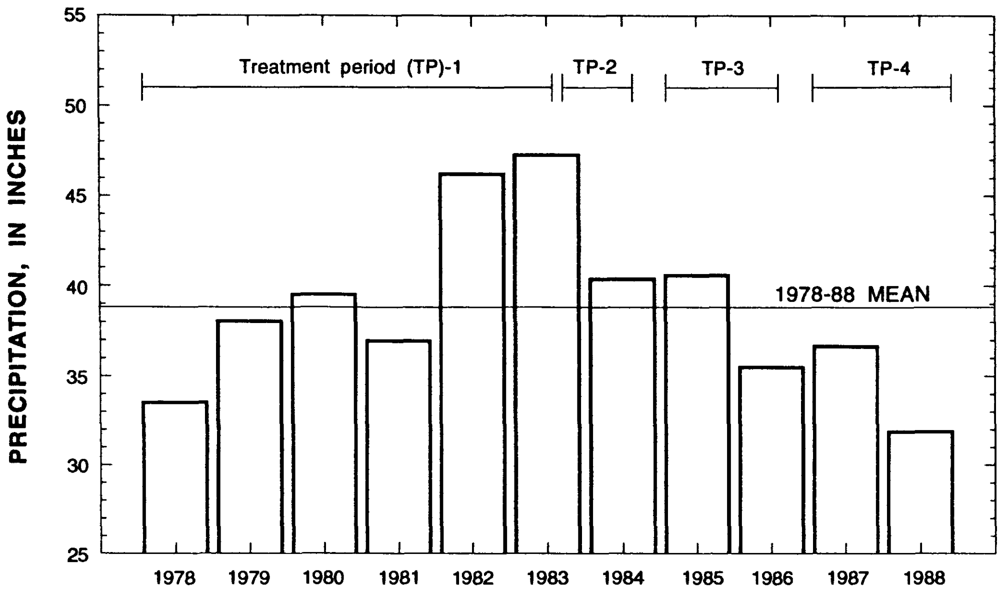


Figure 6. Annual precipitation totals at Midway Airport, 1978-88, and treatment periods at the Calumet Water Reclamation Plant used for this study.

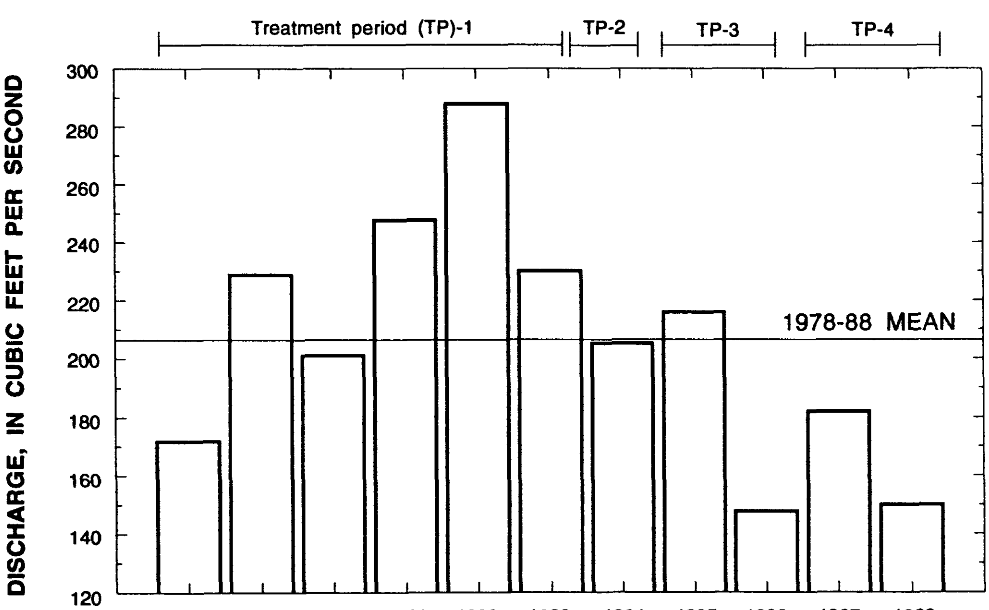


Figure 7. Annual mean discharges for the Little Calumet River at South Holland, Ill., calendar years 1978-88, and treatment periods at the Calumet Water Reclamation Plant used for this study.

Table 7. Summary statistics for densities of fecal coliform bacteria in effluent from the Calumet Water Reclamation Plant and at associated stream-monitoring sites during treatment periods before and after the cessation of chlorination in August 1983

Monitoring site (fig. 5)	Density at indicated percentile[1], in colonies per 100 milliliters				
	10	25	50	75	90
	TP-1 (January 1978-July 1983)				
S-1	220	400	1,100	4,600	15,000
Calumet Water Reclamation Plant effluent	61	290	3,100	6,400	23,000
S-2	150	540	9,500	60,000	60,000
S-3	1,400	5,800	32,000	60,000	60,000
S-4	310	1,500	6,000	38,000	60,000
S-5	330	1,000	3,400	22,000	38,000
	TP-2 (September 1983-August 1984)				
S-1	360	800	1,800	6,900	11,000
Calumet Water Reclamation Plant effluent	150,000	490,000	1,200,000	1,800,000	3,900,000
S-2	67,000	140,000	260,000	360,000	610,000
S-3	1,800	29,000	40,000	80,000	430,000
S-4	530	2,600	21,000	130,000	280,000
S-5	190	540	5,400	13,000	22,000

[1]Percentage of sample for which values were less than or equal to those shown.

Wilcoxon-Mann-Whitney rank-sum test (table 8) indicate statistically significant increases in bacteria densities in the effluent. This change is shown graphically in figure 8.

Bacteria analyses were not done for the influent to the Calumet plant, and changes in bacteria densities in the influent could not be determined. No major changes in the service area of the treatment plant or in pretreatment practices that might have affected bacteria densities in influent were known to have been made.

Changes in bacteria densities at the stream-monitoring sites also are presented in tables 7 and 8 and in figure 8. Median bacteria densities at site S-1 for TP-1 and TP-2 were 1,100 and 1,800 col/100 mL, respectively, and did not change significantly. Downstream, median bacteria densities at site S-2 increased significantly, as indicated by the Wilcoxon-Mann-Whitney rank-sum test (table 8). Median bacteria densities increased from 9,500 col/100 mL (TP-1) to 260,000 col/100 mL (TP-2) at site S-2. Bacteria densities at sites S-3, S-4, and S-5 were not statistically different during TP-1 and TP-2.

During TP-1, densities of bacteria downstream from the Calumet plant were larger than densities upstream or in the effluent. This pattern indicates inputs of bacteria to the Calumet Sag Channel downstream from the Calumet plant. In addition, the lack of significant increases in bacteria densities at sites S-3, S-4, and S-5 from TP-1 to TP-2 indicates that the influence of the effluent was limited to a reach of several miles downstream from the discharge point of the treatment plant (fig. 8).

Table 8. Results of the Wilcoxon-Mann-Whitney rank-sum test for densities of fecal coliform bacteria in effluent from the Calumet Water Reclamation Plant and at associated stream-monitoring sites for treatment periods before and after the cessation of chlorination in August 1983

[<, less than; dashes indicate the change was not significant at the 10-percent level]

Monitoring site (fig. 5)	Direction of change	Level of significance
S-1	--	--
Calumet Water Reclamation Plant effluent	Increase	<0.0001
S-2	Increase	<.0001
S-3	--	--
S-4	--	--
S-5	--	--

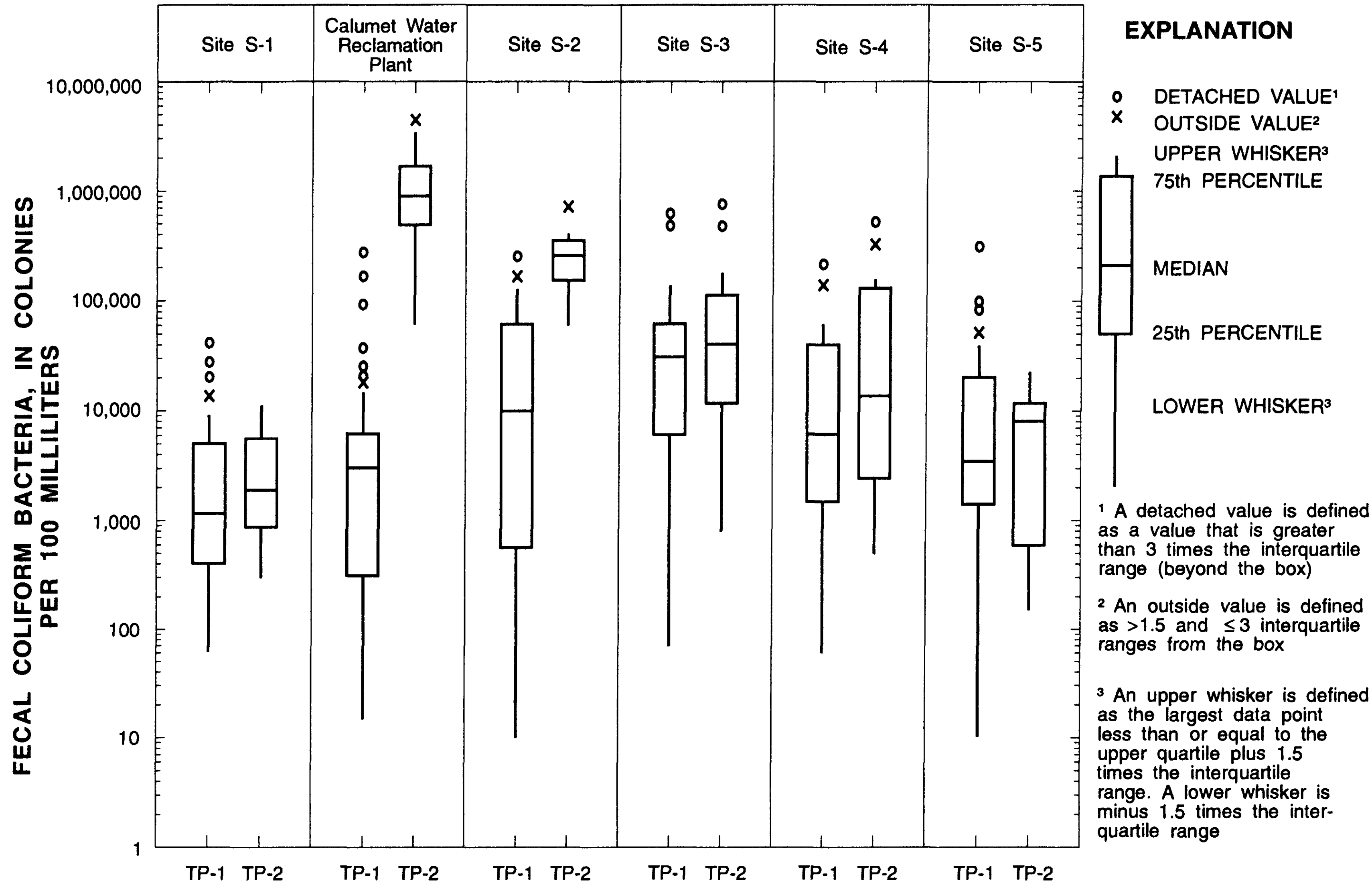


Figure 8. Distribution of densities of fecal coliform bacteria in effluent from the Calumet Water Reclamation Plant and at associated stream-monitoring sites for treatment periods before (TP-1) and after (TP-2) the cessation of chlorination in August 1983.

Expansion of the Treatment Plant

The second major change in treatment practice at the Calumet plant was the addition of primary- and secondary-treatment units, placed in operation between August and December 1984. These additional treatment units were constructed as part of an expansion and improvement program to increase the average design capacity of the treatment plant to 354 Mgal/d. Before the expansion, the Calumet plant often operated at flow rates that exceeded the design capacity. The quantity of water treated by the Calumet plant, therefore, did not change after the construction of the additional treatment units. The increased capacity at the treatment plant allowed for an increase in the residence time of the activated sludge, which provided for more effective removal of carbonaceous biochemical oxygen demand (CBOD) and improved nitrification in the secondary-treatment process.

Biochemical oxygen demand (BOD) is a measure of the oxygen required for the biochemical degradation of organic material, the oxidation of inorganic material, and the oxidation of reduced forms of nitrogen. Because the time required to determine the ultimate oxygen demand of a sample is generally impractical, a 5-day period has been accepted as the standard determination, and the results of the analyses are reported as concentrations of 5-day biochemical oxygen demand (BOD_5). CBOD is the demand for oxygen for the decomposition of organic matter. Nitrogenous oxygen demand is the demand for oxygen used in the oxidation of reduced forms of nitrogen. Available oxygen is first used to meet CBOD needs before it is available in appreciable quantities for oxidation of reduced nitrogen by nitrifying bacteria. Concentrations of CBOD can be no larger than 20 to 30 mg/L for nitrification to occur in the secondary-treatment process. Nitrifying bacteria convert ammonia-N to the less toxic forms of nitrite-N and, in turn, nitrate-N.

Concentrations of BOD_5 in effluent from the Calumet plant were determined from 1978-90. Beginning in 1988, permit requirements were revised to include the analyses of CBOD concentrations. The average CBOD concentration in the influent to the treatment plant during 1988-90 was approximately 125 mg/L. The average CBOD concentration in the effluent from the treatment plant was about 5 mg/L. If it is assumed that concentrations of CBOD in effluent from the treatment plant during TP-3 were comparable to the concentrations from 1988-90 and if CBOD concentrations were reduced to this level either before or during the secondary-treatment process, then the concentrations of CBOD would have been small enough to permit some nitrification during the secondary-treatment process.

Brigham and others (1978) listed ammonia-N concentrations as a major factor in the high toxicity level of the Calumet Sag Channel, and the IEPA (1988) found ammonia-N toxicity to be one of the major water-quality problems in the Calumet River system. A major result expected from the increased capacity at the Calumet plant and the corresponding increase in treatment capability was a reduction in ammonia-N concentrations in effluent from the treatment plant.

The effects of these changes were analyzed on the basis of data from TP-2 and TP-3. After the construction of the additional units, median concentrations of effluent ammonia-N decreased from 14.3 to 12.4 mg/L (table 9), and the average ammonia-N removal efficiency increased from 15.6 to 22.6 percent. The results of the Wilcoxon-Mann-Whitney rank-sum test for TP-2 and TP-3 are given in table 10, and boxplots illustrating the decrease in ammonia-N concentrations are shown in figure 9.

The decrease in ammonia-N concentrations in the effluent, however, cannot be attributed entirely to the improvements at the Calumet plant. Percentiles of ammonia-N concentrations for the influent during TP-2 and TP-3 also are shown in table 9 and show decreases in all percentiles. Ammonia-N percentiles for the influent decreased by 1.2 to 3.2 mg/L from TP-2 to TP-3, and the median effluent percentiles decreased by 0.5 to 5.4 mg/L. Much of the decrease in effluent ammonia-N concentrations, therefore, could be accounted for by the decreases in influent concentrations.

Regardless of the specific reason for the decreases, the effects of the decreased effluent ammonia-N concentrations on downstream water quality were evident. The median ammonia-N concentration at site S-2 decreased from 9.15 to 6.65 mg/L, about 27 percent, from TP-2 to TP-3 (tables 9 and 10). The persistence of this decrease in the stream was limited, however, and ammonia-N concentrations did not change significantly at sites S-3, S-4, or S-5. In fact, ammonia-N concentrations increased slightly at site S-3, although this increase was not statistically significant.

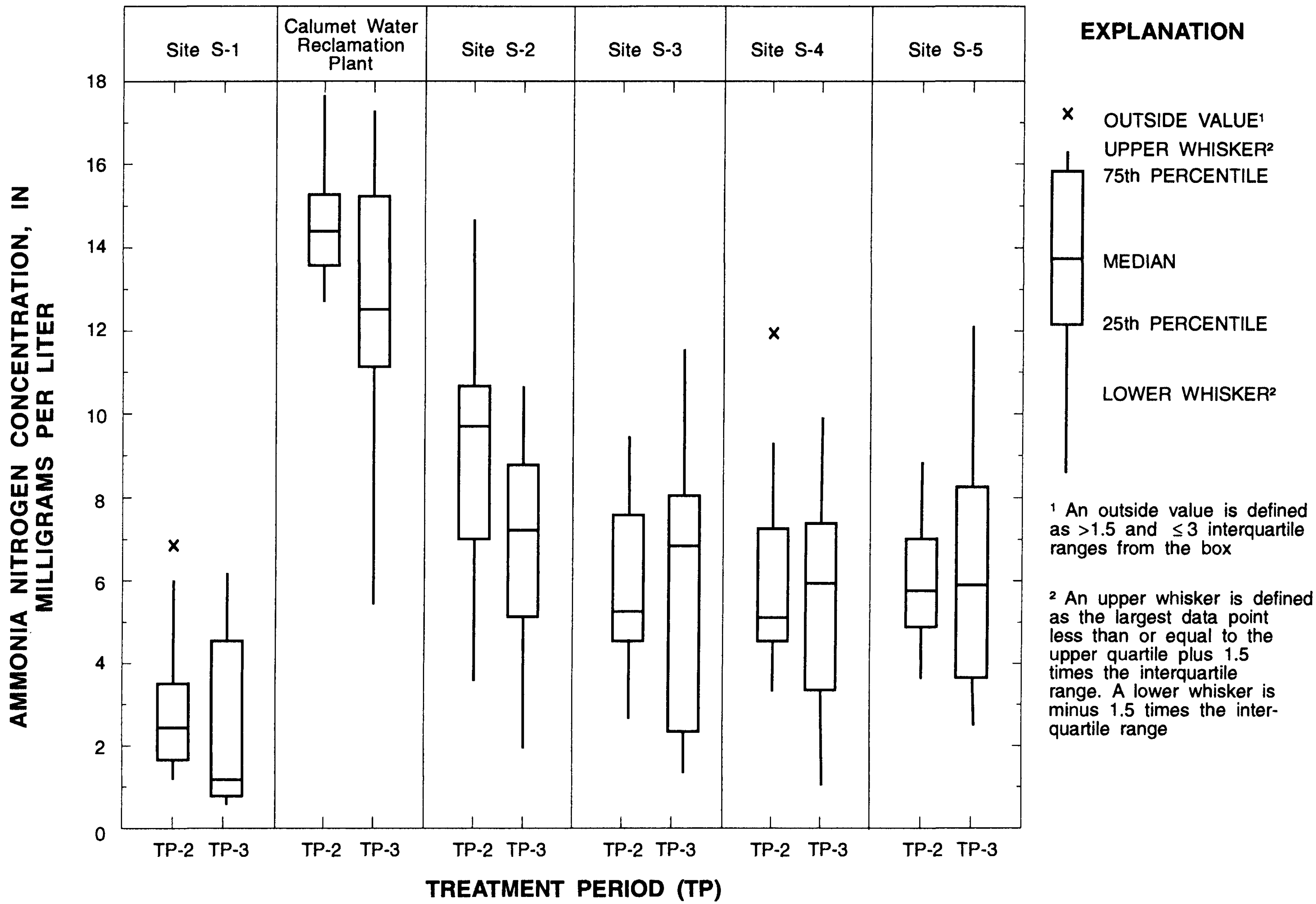


Figure 9. Concentrations of total ammonia nitrogen in effluent from the Calumet Water Reclamation Plant and at associated stream-monitoring sites for treatment periods before (TP-2) and after (TP-3) the expansion of the treatment plant in September 1984.

Table 9. Summary statistics for concentrations of total ammonia nitrogen in effluent from the Calumet Water Reclamation Plant and at associated stream-monitoring sites during treatment periods before and after expansion of the treatment plant in September 1984

Monitoring site (fig. 5)	Concentration at indicated percentile[1], in milligrams per liter				
	10	25	50	75	90
TP-2 (September 1983-August 1984)					
S-1	1.12	1.50	2.30	3.50	6.64
Calumet Water Reclamation Plant:					
Influent	13.6	15.4	15.9	17.6	20.0
Effluent	12.9	13.4	14.3	15.6	17.6
S-2	4.06	6.60	9.15	10.9	13.5
S-3	2.64	4.30	4.80	8.10	9.16
S-4	3.38	4.10	5.10	8.20	11.4
S-5	3.88	4.90	5.80	7.62	8.51
TP-3 (January 1985-August 1986)					
S-1	0.60	0.70	1.20	4.68	5.74
Calumet Water Reclamation Plant:					
Influent	10.7	12.2	14.4	16.4	17.7
Effluent	6.53	11.0	12.4	15.1	15.9
S-2	2.09	3.95	6.65	8.50	10.4
S-3	1.54	2.18	6.90	8.47	9.79
S-4	1.90	3.30	5.90	7.70	9.00
S-5	2.57	3.60	5.90	8.22	11.3

[1]Percentage of sample for which values were less than or equal to those shown.

Table 10. Results of the Wilcoxon-Mann-Whitney rank-sum test for concentrations of total ammonia nitrogen in effluent from the Calumet Water Reclamation Plant and at associated stream-monitoring sites for treatment periods before and after expansion of the treatment plant in September 1984

[Dashes indicate the change was not significant at the 10-percent level]

Monitoring site (fig. 5)	Direction of change	Level of significance
S-1	--	--
Calumet Water Reclamation Plant effluent	Decrease	0.0136
S-2	Decrease	.0564
S-3	--	--
S-4	--	--
S-5	--	--

Implementation of the Tunnel and Reservoir Plan and Improvements in Aeration

The implementation of TARP presented a complicated analysis. TARP collects overflow from combined sewers and stores the water until the Calumet plant can process the additional quantities of water under controlled conditions. Water collected by TARP is usually processed during the night, when demand on the treatment plant is typically lower than during the day. Storms in the region are typical of those found in the Midwest, with variable spatial distribution and local intensity. Some parts of the Calumet plant's service area have a history of frequent flooding and receive priority service by TARP during high-runoff events. The particular segments of TARP activated for any particular storm depend upon the characteristics and location of the storm. The analysis presented here does not attempt to differentiate between individual storms but looks at the overall changes in effluent and stream-water quality for periods before and after the implementation of TARP and the improvements in aeration.

Studies, including Manning and others (1977), have shown that urban storm runoff commonly contains large concentrations of pollutants, depending to some extent upon antecedent and storm conditions and the specific land use. The implementation of TARP, therefore, was expected to affect primarily the larger concentrations associated with storm runoff. Specific storm-runoff samples and streamwater samples following storms, however, were not collected.

The initial portion of the Calumet system of TARP (fig. 4) was fully implemented by January 1987. Some portions of the Calumet TARP system are currently under construction or are awaiting funding. Stream-monitoring sites S-1 and S-2 were within the TARP service area; sites S-3 and S-4 were downstream from the service area. These sites were all affected, in various ways, by TARP. Some overflows that had formerly discharged to the Little Calumet River upstream from site S-1 were intercepted by TARP, routed through the Calumet plant, and discharged with the effluent, downstream from site S-1. Following the implementation of TARP, the Little Calumet River at site S-2 included overflows from upstream and some overflows from downstream, although many of the overflows were not treated at the Calumet plant. Sites S-3 and S-4 continued to receive inputs from the entire upstream area, but a larger percentage of the discharge was treated following the implementation of TARP.

Daily influent and effluent data were the most appropriate data for evaluating changes resulting from TARP. To maintain comparability among influent, effluent, and in-stream monitoring data, however, monthly mean data were used for this analysis. The cumulative frequency of occurrence of the daily and monthly concentrations of selected constituents in the effluent from the Calumet plant are shown in figure 10. The plots show similar distributions of concentrations except at the larger probabilities, where daily samples were found to have larger concentrations. Some large concentrations, therefore, were excluded by using the monthly mean data.

Because the operation of TARP is dependent upon storms and because water quality generally varies with streamflow, it is useful to note the hydrologic conditions during TP-3 and TP-4 as these conditions likely affected the results of the analyses to some degree. The annual precipitation totals at Midway Airport for 1985-88 were all below the 1978-88 mean, and the annual totals for 1987 and 1988 were the lowest annual totals during the 11-year period. Annual mean discharges for Little Calumet River at South Holland for 1986-88 were among the smallest during 1978-88. Extremely low streamflows were recorded throughout the Midwest in 1988.

Hydrologic conditions and water quality also are affected by weather conditions. To determine if the quality of the effluent from the Calumet plant varied seasonally, effluent data for TP-3 and TP-4 were smoothed (Velleman and Hoaglin, 1981) and plotted. Graphs of smoothed data for selected constituents in effluent from the Calumet plant are shown in figure 11. Two general seasons were identified: a warm season, May through October, and a cold season, November through April.

The Q-Q plots of selected constituents in effluent from the Calumet plant for TP-3 and TP-4 are shown in figure 12. The Q-Q plots compare the data from TP-3 and TP-4, and the symbols used in the plots designate the data as being from either the warm season or from the cold season. The plots show general improvements in water quality from TP-3 to TP-4. Some degree of decrease in concentration was found for most of the constituents. There were, however, no appreciable changes in dissolved oxygen (DO). There were some increases in phosphorus and oil and grease concentrations.

Bacteria densities, pH, and concentrations of chemical oxygen demand (COD), suspended solids, ammonia-N, and cyanide show substantial decreases from TP-3 to TP-4, particularly at larger values. These were the types of improvements in water quality that were expected following the implementation of TARP. Ammonia-N concentrations decreased at all levels, indicating that the improvements in aeration likely aided in nitrification and the reduction of ammonia concentrations.

In most cases, changes in concentrations from TP-3 to TP-4 appeared to be related to climatic season. Changes in data from the warm and cold seasons differed in a variety of ways. For many constituents, both warm- and cold-season concentrations decreased between TP-3 and TP-4, but the magnitude of the decreases in warm-season concentrations was often greater. Natural streamflow is typically low in the summer, but seasonal thunderstorms can produce large amounts of runoff that require TARP to be put into operation. Some of the most pronounced effects of TARP occur under these conditions. For some constituents, changes in concentrations were found with data from one season only. For COD, warm-season concentrations decreased, while cold-season concentrations remained relatively unchanged. For phosphorus, cold-season concentrations increased, but no appreciable change in warm-season concentrations was seen.

The quality of the influent to the Calumet plant also changed from TP-3 to TP-4. The Q-Q plots of influent concentrations of BOD, ammonia-N, and

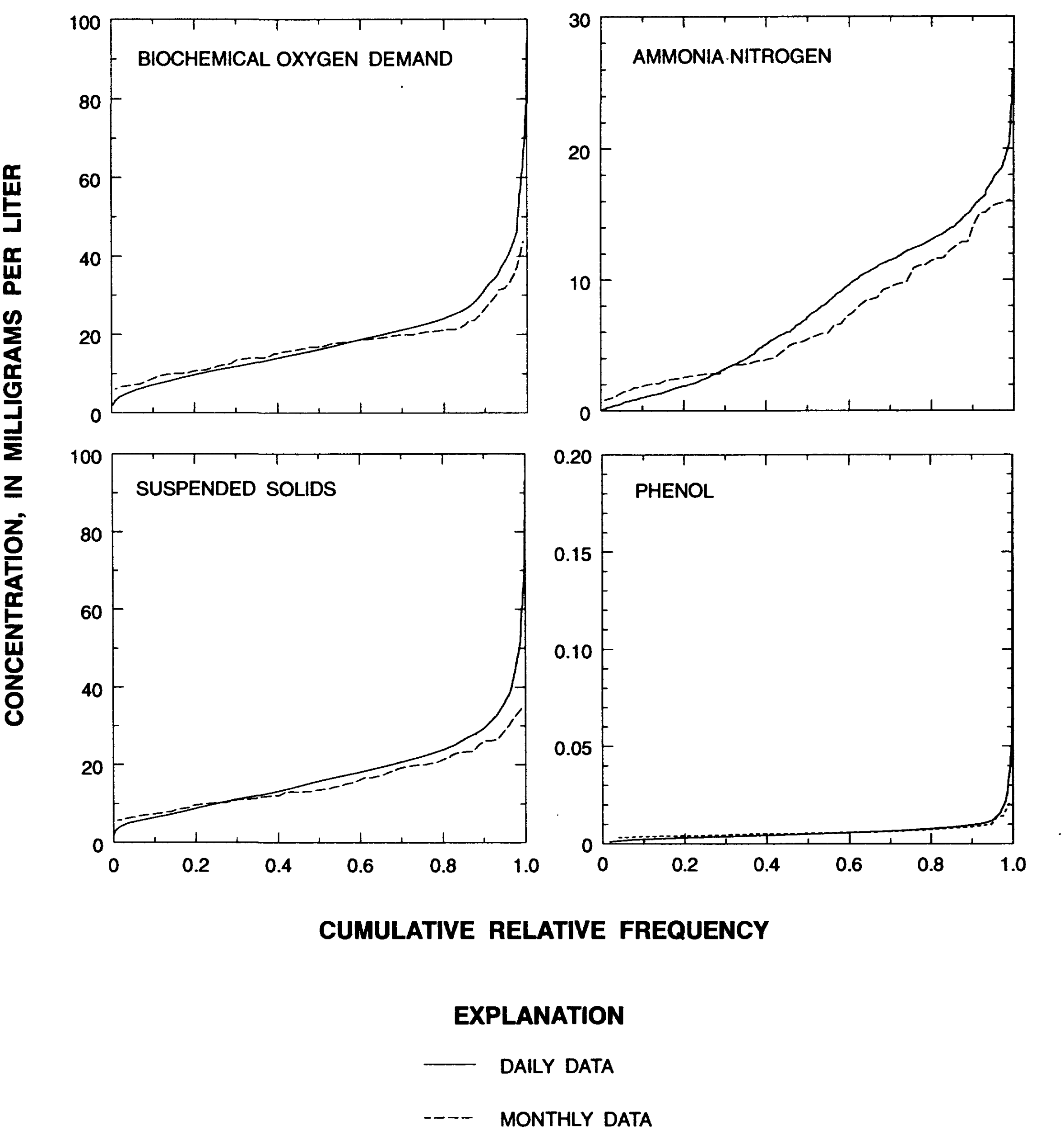


Figure 10. Cumulative relative frequency distribution of concentrations of selected constituents in effluent from the Calumet Water Reclamation Plant, 1985-88.

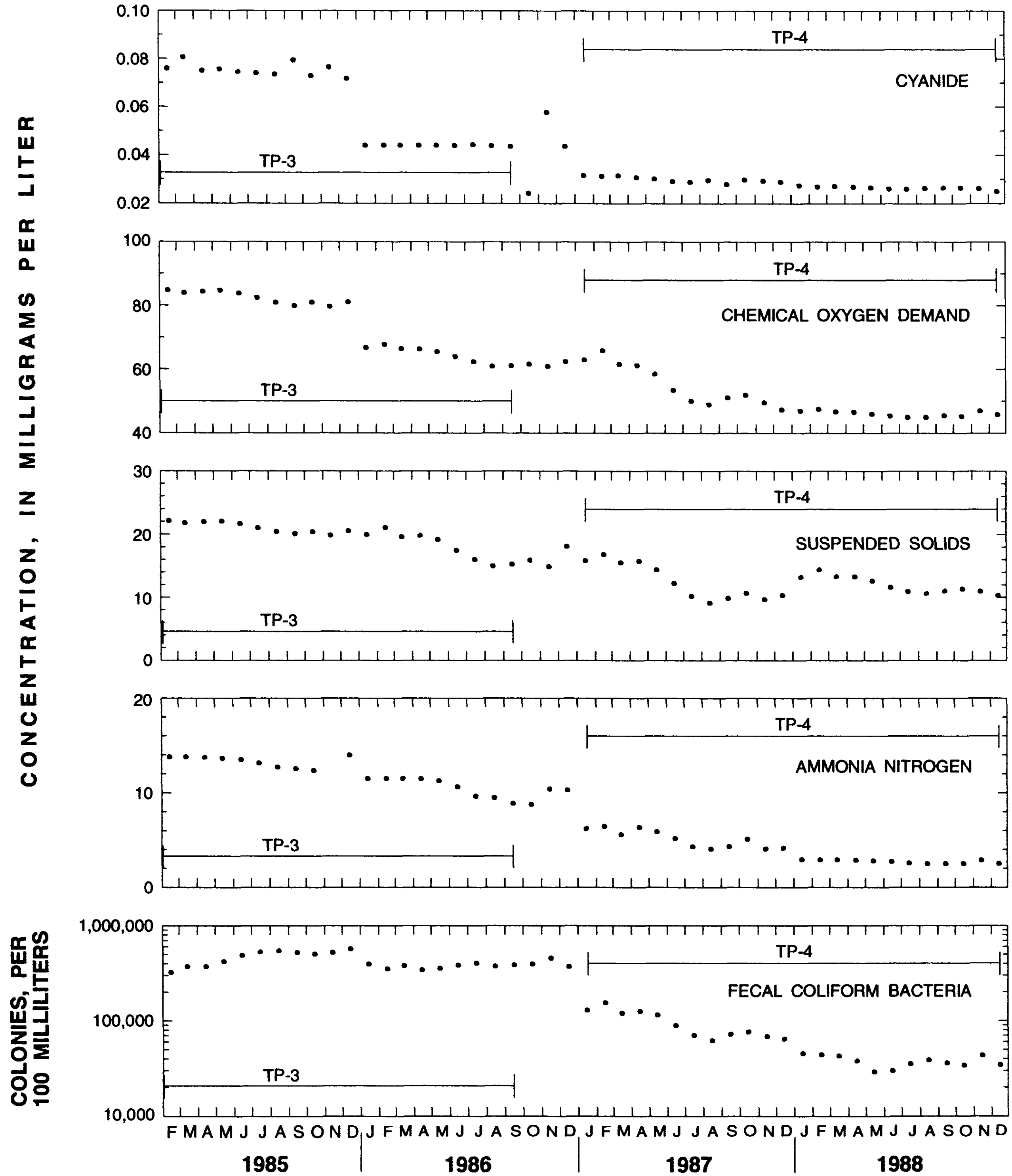
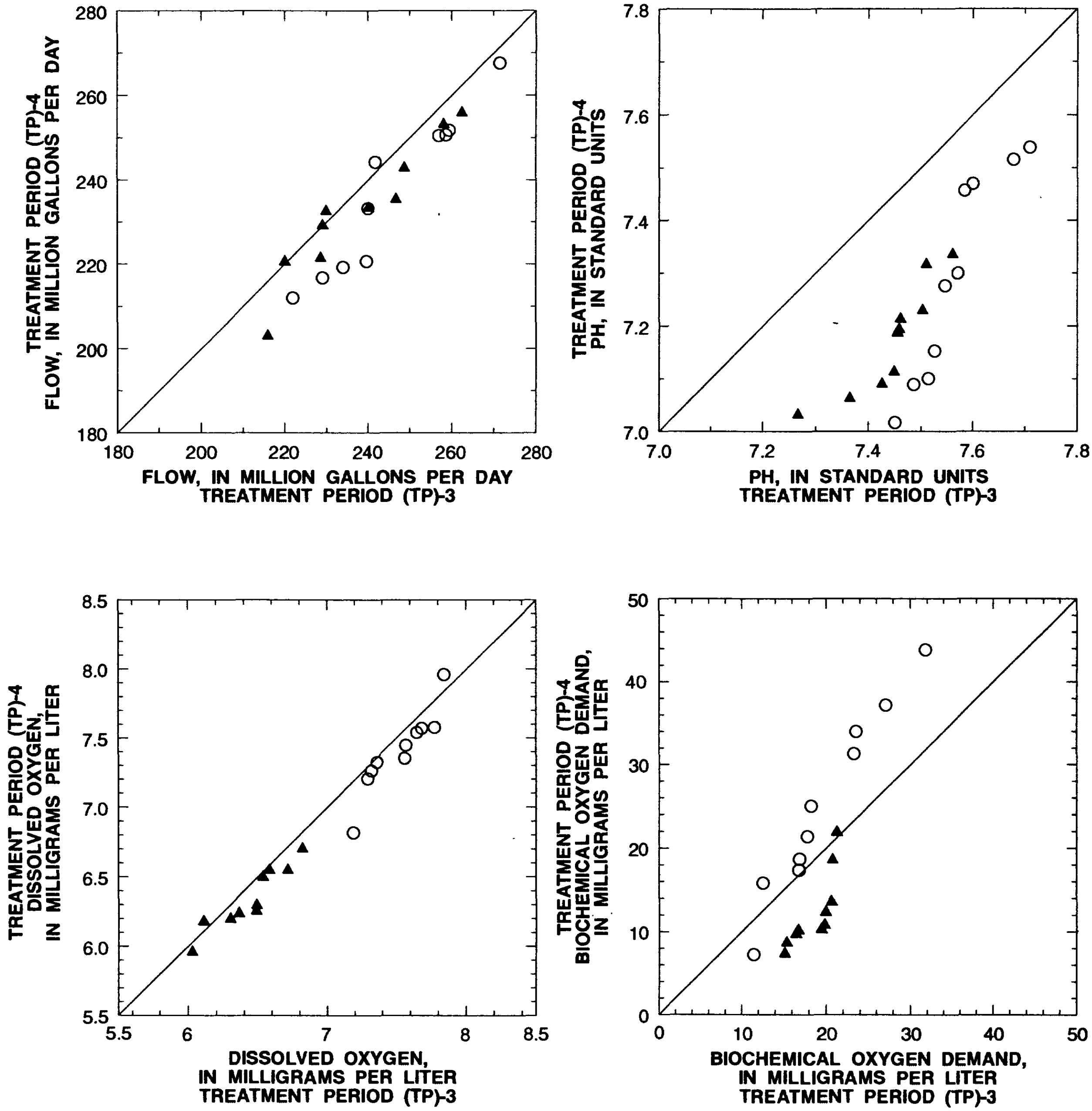


Figure 11. Seasonal variations of smoothed concentrations for selected constituents in effluent from the Calumet Water Reclamation Plant for treatment periods before (TP-3) and after (TP-4) the implementation of the Tunnel and Reservoir Plan.



EXPLANATION

▲ WARM SEASON (MAY-OCTOBER)

○ COLD SEASON (NOVEMBER-APRIL)

Figure 12. Quantile-quantile plots of concentrations of selected constituents in effluent from the Calumet Water Reclamation Plant for treatment periods before (TP-3) and after (TP-4) the implementation of the Tunnel and Reservoir Plan.

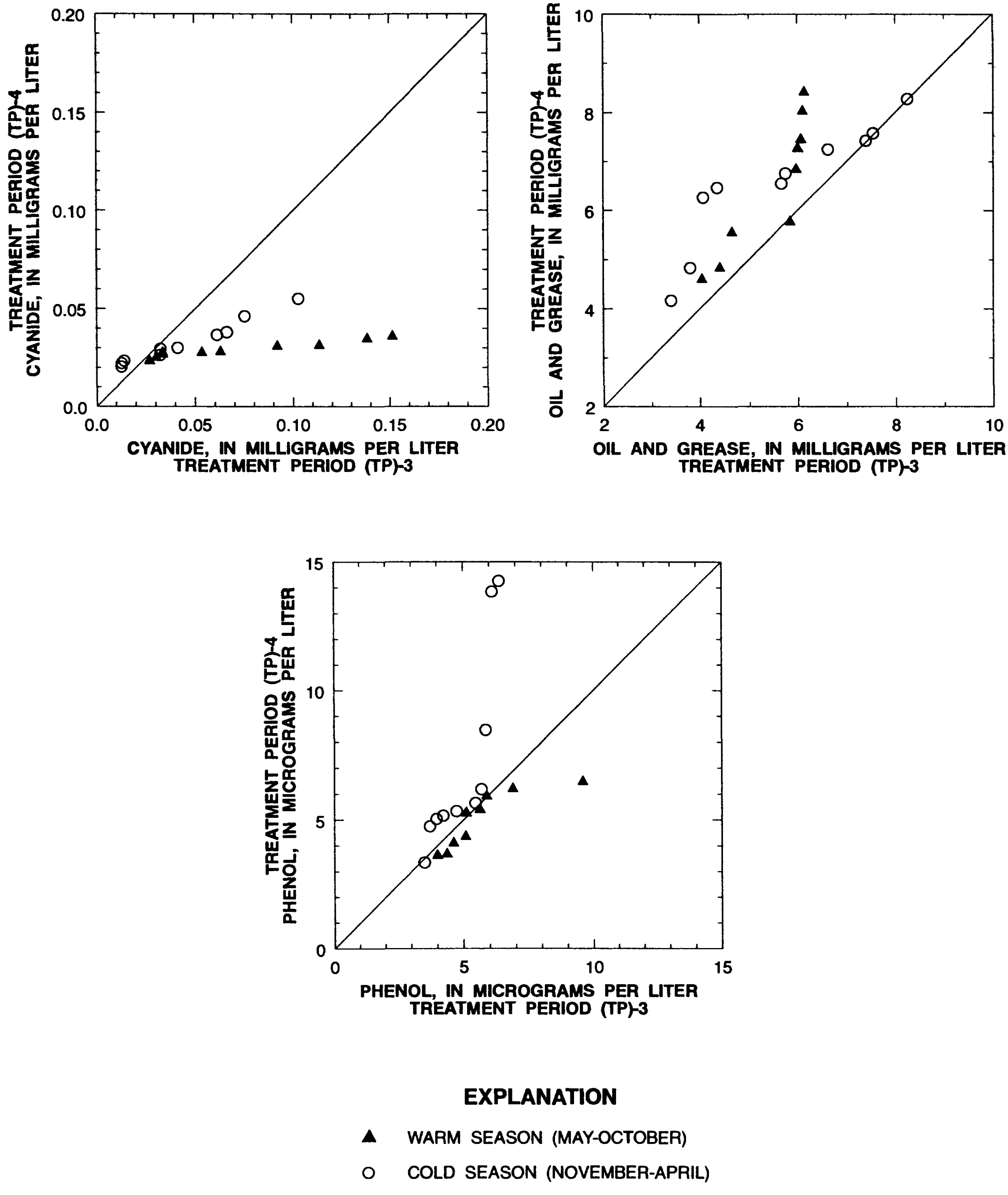


Figure 12. Continued.

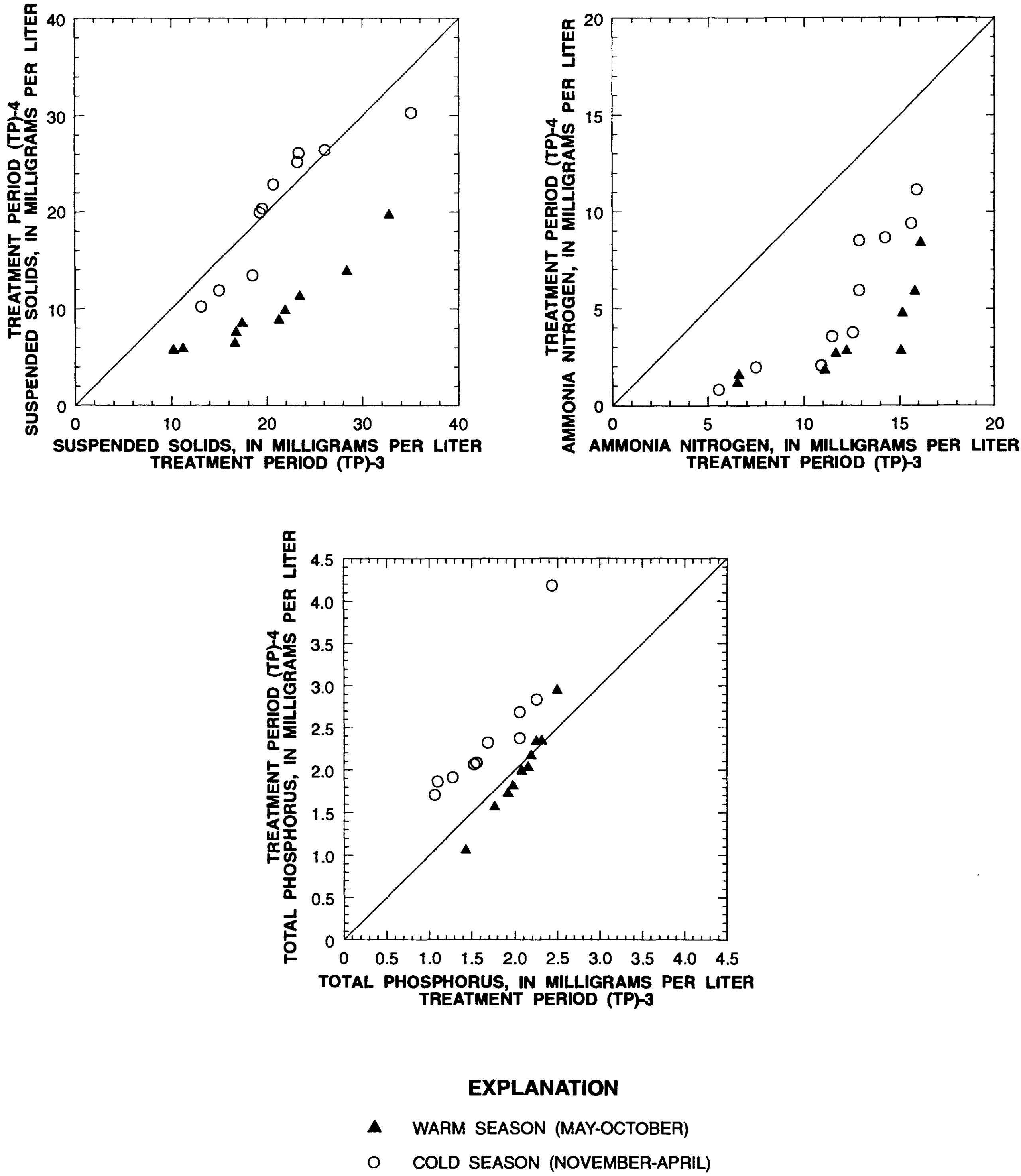
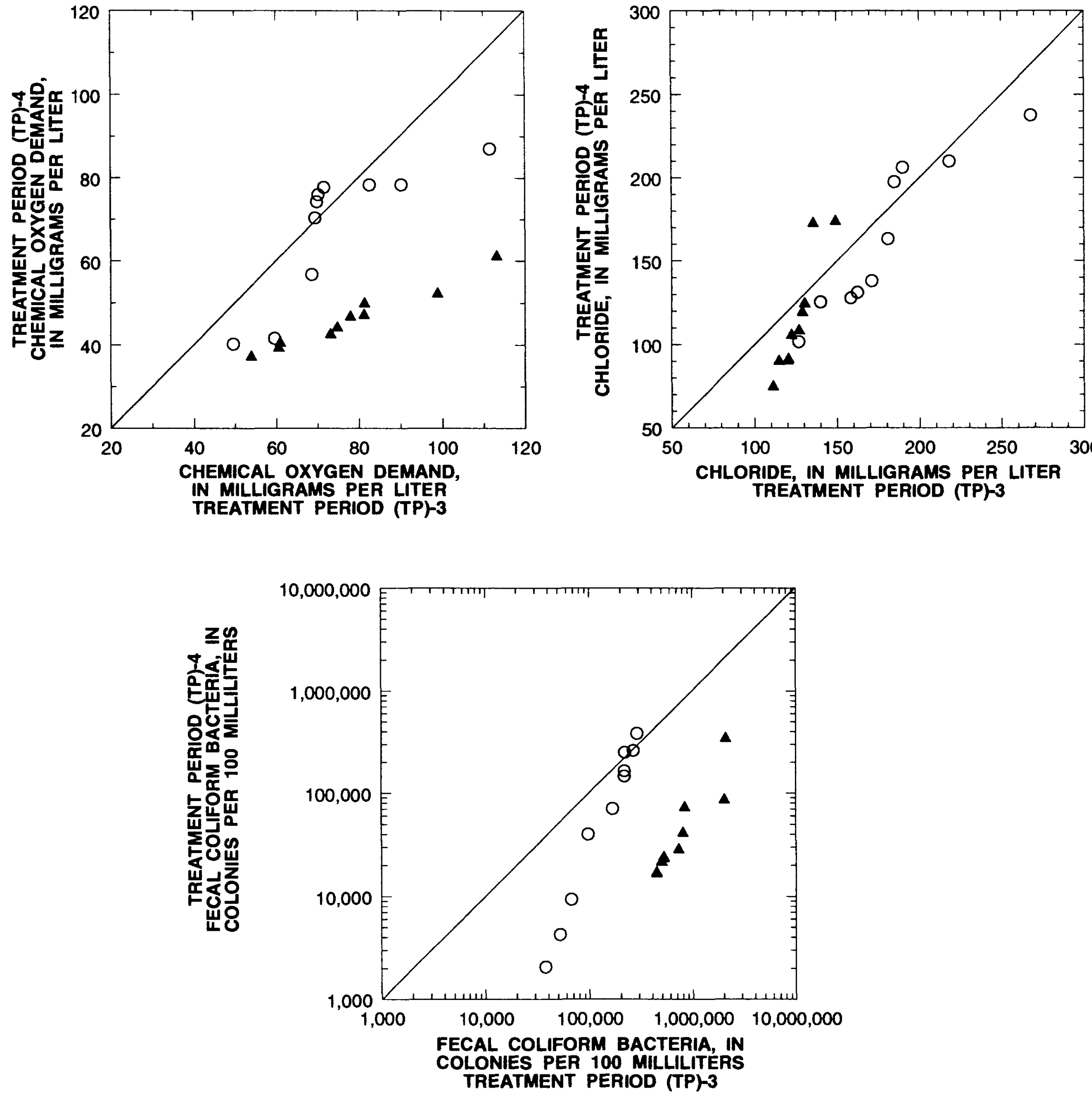


Figure 12. Continued.



EXPLANATION

▲ WARM SEASON (MAY-OCTOBER)

○ COLD SEASON (NOVEMBER-APRIL)

Figure 12. Continued.

phenol for TP-3 and TP-4 are shown in figure 13. Concentrations of BOD in the influent increased from TP-3 to TP-4, likely because of the captured combined sewer overflows routed to the plant through TARP. The effectiveness of the improvements in aeration at the Calumet plant are evident because, although there were increases in influent BOD concentrations, effluent BOD concentrations generally decreased from TP-3 to TP-4.

Influent ammonia-N and phenol concentrations, particularly larger concentrations, generally decreased from TP-3 to TP-4. Reasons for these decreases are not known, but dilution of routine influent by storm-water captured through TARP might have a large effect. No general differences between concentrations from the warm and cold seasons were noted.

The major changes in water quality downstream from the Calumet plant included changes in BOD, ammonia-N, and phenol concentrations. Probability plots showing these changes at site S-2 are shown in figure 14. Concentrations of BOD and phenol were smaller during TP-4 than during TP-3, although the largest concentrations during TP-4 were comparable to the largest concentrations during TP-3. All levels of ammonia-N concentrations were smaller during TP-4. Changes for the remaining downstream monitoring sites were similar to the results found at site S-2.

This analysis showed that concentrations of those constituents examined generally decreased from TP-3 to TP-4. Many of the decreases were attributed to the implementation of TARP, and some were likely the result of improved aeration at the Calumet plant. Specific storm samples and streamflow data would allow a quantification of the changes in the amounts of constituents transported in the stream system following these changes in treatment practices. In addition, such samples also would provide insight into the variability of concentrations during storms and might assist treatment-plant and TARP operators in the effective operation of the systems.

Changes in Biotic Integrity

The effects of the changes in wastewater-treatment practices at the Calumet Water Reclamation Plant on the health of the aquatic biological communities in the Little Calumet River and the Calumet Sag Channel were assessed from fish-assemblage data collected by the MWRDGC at six sites in the Calumet River system. Fish-assemblage data were available at three sites upstream from the Calumet plant and at three sites downstream from the treatment plant (fig. 15). Electrofishing surveys were made at these sites during 1974-77 and again during 1985-90. Data from these surveys included calculated IBI scores. The IBI includes 12 metrics in the categories of species composition, trophic composition, and fish abundance and condition. IBI scores calculated from data collected during 1974-77 were used to describe conditions during TP-1. No data were available for the 1979-84 period, which included all of TP-2. Data collected during 1985-90 provided IBI scores used to characterize biological conditions in the streams during TP-3 and TP-4.

Figure 16 shows the low, high, and average IBI scores for the six fish-sampling sites for TP-1, TP-3, and TP-4. Samples were collected annually during 1974-77 and two to three times a year during 1985-90. The changes in fish-community structure after changes in wastewater-treatment practices were evaluated to the extent possible on the basis of the IBI data set; results did not conform to expectations. Changes in treatment practices at the Calumet plant from TP-1 to TP-3 included the cessation of chlorination and the expansion of the plant. These changes resulted in reduced concentrations of chlorine and ammonia-N in the receiving stream. Increased diversity of species and fish populations normally would be expected to follow these changes in treatment practices. As figure 16 shows, the opposite result occurred at the two nearest downstream sites. Although IBI scores were already low at these sites during TP-1, they decreased further during TP-3. No fish were found during TP-3 at the fish-sampling site 6.6 mi downstream from the Calumet plant. IBI scores recovered at the two nearest downstream sites during TP-4 after improvements in effluent quality resulted from the implementation of TARP and improved aeration at the Calumet plant. The variability of IBI scores (the difference between the minimum and the maximum scores) was largest at most sites during TP-4 and could have been a function of the variable hydrologic conditions in 1987-90. All of the IBI scores for the stream-monitoring sites, regardless of the treatment period, were indicative of poor to very poor ability to support diverse fish communities (Karr and others, 1986). Even though apparent changes in biotic integrity are depicted in figure 16, these differences do not represent substantial changes in the biotic integrity of the streams.

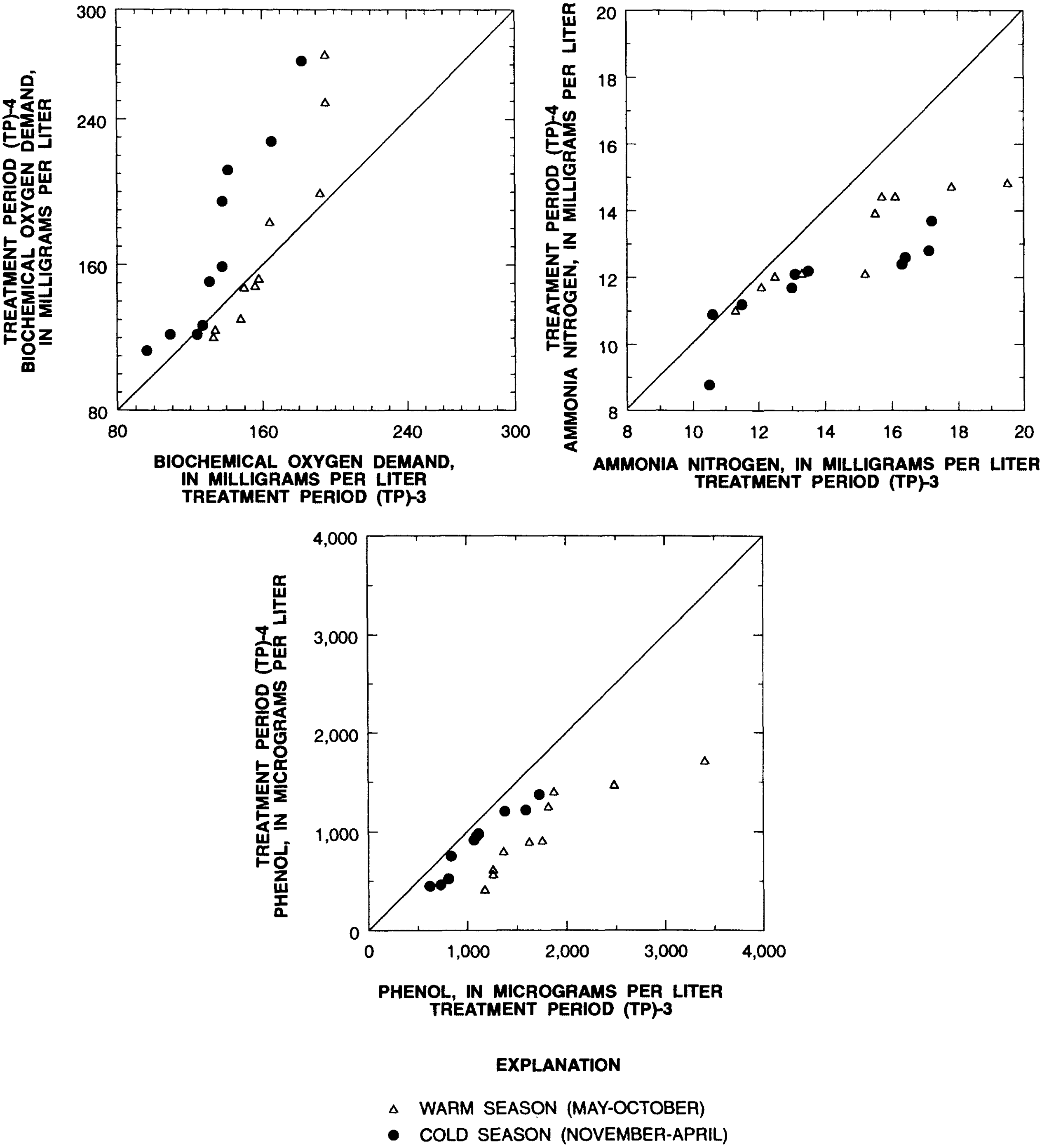


Figure 13. Quantile-quantile plots of concentrations of selected constituents in influent to the Calumet Water Reclamation Plant for treatment periods before (TP-3) and after (TP-4) the implementation of the Tunnel and Reservoir Plan.

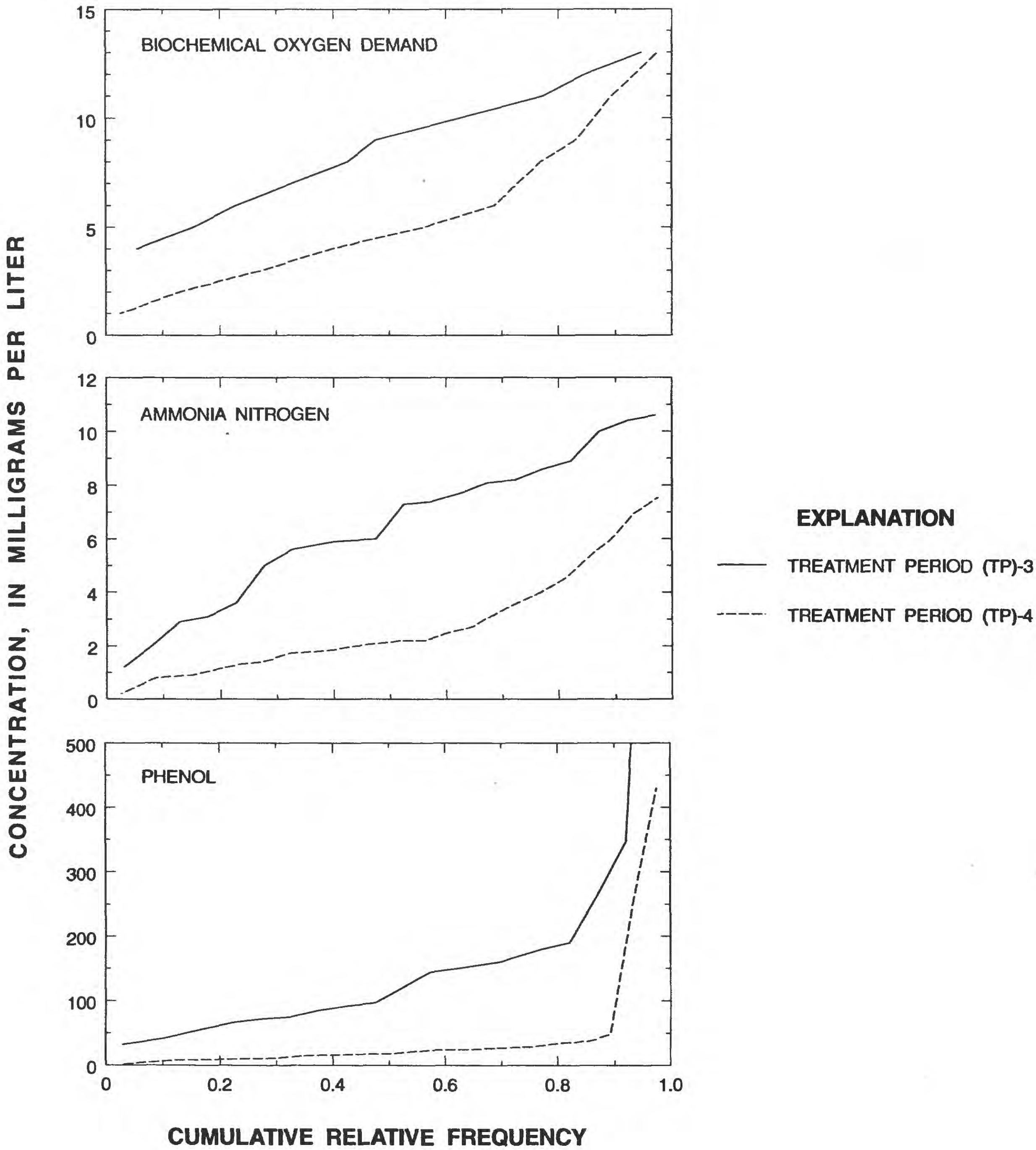


Figure 14. Cumulative relative frequency distribution of concentrations of selected constituents at stream-monitoring site S-2 for treatment periods before (TP-3) and after (TP-4) the implementation of the Tunnel and Reservoir Plan.

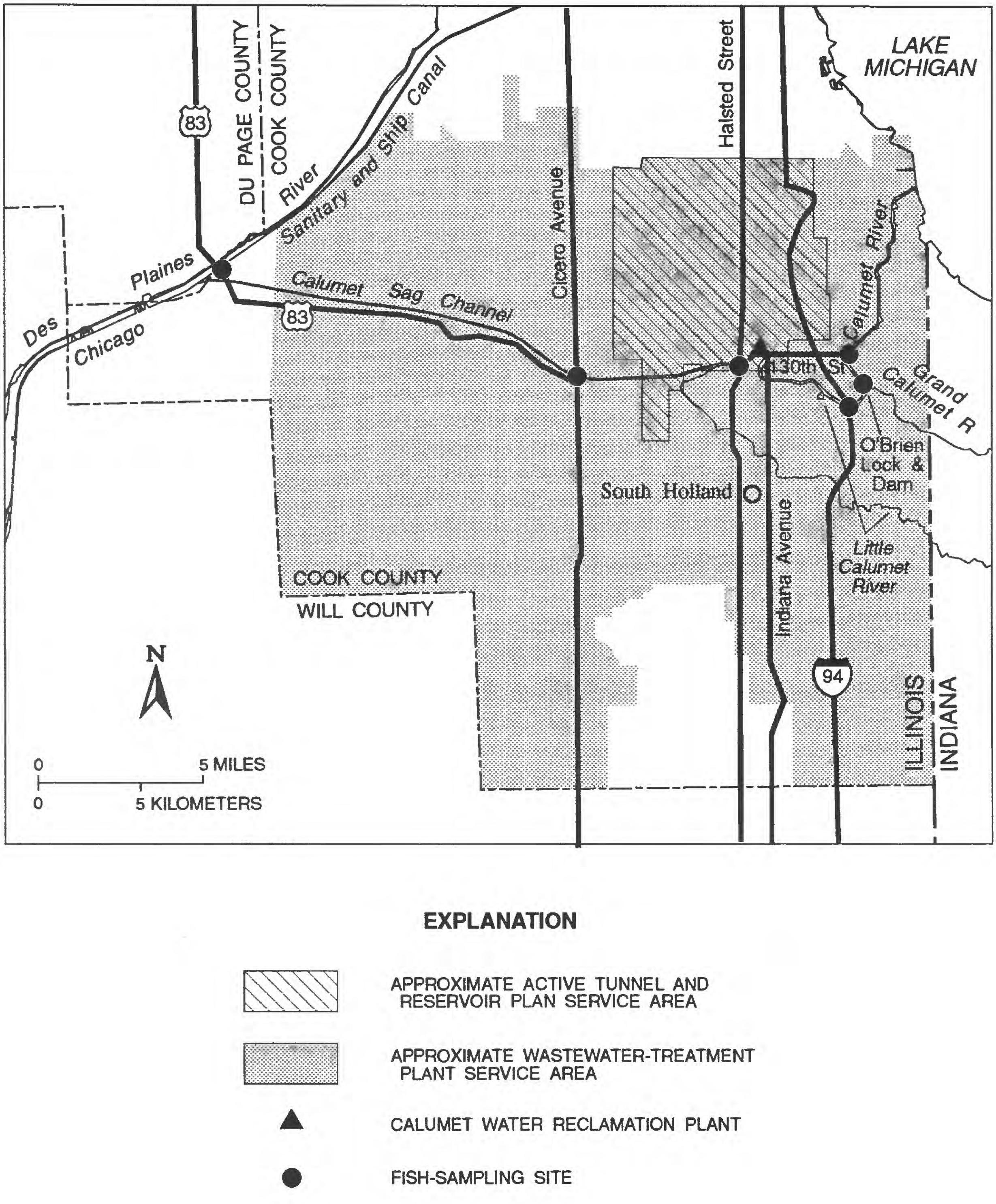


Figure 15. Locations of the Calumet Water Reclamation Plant and associated fish-sampling sites.

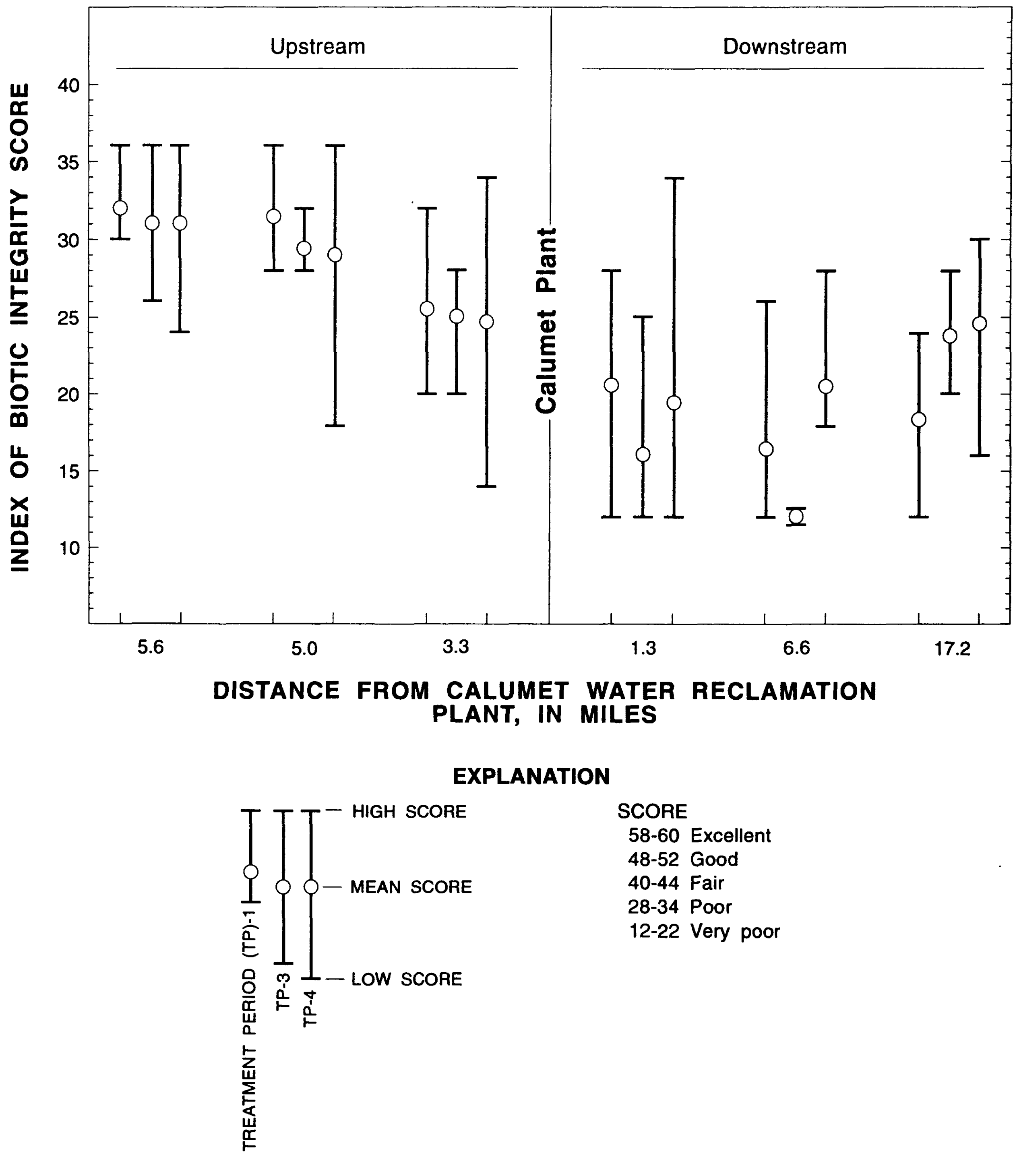


Figure 16. Index of Biotic Integrity scores for fish-sampling sites associated with the Calumet Water Reclamation Plant for treatment periods before (TP-1) the cessation of chlorination and before (TP-3) and after (TP-4) the implementation of the Tunnel and Reservoir Plan.

Observations from the Analysis of Changes at the Calumet Water Reclamation Plant

Several general observations can be made from the analysis of the changes at the Calumet Water Reclamation Plant and changes in water quality. The number and locations of the associated stream-monitoring sites were suitable; in fact, several additional sites that could have been used were not used in the analysis. The absence of discharge data from the stream-monitoring program prohibited any mass-loading and constituent-transport analyses. These types of analyses would have provided additional evidence regarding the factors contributing to changes in stream-water quality and whether or not these changes resulted from changes in wastewater-treatment practices.

Collection of samples at the stream-monitoring sites during and after runoff-producing storms is needed for full determination of the benefits of TARP in terms of stream-water quality. Future expansions of the TARP system may provide an opportunity to collect such measurements and to determine in greater detail the effects of the implementation of TARP on stream-water quality.

Stream-monitoring sites S-4 and S-5 were at the same location–site S-4 was sampled by the MWRDGC and site S-5 was sampled by the IEPA. Although most median concentrations from MWRDGC and IEPA data sets used in this analysis were comparable, there were substantial differences between the data sets for the upper and lower percentiles for some constituents. Bacteria densities were virtually always lower at site S-5. Discrepancies between data from MWRDGC and IEPA can probably be attributed to the differences in sampling methods. MWRDGC uses a grab method; IEPA uses a depth-integrated cross-section method. The differences in the data collected by these two agencies leaves some questions regarding appropriate sample-collection methods and the design of monitoring programs.

Changes have been made in the MWRDGC biological sampling program, and collection of data has been more frequent and consistent since 1985. These improvements should provide a data set more suitable for analyzing changes in stream-water quality.

The analysis of the Calumet Water Reclamation Plant revealed that current monitoring programs, although sufficient for intended regulatory purposes, do not provide all of the information needed for a retrospective assessment to determine changes in stream-water quality resulting from changes in wastewater-treatment practices. A summary of the information needed and the information found for such a retrospective analysis is given in table 11. Potential improvements to enhance the utility of data from the monitoring programs for this type of assessment also are provided in table 11. For these reasons, and because of the extensive effort required to examine other potential influential factors (such as hydrologic conditions and land-use changes), detailed analyses were not done for the remaining four treatments plants. The results of the analysis for these treatment plants are presented, briefly, in the following discussions. The reader should keep in mind, however, that factors other than changes in wastewater-treatment practices probably affected observed water-quality conditions, and more detailed analyses are required for conclusive determination of the relations of changes in wastewater-treatment practices to changes in stream-water quality.

Stickney Water Reclamation Plant

The locations of the Stickney Water Reclamation Plant and the associated stream-monitoring sites, S-6, S-7, and S-8, are shown in figure 3. Stream-monitoring site S-6 was on the Chicago Sanitary and Ship Canal approximately 5.5 mi upstream from the discharge point for effluent from the Stickney Water Reclamation Plant. Sites S-7 and S-8 were on the Chicago Sanitary and Ship Canal, 1.7 and 11.7 mi downstream, respectively, from the point of discharge.

The two major changes in treatment practices at the Stickney plant were the cessation of chlorination in April 1984 and the implementation of TARP in May 1985. The treatment periods established for the analysis of the Stickney Water Reclamation Plant were as follows:

TP-1: January 1978-March 1984,
TP-2: April 1984-April 1985, and
TP-3: May 1985-December 1988.

After the cessation of chlorination, bacteria densities increased in the effluent and downstream at site S-7 (table 12). The Wilcoxon-Mann-Whitney rank-sum test identified these increases with significance levels of 0.0014 for the effluent and 0.0273 for site S-7. Changes in bacteria densities were not statistically significant 11.7 mi downstream at site S-8.

Table 11. Availability of and potential improvements to wastewater-treatment information for the Calumet Water Reclamation Plant and associated stream-monitoring sites

1.	Information desired:	Description and chronology of changes in wastewater-treatment practices.
	Information available:	Major changes documented in Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) annual reports; information also available from Illinois Environmental Protection Agency (IEPA).
		Some more detailed information available from personal communication with MWRDGC personnel.
		Dates associated with major changes; some changes took place concurrently, and some changes required extended periods of time for completion so that specific dates were not available.
	Potential improvement:	Inclusion of information describing changes in wastewater-treatment practices in Federal and (or) State data base(s), such as the Industrial Facilities Discharge or Permit Compliance System data base; annual updates.
		Annual reporting of changes in wastewater-treatment practices, perhaps as a requirement in National Pollutant Discharge Elimination System (NPDES) permits.
2.	Information desired:	Time series water-quality and flow-rate data for treatment-plant influent and effluent for periods before and after changes in treatment practices.
	Information available:	Monthly influent and effluent water-quality data and effluent flow-rate data for 1978-81 from MWRDGC.
		Computerized daily influent and effluent water-quality data and daily effluent flow-rate data for 1982-88 from MWRDGC.
	Potential improvement:	None.
3.	Information desired:	Time series streamflow and water-quality data for stream-monitoring sites above and below the treatment plant for periods before and after changes in treatment practices.
	Information available:	Computerized monthly water-quality data from MWRDGC for 1978-88 at approximately 12 stream-monitoring sites; no streamflow data.
		Computerized IEPA water-quality data on approximately 6-week schedule at one downstream Ambient Water-Quality Monitoring Network site; no streamflow data.
		Different sample-collection methodologies used by MWRDGC and IEPA monitoring programs.
	Potential improvement:	Collection of streamflow data at all or selected stream-monitoring sites to facilitate mass-loading and constituent transport analyses.
		Comparable sample-collection methods between agencies.
4.	Information desired:	Biological data for sites above and below the treatment plant for periods before and after changes in treatment practices.
	Information available:	Wide variety of data collected by several agencies that used different collection and analyses methods and collected data for various purposes.
		Data-collection efforts that were generally less than 3-year duration.
	Potential improvement:	Consistency of biological sampling and analysis methods between agencies.
		Long-term biological monitoring at selected sampling sites.
5.	Information desired:	Stream-water-quality and streamflow data collected during storms and at times when the Tunnel and Reservoir Plan (TARP) was known to be in operation.
	Information available:	No specific water-quality samples associated with storms; no streamflow data.
	Potential improvement:	Collection of stream-water-quality and streamflow data during periods when TARP is known to be in operation.

Table 12. Summary statistics for densities of fecal coliform bacteria in effluent from the Stickney Water Reclamation Plant and at associated stream-monitoring sites during treatment periods before and after the cessation of chlorination in April 1984

Monitoring site (fig. 3)	Density at indicated percentile[1], in colonies per 100 milliliters				
	10	25	50	75	90
TP-1 (January 1978-March 1984)					
S-6	160	430	4,000	26,000	60,000
Stickney Water Reclamation Plant effluent	220	760	3,800	11,000	38,000
S-7	10	52	1,400	16,000	50,000
S-8	60	230	1,900	4,800	37,000
TP-2 (April 1984-April 1985)					
S-6	300	1,100	2,600	22,000	120,000
Stickney Water Reclamation Plant effluent	5,100	11,000	19,000	30,000	37,000
S-7	1,500	2,700	8,000	21,000	82,000
S-8	520	950	2,900	4,800	40,000

[1]Percentage of sample for which values were less than or equal to those shown.

Probability plots of constituent concentrations in effluent from the Stickney plant for TP-2 and TP-3 are given in figure 17. Concentrations of DO and phenol were lower during TP-3, but concentrations of BOD_5, suspended solids, ammonia-N, and cyanide were larger after the implementation of TARP. Constituents that did not have substantial changes in concentrations included COD, chloride, and phosphorus. There were few similarities between the changes in effluent from the Stickney plant and the changes in effluent from the Calumet plant after the implementation of TARP.

Probability plots of ammonia-N and suspended solids concentrations at downstream monitoring sites S-7 and S-8 are shown in figures 18 and 19. These figures show that the increases in ammonia-N concentrations were mostly in the larger concentrations, whereas the decreases in suspended solids were found for all concentration levels. Additional changes at these sites included decreases in phenol at both sites, decreases in BOD and COD at site S-7, and an increase in oil and grease at site S-8. No notable differences in concentrations at site S-6, upstream from the Stickney plant, were detected.

North Side Water Reclamation Plant

The locations of the North Side Water Reclamation Plant and the associated stream-monitoring sites, S-9 and S-10, are shown in figure 3. Site S-9 is on the North Shore Channel approximately 0.8 mi downstream from the diversion at Wilmette and 3.2 mi upstream from the effluent discharge point of the North Side plant. Site S-10 is on the North Shore Channel about 0.7 mi downstream from the point of discharge (Johnson, 1987). Both stream-monitoring sites are within the service area of the North Side plant and within the TARP service area.

Several changes in wastewater-treatment practices were made at the North Side Water Reclamation Plant between 1978 and 1988. Chlorination was discontinued in March 1984, concurrent with the cessation at the Stickney plant. The hydraulic capacity of the treatment plant was increased in 1984, and parts of the plant were taken out of operation during related construction activities. TARP was implemented in the service area of the treatment plant in May 1985. From 1986 through 1988, additional primary- and final-settling tanks were constructed, and diffuser plates for the secondary-treatment process were replaced.

Two treatment periods were used in the analysis of the cessation of chlorination: TP-1 (January 1978-March 1984) and TP-2 (April 1984-April 1985). After the cessation of chlorination, bacteria densities increased significantly in the effluent and at downstream site S-10 (table 13).

Because several changes and improvements were made at the North Side plant throughout the

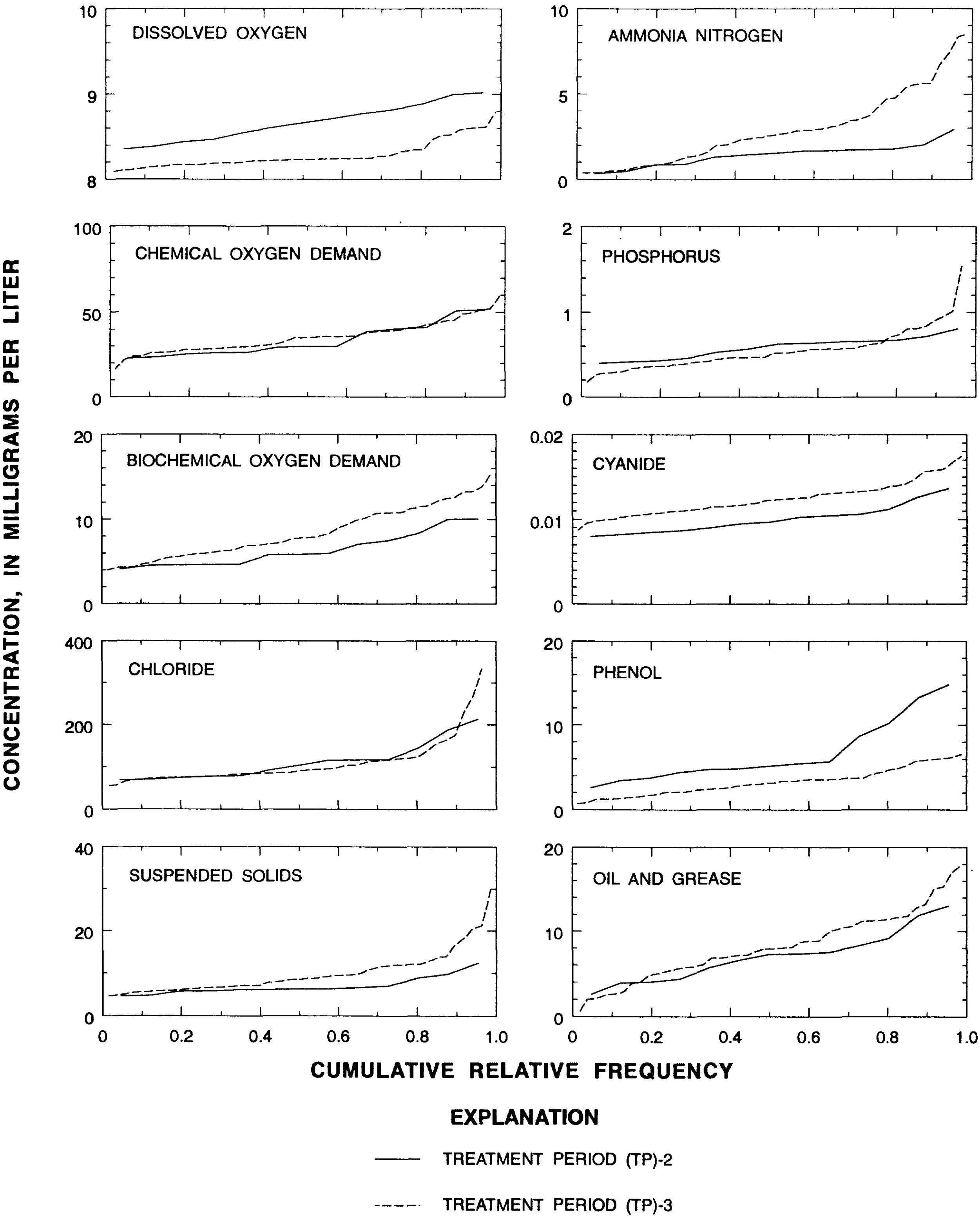


Figure 17. Cumulative relative frequency distribution for selected constituents in effluent from the Stickney Water Reclamation Plant for treatment periods before (TP-2) and after (TP-3) the implementation of the Tunnel and Reservoir Plan.

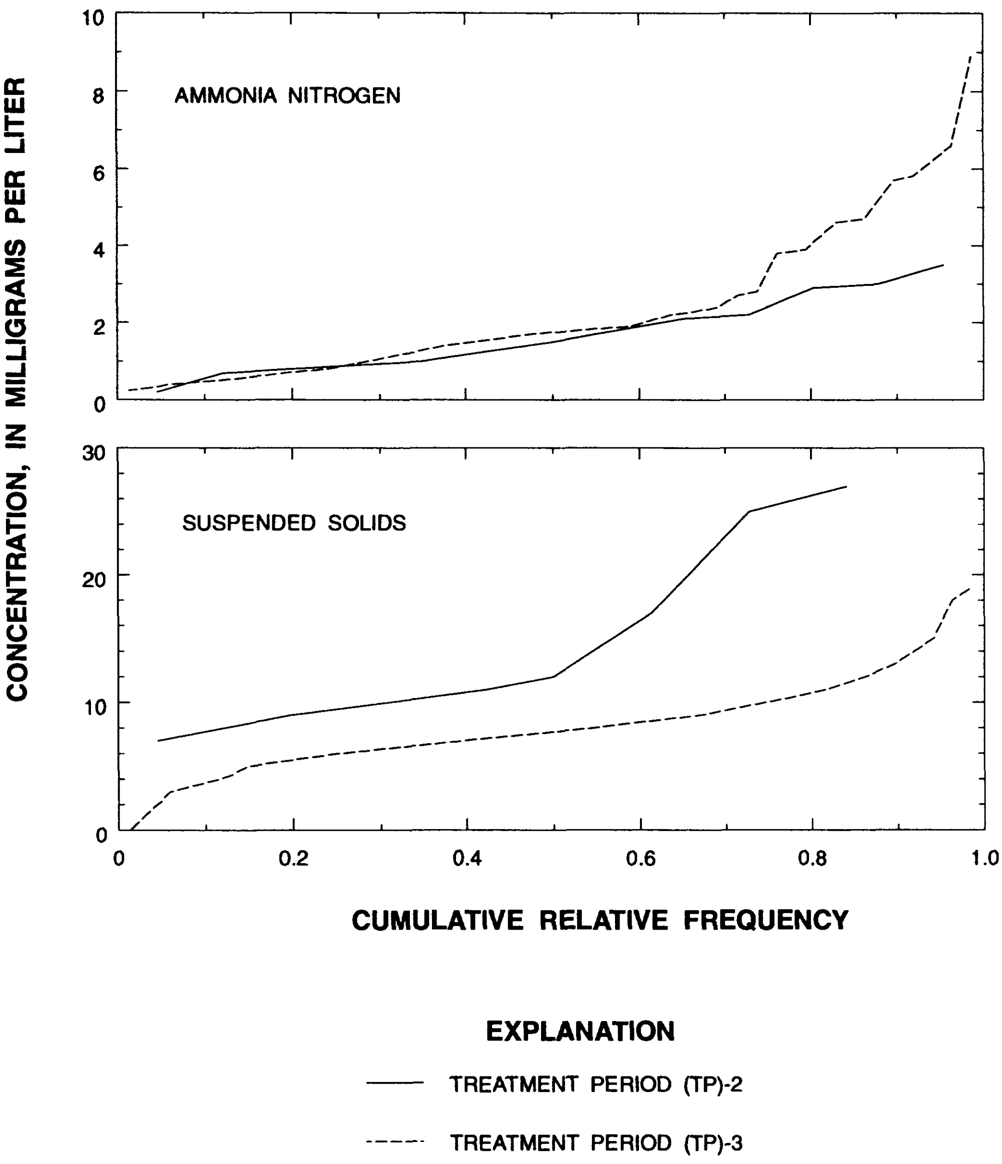


Figure 18. Cumulative relative frequency distribution of ammonia nitrogen and suspended solids concentrations at stream-monitoring site S-7 for treatment periods before (TP-2) and after (TP-3) the implementation of the Tunnel and Reservoir Plan.

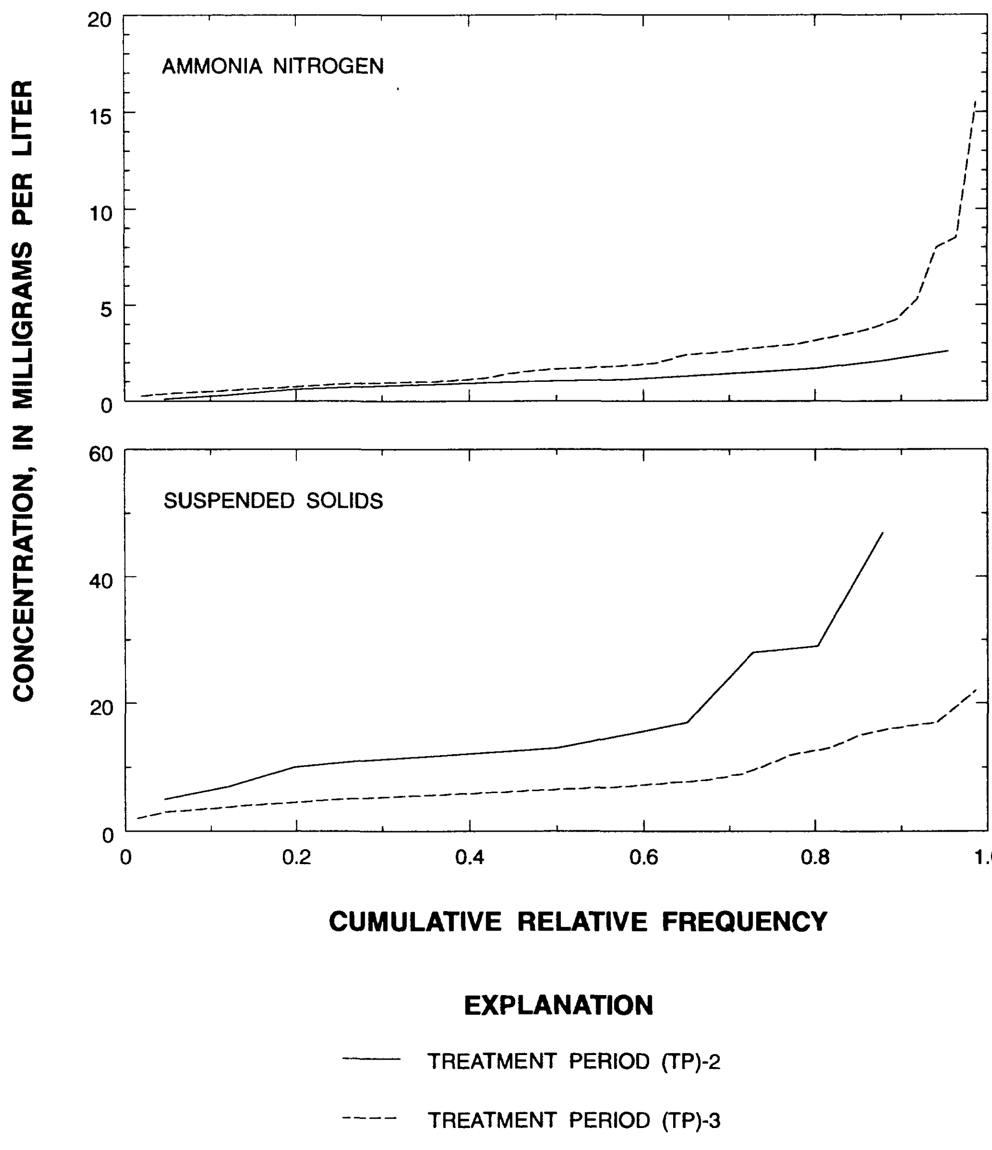


Figure 19. Cumulative relative frequency distribution of ammonia nitrogen and suspended solids concentrations at stream-monitoring site S-8 for treatment periods before (TP-2) and after (TP-3) the implementation of the Tunnel and Reservoir Plan.

Table 13. Summary statistics for densities of fecal coliform bacteria in effluent from the North Side Water Reclamation Plant and at associated stream-monitoring sites during treatment periods before and after the cessation of chlorination in March 1984

Monitoring site (fig. 3)	Density at indicated percentile[1], in colonies per 100 milliliters				
	10	25	50	75	90
TP-1 (January 1978-March 1984)					
S-9	32	130	1,000	9,000	37,000
North Side Water Reclamation Plant effluent	110	220	380	780	1,600
S-10	10	10	40	15	2,400
TP-2 (April 1984-April 1985)					
S-9	13	50	400	1,600	35,000
North Side Water Reclamation Plant effluent	6,700	18,000	25,000	36,000	130,000
S-10	3,800	7,000	15,000	23,000	970,000

[1]Percentage of sample for which values were less than or equal to those shown.

1984-88 period, analyses of individual changes could not be done. Instead, a seasonal Kendall trend test was used to determine significant trends in constituent concentrations during 1978-88, and relations between trends in effluent and stream-water quality were examined.

A single system of TARP serves the service areas of both the North Side and Stickney Water Reclamation Plant (fig. 4). TARP does not convey captured overflows to the North Side plant, but routes captured flows to the Stickney plant for treatment. Historically, periodic storm runoff from streets and overflows from combined sewers were the only sources of contaminants to the North Shore Channel upstream from the North Side plant. Before TARP was implemented, overflows occurred whenever the capacity of the North Side plant was exceeded (Polls and others, 1980). Because TARP operates only when the capacity of the combined-sewer system is exceeded, the quantity of influent to the North Side plant remained virtually unchanged after the implementation of TARP. TARP, however, reduced the quantities of overflows from combined sewers that entered the North Shore Channel during storms.

The results of the seasonal Kendall trend test are presented in table 14. Only a few significant trends were evident at site S-9. The water quality at site S-9 is not influenced much by changes in service area of the treatment plant or by storm runoff and other flows to the North Shore Channel. Water quality at site S-9 primarily reflects the quality of Lake Michigan water.

The changes in the quality of the effluent from the North Side plant presumably were not influenced by TARP, for reasons previously mentioned, but were the result of the other improvements at the treatment plant. Significant trends were indicated for virtually every constituent. With the exception of BOD_5, bacteria, and suspended solids, the trends were all decreases. COD and oil and grease were the two constituents for which no trend in effluent concentration was found. On the basis of the results from the Calumet and Stickney plants, the cessation of chlorination was the probable cause for the increases in bacteria densities.

Trends in stream-water quality at site S-10 were attributed to changes in effluent quality and the reduction in the amount of overflows from combined sewers. For those constituents with a similar trend for the effluent and for site S-10, the magnitude of the trend in effluent quality was larger than, and might have been the cause for, the trend in the stream. In contrast, trends at site S-10 that were opposite of trends for the effluent were presumably due to the elimination of some overflows to the North Shore Channel from combined sewers, a result of TARP.

The analysis of the North Side Water Reclamation Plant emphasized that the setting for each treatment plant is unique and that careful consideration is required in the design of the local monitoring network. In this analysis, the water quality at site S-9 was determined primarily by the quality of water diverted from Lake Michigan and not by changes in the service area

Table 14. Results of the seasonal Kendall trend test for measurements of selected properties and concentrations of selected constituents in effluent from the North Side Water Reclamation Plant and at associated stream-monitoring sites, 1978-88

[Mgal/d, million gallons per day; mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; µg/L, micrograms per liter; n.d., no data were available for this constituent at this site; n.c., the trend was not significant at the 10-percent level; <, less than; --, not applicable. Unless otherwise indicated, concentrations refer to the total amount of constituent present in all phases (solid, suspended, or dissolved; elemental or combined), including all oxidation states]

	Site S-9			North Side Water Reclamation Plant effluent			Site S-10		
Property or constituent	Level of significance	Units per year	Percent of median per year	Level of significance	Units per year	Percent of median per year	Level of significance	Units per year	Percent of median per year
Discharge (Mgal/d)	n.d.	--	--	0.0024	-2.4	-0.83	n.d.	--	--
pH (standard units)	n.c.	--	--	<.0001	-.04	-.46	0.0125	0.02	0.30
Dissolved oxygen (mg/L)	n.c.	--	--	<.0001	-.14	-2.08	n.c.	--	--
Chemical oxygen demand (mg/L)	0.0055	-0.8	-5.77	n.c.	--	--	<.0001	-3.5	-10.3
Biochemical oxygen demand, 5-day (mg/L)	n.c.	--	--	.0216	.3	2.27	n.c.	--	--
Fecal coliform bacteria (col/100 mL)	.0475	-28	-13.3	<.0001	2,930	218	<.0001	999	51.2
Chloride (mg/L)	n.c.	--	--	<.0001	-1.9	-2.08	.0006	-1.5	-2.27
Suspended solids (mg/L)	n.c.	--	--	<.0006	.4	4.35	.0314	-.4	-2.86
Ammonia-N (mg/L)	n.c.	--	--	<.0004	-.202	-5.30	.0025	-.146	-6.66
Phosphorus (mg/L)	.0372	-.005	-7.14	<.0001	-.068	-5.82	<.0001	-.075	-9.74
Cyanide (mg/L)	n.c.	--	--	<.0001	-.001	-4.17	<.0001	-.0015	-12.5
Phenol (µg/L)	.0028	1.0	10.0	<.0001	-.2	-9.30	<.0001	1.4	11.5
Oil and grease (mg/L)	n.c.	--	--	n.c.	--	--	.0694	-.5	-5.56

of the treatment plant or by other inputs to the North Shore Channel. Moreover, water collected by TARP was transported out of the service area entirely, so influent to the North Side plant remained virtually unchanged.

James C. Kirie Water Reclamation Plant

The locations of the James C. Kirie Water Reclamation Plant and the associated stream-monitoring sites, S-11, S-12, S-13, and S-14, are shown in figure 3. The James C. Kirie plant discharges effluent to Higgins Creek, a general-use stream. Higgins Creek is a tributary to Willow Creek, which is a tributary to the Des Plaines River. The James C. Kirie plant is approximately 7 mi upstream from the Des Plaines River. Stream-monitoring sites S-11 and S-12, on Higgins Creek, are monitored by the MWRDGC; site S-11 is approximately 0.2 mi upstream from the James C. Kirie plant, and site S-12 is about 0.06 mi downstream from the discharge point for effluent from the plant. Sites S-13 and S-14 are on the Des Plaines River approximately 9.4 mi upstream and 3 mi downstream, respectively, from the mouth of Willow Creek. They are monitored by the IEPA.

In contrast to the Calumet, Stickney, and North Side plants, no major changes were made in treatment practices or facility improvements at the James C. Kirie plant. Because effluents from the treatment plant are discharged to a general-use stream, chlorination has been used since the plant started operation. The James C. Kirie TARP system began operation concurrently with the treatment plant. The overflows from combined sewers captured by the TARP system are treated at the James C. Kirie plant. Before operation of the James C. Kirie plant, wastewater from the service area was treated by the Calumet, Stickney, and North Side plants.

Stream-water-quality data were collected for several years before the construction of the James C. Kirie Water Reclamation Plant. The construction of the treatment plant provided an opportunity to determine changes in stream-water quality resulting from the discharge of effluent from the wastewater-treatment plant. The periods before and after the construction of the James C. Kirie plant are represented by TP-1 (January 1978-April 1980) and TP-2 (May 1980-December 1988).

Statistically significant increases in concentrations of chloride, ammonia-N, phosphorus, and cyanide were identified at site S-12 after the construction of the James C. Kirie plant (tables 15 and 16). These increases were not indicated upstream at site S-11 and, therefore, were attributed to the discharge of effluent from the James C. Kirie plant to Higgins Creek. Numerous decreases in concentrations were common to sites S-11 and S-12. These decreases presumably were results of the elimination of overflows from combined sewers because of the TARP system.

Sites S-13 and S-14 are on the Des Plaines River. Water-quality data from these sites were used to evaluate the effects of the effluent from the James C. Kirie plant in a large stream and at a greater distance from the effluent discharge point. Effluent from the James C. Kirie plant composed about 24 percent of the total discharge of Des Plaines River at site S-14. The only statistically significant change in water quality indicated at site S-14 that was not indicated at site S-13 was an increase in concentration of suspended solids. Because this increase was not indicated at site S-12, it is unlikely that the increase was caused by the effluent from the James C. Kirie plant. In addition, table 16 shows that the median concentration of total suspended solids at site S-13 increased almost as much as the median concentration at site S-14. These increases may have resulted from construction activities in the expanding residential developments in this area. The operation of the James C. Kirie plant, therefore, was not found to have promulgated changes in water quality in the Des Plaines River for the constituents analyzed.

Some changes, such as decreases in COD concentrations and decreases in bacteria densities, were identified at all four of the stream-monitoring sites upstream and downstream from the treatment plant and may have resulted from the implementation of TARP. It would, however, be difficult to determine whether these changes were attributed to TARP or to other changes in the river basin. The influence of TARP on the water quality of the Des Plaines River at site S-13 would have been minimal because only a very small part of the drainage area upstream from site S-13 was included in the TARP service area.

John E. Egan Water Reclamation Plant

The locations of the John E. Egan Water Reclamation Plant and the associated stream-monitoring sites, S-15 and S-16, are shown in figure 3. The two stream-monitoring sites are on Salt Creek; S-15 is approximately 1.4 mi upstream from the treatment plant, and S-16 is about 0.4 mi downstream from the effluent discharge point of the treatment plant. No major changes in wastewater-treatment practices were identified from 1978 through 1988, and there is no TARP system associated with this plant. Rapid urbanization, however, is occurring in the service area and may be the reason for some changes in effluent, particularly an increase in discharge. The seasonal Kendall trend test was used to identify significant trends in effluent and stream-water quality and to determine any relations between common trends in the effluent and in the stream. Four operating permits were issued for the John E. Egan plant during 1978-88. The major changes in permit requirements became effective in July 1985 and included lower limits for concentrations of BOD_5, suspended solids, and ammonia-N.

Statistical summaries of constituent concentrations for effluent from the John E. Egan Water Reclamation Plant and the associated stream-monitoring sites are given in table 17. Results of the seasonal Kendall trend test for these sites are given in table 18. Significant trends that were indicated for the effluent and downstream at site S-16, but were not indicated upstream at site S-15, included an increase in total phosphorus concentrations and decreases in concentrations of dissolved oxygen and chloride. The magnitudes of these trends were greater for the effluent than for site S-16; and downstream trends, therefore, presumedly resulted from the changes in effluent quality. The trend test indicated an increase in effluent discharge. As urbanization continues, this increase also is expected to continue, and the quality of the effluent may have an increasing effect on stream-water quality.

Changes in effluent quality from the John E. Egan plant also affected constituent concentrations downstream by attenuating upstream trends. In effluent from the John E. Egan plant, COD concentrations increased and suspended solids concentrations decreased slightly. No trend in oil and grease concentrations was indicated. Although trends identified upstream and downstream were similar to one another,

Table 15. Summary statistics for measurements of selected properties and concentrations of selected constituents in effluent from the James C. Kirie Water Reclamation Plant and at associated stream-monitoring sites during treatment periods before and after the construction of the treatment plant

[Mgal/d, million gallons per day; mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; µg/L, micrograms per liter; <, less than; dashes indicate no data were available for this constituent at this site. Unless otherwise indicated, concentrations refer to the total amount of constituent present in all phases (solid, suspended, or dissolved; elemental or combined), including all oxidation states]

Property or constituent	Percentile[1]									
	TP-1 (January 1978-April 1980)					TP-2 (May 1980-December 1988)				
	10	25	50	75	90	10	25	50	75	90
Site S-11										
Discharge (Mgal/d)	--	--	--	--	--	--	--	--	--	--
pH (standard units)	7.0	7.1	7.3	7.7	8.1	7.1	7.3	7.6	7.7	8.0
Dissolved oxygen (mg/L)	4.9	6.0	8.7	11.0	11.5	4.2	6.3	8.0	10.9	12.1
Chemical oxygen demand (mg/L)	39	52	84	119	146	25	31	41	51	63
Biochemical oxygen demand, 5-day (mg/L)	5	6	8	11	18	2	3	5	7	9
Fecal coliform bacteria (col/100 mL)	77	220	1,200	7,000	60,000	30	130	440	2,000	12,800
Chloride (mg/L)	61	80	107	222	311	58	83	126	210	325
Suspended solids (mg/L)	17	27	39	62	174	7	16	27	50	76
Ammonia-N (mg/L)	<.02	.02	.10	.30	.45	<.01	.10	.10	.20	.40
Phosphorus (mg/L)	.08	.15	.24	.40	.57	.02	.09	.15	.24	.48
Cyanide (mg/L)	.002	.003	.006	.008	.010	.002	.002	.004	.005	.010
Phenol (µg/L)	<1	<1	1	5	9	3	13	26	38	64
Oil and grease (mg/L)	<1	8	15	23	35	<1	2	6	13	21
Site S-13										
Discharge (Mgal/d)	65	76	125	198	217	--	--	--	--	--
pH (standard units)	7.6	7.7	7.9	8.2	8.4	7.1	7.3	7.5	7.8	7.9
Dissolved oxygen (mg/L)	6.8	7.7	10.4	12.0	14.3	5.8	6.8	7.9	10.2	12.1
Chemical oxygen demand (mg/L)	20	28	36	40	53	20	23	32	38	50
Biochemical oxygen demand, 5-day (mg/L)	--	--	--	--	--	--	--	--	--	--
Fecal coliform bacteria (col/100 mL)	92	215	465	2,120	9,160	45	120	310	1,050	4,780
Chloride (mg/L)	52	78	115	142	180	60	74	98	120	140
Suspended solids (mg/L)	9	13	29	60	130	7	15	39	71	110
Ammonia-N (mg/L)	.10	.19	.51	1.13	2.38	.08	.13	.24	.39	.81
Phosphorus (mg/L)	.36	.56	.86	1.30	1.56	.15	.28	.50	.72	1.10
Cyanide (mg/L)	<.01	<.01	<.01	<.01	<.01	<.01	<.01	.005	.010	.010
Phenol (µg/L)	--	--	--	--	--	<1	<1	1	1	1
Oil and grease (mg/L)	<1	<1	1	1	2	<1	<1	1	1	2

Table 15. Summary statistics for measurements of selected properties and concentrations of selected constituents in effluent from the James C. Kirie Water Reclamation Plant and at associated stream-monitoring sites during treatment periods before and after the construction of the treatment plant—Continued

Property or constituent	Percentile[1]									
	TP-1 (January 1978-April 1980)					TP-2 (May 1980-December 1988)				
	10	25	50	75	90	10	25	50	75	90
Effluent from the James C. Kirie Water Reclamation Plant										
Discharge (Mgal/d)	--	--	--	--	--	24	28	32	39	45
pH (standard units)	--	--	--	--	--	7.3	7.7	7.8	7.9	8.0
Dissolved oxygen (mg/L)	--	--	--	--	--	8.0	8.4	8.7	9.1	9.7
Chemical oxygen demand (mg/L)	--	--	--	--	--	19	22	26	29	32
Biochemical oxygen demand, 5-day (mg/L)	--	--	--	--	--	2	2	2	2	3
Fecal coliform bacteria (col/100 mL)	--	--	--	--	--	11	28	71	177	438
Chloride (mg/L)	--	--	--	--	--	140	155	203	231	272
Suspended solids (mg/L)	--	--	--	--	--	2	2	2	2	3
Ammonia-N (mg/L)	--	--	--	--	--	.11	.14	.25	.36	.59
Phosphorus (mg/L)	--	--	--	--	--	.49	.67	.94	1.28	1.80
Cyanide (mg/L)	--	--	--	--	--	.007	.008	.009	.011	.012
Phenol (μg/L)	--	--	--	--	--	1	1	2	2	3
Oil and grease (mg/L)	--	--	--	--	--	<1	1	1	1	1
Site S-12										
Discharge (Mgal/d)	--	--	--	--	--	--	--	--	--	--
pH (standard units)	6.8	7.3	7.5	7.7	8.1	7.1	7.3	7.5	7.7	7.8
Dissolved oxygen (mg/L)	4.4	5.9	9.7	11.4	12.0	6.3	7.8	9.0	10.2	11.1
Chemical oxygen demand (mg/L)	40	64	80	107	163	15	23	29	36	45
Biochemical oxygen demand, 5-day (mg/L)	2	4	6	11	17	1	2	3	4	6
Fecal coliform bacteria (col/100 mL)	12	60	310	9,400	60,000	10	10	80	510	4,500
Chloride (mg/L)	49	73	112	227	330	123	148	195	232	281
Suspended solids (mg/L)	17	24	40	89	316	2	3	6	12	26
Ammonia-N (mg/L)	<.10	<.10	.10	.32	.40	<.10	.10	.20	.30	.60
Phosphorus (mg/L)	.04	.09	.18	.30	.92	.24	.47	1.13	1.74	2.24
Cyanide (mg/L)	.003	.004	.006	.010	.020	.006	.009	.013	.017	.022
Phenol (μg/L)	<1	<1	<1	6	9	2	9	18	34	50
Oil and grease (mg/L)	1	12	14	22	34	<1	2	7	12	16

Table 15. Summary statistics for measurements of selected properties and concentrations of selected constituents in effluent from the James C. Kirie Water Reclamation Plant and at associated stream-monitoring sites during treatment periods before and after the construction of the treatment plant—Continued

Property or constituent	Percentile[1]									
	TP-1 (January 1978-April 1980)					TP-2 (May 1980-December 1988)				
	10	25	50	75	90	10	25	50	75	90
					Site S-14					
Discharge (Mgal/d)	91	141	186	837	1,860	775	775	930	1,350	1,350
pH (standard units)	7.4	7.7	7.9	8.1	8.3	7.0	7.2	7.4	7.7	8.0
Dissolved oxygen (mg/L)	4.5	6.6	8.9	10.3	11.8	5.6	7.2	8.9	10.6	12.2
Chemical oxygen demand (mg/L)	24	32	40	44	86	18	25	32	38	45
Biochemical oxygen demand, 5-day (mg/L)	--	--	--	--	--	--	--	--	--	--
Fecal coliform bacteria (col/100 mL)	622	1,020	5,350	12,500	38,300	112	665	1,500	3,600	9,000
Chloride (mg/L)	55	65	110	200	220	72	87	110	150	180
Suspended solids (mg/L)	4	14	29	47	64	11	21	45	74	110
Ammonia-N (mg/L)	.19	.36	.61	1.37	2.70	.09	.16	.30	.46	.79
Phosphorus (mg/L)	.22	.42	.93	1.32	4.30	.19	.32	.51	.81	1.10
Cyanide (mg/L)	<.005	<.005	<.005	<.005	<.005	<.005	<.005	.005	.010	.010
Phenol (µg/L)	--	--	--	--	--	<1	1	5	5	6
Oil and grease (mg/L)	<1	<1	1	1	3	<1	<1	1	1	2

[1]Percentage of sample for which values were less than or equal to those shown.

Table 16. Results of the Wilcoxon-Mann-Whitney rank-sum test for measurements of selected properties and concentrations of selected constituents at stream-monitoring sites associated with the James C. Kirie Water Reclamation Plant for treatment periods before and after the construction of the treatment plant

[+, increase in value or concentration; -, decrease in value or concentration; n.c. indicates that the change was not significant at the 10-percent level; n.d. indicates no data were available for this constituent at this site; <, less than. Test results based on the total amount of constituent present in all phases (solid, suspended, or dissolved; elemental or combined), including all oxidation states]

Property or constituent	Direction of change and (level of significance)			
	Upstream		Downstream	
	S-11	S-13	S-12	S-14
Discharge	n.d.	n.d.	n.d.	+ (0.0139)
pH	n.c.	- (<0.0001)	n.c.	- (.0002)
Dissolved oxygen	n.c.	- (.0713)	n.c.	n.c.
Chemical oxygen demand	- (<0.0001)	- (.0986)	- (<0.0001)	- (.0299)
Biochemical oxygen demand, 5-day	- (<.0001)	n.d.	- (<.0001)	n.d.
Fecal coliform bacteria	- (.0901)	n.c.	- (.0426)	- (.0319)
Chloride	n.c.	n.c.	+ (.0081)	n.c.
Suspended solids	- (.0523)	n.c.	- (<.0001)	+ (.0088)
Ammonia-N	n.c.	- (.0032)	+ (.0140)	- (.0712)
Phosphorus	- (.0185)	- (.0145)	+ (<.0001)	- (.0959)
Cyanide	- (.0169)	+ (.0004)	+ (<.0001)	+ (.0290)
Phenol	+ (<.0001)	n.c.	+ (<.0001)	n.c.
Oil and grease	- (<.0002)	n.c.	- (<.0001)	n.c.

the magnitude of the downstream trend was sometimes smaller because of an opposite trend in the effluent or because of the absence of a trend in the effluent. Because of this, the magnitudes of decreases in concentrations of COD, suspended solids, and oil and grease were smaller at site S-16 (downstream) than at site S-15 (upstream). The decrease in bacteria densities at site S-15 was not indicated at site S-16 because of the comparatively large bacteria densities in the effluent and the lack of a trend in effluent bacteria densities. The magnitude of the increase in phenol concentrations was reduced from site S-15 to site S-16 because of the decrease in phenol concentrations in the effluent.

IMPLICATIONS OF STUDY RESULTS FOR REGIONAL AND NATIONAL WATER-QUALITY ASSESSMENTS

This assessment used available information to determine relations between changes in wastewater-treatment practices and changes in stream-water quality. In addition to analyzing these relations in the study area, inferences for implications to regional and national water-quality assessments were made. The information used for this assessment was available primarily from the MWRDGC and the IEPA. The water-quality monitoring programs of these two agencies are well developed, and many monitoring programs will not provide such comprehensive data sets. Nonetheless, this assessment provided a case study that indicated how available information could be used to relate changes in wastewater-treatment practices to changes in stream-water quality and also identified some needed enhancements and improvements to the monitoring programs that would increase the usefulness of the data. Six implications for regional and national water-quality assessments were indicated by the results of this assessment.

1. **Changes in wastewater-treatment practices may affect stream-water quality, and these effects may vary temporally, spatially, and in magnitude.**

This study exemplified how changes in wastewater-treatment practices may affect the quality of treatment-plant effluent and the water quality of receiving streams. Depending on local conditions,

Table 17. *Summary statistics for measurements of selected properties and concentrations of selected constituents in effluent from the John E. Egan Water Reclamation Plant and at associated stream-monitoring sites, 1978-88*

[Mgal/d, million gallons per day; mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; µg/L, micrograms per liter; <, less than; dashes indicate no data were available for this constituent at this site. Unless otherwise indicated, concentrations refer to the total amount of constituent present in all phases (solid, suspended, or dissolved; elemental or combined), including all oxidation states]

Property or constituent	Percentile[1] 10	25	50	75	90
Site S-15					
Discharge (Mgal/d)	--	--	--	--	--
pH (standard units)	7.1	7.4	7.6	7.8	8.1
Dissolved oxygen (mg/L)	4.5	6.5	8.4	10.2	11.2
Chemical oxygen demand (mg/L)	25	29	38	52	85
Biochemical oxygen demand, 5-day (mg/L)	2	3	4	5	7
Fecal coliform bacteria (col/100 mL)	10	50	190	800	2,720
Chloride (mg/L)	75	90	124	187	250
Suspended solids (mg/L)	11	18	29	47	77
Ammonia-N (mg/L)	<.02	.02	.10	.20	.30
Phosphorus (mg/L)	.05	.10	.14	.20	.50
Cyanide (mg/L)	.002	.003	.004	.005	.009
Phenol (µg/L)	<1	3	16	30	52
Oil and grease (mg/L)	<1	2	7	12	21
Effluent from the John E. Egan Water Reclamation Plant					
Discharge (Mgal/d)	16	19	21	24	26
pH (standard units)	7.2	7.5	7.7	7.8	7.9
Dissolved oxygen (mg/L)	6.0	6.3	7.2	8.2	9.3
Chemical oxygen demand (mg/L)	21	23	25	28	31
Biochemical oxygen demand, 5-day (mg/L)	2	2	2	3	3
Fecal coliform bacteria (col/100 mL)	29	92	239	587	1,690
Chloride (mg/L)	142	189	231	248	282
Suspended solids (mg/L)	1	1	2	2	2
Ammonia-N (mg/L)	.10	.20	.30	.52	.94
Phosphorus (mg/L)	2.39	2.98	3.94	4.89	5.61
Cyanide (mg/L)	.013	.016	.019	.024	.037
Phenol (µg/L)	1	1	2	2	3
Oil and grease (mg/L)	<1	1	1	1	1
Site S-16					
Discharge (Mgal/d)	--	--	--	--	--
pH (standard units)	7.2	7.4	7.6	7.7	7.9
Dissolved oxygen (mg/L)	7.2	8.0	9.0	10.5	11.7
Chemical oxygen demand (mg/L)	21	26	30	43	110
Biochemical oxygen demand, 5-day (mg/L)	1	2	3	3	5
Fecal coliform bacteria (col/100 mL)	10	40	180	670	3,000
Chloride (mg/L)	104	135	190	246	291
Suspended solids (mg/L)	4	7	10	17	31
Ammonia-N (mg/L)	<.02	.10	.20	.40	1.08
Phosphorus (mg/L)	.47	1.09	1.97	3.40	4.71
Cyanide (mg/L)	.005	.009	.013	.017	.026
Phenol (µg/L)	<1	2	11	22	37
Oil and grease (mg/L)	<1	2	8	14	23

[1]Percentage of sample for which values were less than or equal to those shown.

Table 18. Results of the seasonal Kendall trend test for measurements of selected properties and concentrations of selected constituents in effluent from the John E. Egan Water Reclamation Plant and at associated stream-monitoring sites, 1978-88

[Mgal/d, million gallons per day; mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; µg/L, micrograms per liter; n.d., no data were available for this constituent at this site; n.c., the trend was not significant at the 10-percent level; <, less than; --, not applicable. Unless otherwise indicated, concentrations refer to the total amount of constituent present in all phases (solids, suspended, or dissolved; elemental or combined), including all oxidation states]

Property or constituent	Site S-15			John E. Egan Water Reclamation Plant effluent			Site S-16		
	Level of significance	Units per year	Percent of median per year	Level of significance	Units per year	Percent of median per year	Level of significance	Units per year	Percent of median per year
Discharge (Mgal/d)	n.d.	--	--	<0.0001	0.5	2.33	n.d.	--	--
pH (standard units)	n.c.	--	--	<.0001	-.06	-.71	n.c.	--	--
Dissolved oxygen (mg/L)	n.c.	--	--	<.0001	-.18	-2.46	0.0086	-0.07	-0.81
Chemical oxygen demand (mg/L)	<0.0001	-3.2	-8.55	.0002	.4	1.60	<.0001	-2.6	-8.52
Biochemical oxygen demand, 5-day (mg/L)	.0489	-<.1	-<.01	<.0001	-.1	-3.63	.0444	-<.1	-<.01
Fecal coliform bacteria (col/100 mL)	.0002	-30.8	-16.2	n.c.	--	--	n.c.	--	--
Chloride (mg/L)	.0277	5.4	4.31	<.0001	-10.2	-4.44	.0457	-4.0	-2.11
Suspended solids (mg/L)	.0237	-2.0	-6.90	.0013	-.1	-4.27	.0002	-.8	-8.17
Ammonia-N (mg/L)	n.c.	--	--	.0916	-.014	-4.54	n.c.	--	--
Phosphorus (mg/L)	.0740	-.008	-5.34	<.0001	.242	6.14	.0021	.110	5.57
Cyanide (mg/L)	n.c.	--	--	<.0001	-.001	-5.90	n.c.	--	--
Phenol (µg/L)	<.0001	2.6	16.1	<.0001	-.1	-6.12	<.0001	1.7	15.2
Oil and grease (mg/L)	.0303	-.7	-9.52	n.c.	--	--	.0852	-.3	-4.17

these effects may vary spatially, temporally, and in magnitude. Some changes in wastewater-treatment practices may affect only a limited number of constituents, such as the effect of the cessation of chlorination on the densities of fecal coliform bacteria. Other changes, like TARP, may affect many different constituents. In this study, water-quality data from stream-monitoring sites located short distances (less than 7 mi) downstream from treatment plants often showed changes related to changes in wastewater-treatment practices. In some cases, water quality at some stream-monitoring sites farther downstream also was affected. The extent to which changes in wastewater-treatment practices will affect stream-water quality is determined by the physical, chemical, and biological characteristics of the stream, the nature of the change in treatment, and other physical and chemical factors. These factors will differ for each treatment plant and receiving stream. Treatment plants are in most municipalities throughout the Nation and differ greatly with respect to treatment capacity, level of treatment, and effluent quality. Furthermore, treatment-plant effluents, and changes thereto, virtually always affect local stream-water quality and may possibly affect regional stream-water quality to some degree. In a large-scale water-quality assessment, treatment-plant effluents and changes in wastewater-treatment practices need to be recognized as influences on stream-water quality and as potential causes for important changes in stream-water quality.

2. **Available information to document changes in wastewater-treatment practices needs improvement.**

Adequate documentation of changes in wastewater-treatment practices is required to evaluate possible relations between changes in treatment practices, changes in effluent quality, and changes in stream-water quality. For this study, documentations of changes in wastewater-treatment practices were available in MWRDGC annual summary reports and from communication with the treatment-plant operators. Regulatory agencies, such as the IEPA, also maintain some records of changes in wastewater-treatment practices and facility improvements. Specific dates were associated only with major changes in wastewater-treatment practices. Equipment upgrades and replacements also might have altered effluent quality, but these changes were often made concurrent with other changes or implemented over long periods and specific dates of the changes were not available.

In order to facilitate accurate analyses of relations among changes in wastewater-treatment practices and changes in stream-water quality, comprehensive documentation of changes need to be available. Examples of changes that need adequate documentation include changes in treatment processes, such as the cessation of chlorination; treatment upgrades, such as upgrading from secondary to tertiary treatment or the construction of additional treatment units; and changes in the influent to the treatment plants, such as those caused by service-area expansion, the inclusion of combined-sewer overflows, the addition or deletion of industrial effluents, or changes in pretreatment programs. Documentation of changes in wastewater-treatment practices need to include a detailed description of the change, rationale for implementing the change, pertinent dates, and anticipated benefits of the change. In addition, the inclusion of a chronology of changes in wastewater-treatment practices into Federal computerized data bases, such as the Permit Compliance System and the Industrial Facilities Discharge data bases, would increase the utility and dissemination of the information. Annual reporting of changes in wastewater-treatment practices and water-quality-monitoring programs could be incorporated into National Pollutant Discharge Elimination System (NPDES) permit requirements.

3. **Discharge data are needed for all monitoring locations.**

Although extensive water-quality data were available for this assessment, the lack of stream-discharge data prevented the computation of constituent loads and analyses of constituent transport in the receiving streams. For this assessment, records of effluent discharge were available, but stream discharge was measured at only 1 of the 15 stream-monitoring sites. Constituent concentrations provide vital information, but concentrations fluctuate with changes in discharge. Concentrations of a particular constituent may be similar during high- and low-flow periods, but the quantity of the constituent transported during these periods would be markedly different. The calculation of constituent loads is required to determine not only the amounts of constituents discharged and transported but also how these quantities change with time and distance downstream and in response to changes in wastewater-treatment practices. Accurate discharge records are needed for the effluent and at stream-monitoring sites to calculate constituent loads, determine mass transport, and quantitatively evaluate relations between effluent quality and stream-water quality.

4. **Existing monitoring programs differ widely in their ability to detect changes in effluent quality and stream-water quality related to changes in wastewater-treatment practices.**

Some water-quality-monitoring programs analyze several constituents on a monthly frequency; others programs, such as the MWRDGC's, analyze dozens of constituents on a daily basis. In addition, some programs monitor influent, effluent, and stream-water quality; others sample only the effluent. Zogorski and others (1990) examined the availability and suitability of municipal wastewater information in the upper Illinois River Basin for use in a water-quality assessment and found the suitability of the data to accomplish the objectives of the NAWQA was significantly limited. They suggested increasing the number of constituents determined, increasing the frequency of sampling, and developing quality assurance for flow-rate determination. In many instances, enhancements that would markedly increase the utility of the data to evaluate the benefits derived from changes in wastewater-treatment practices in terms of improved stream-water quality could be made to many programs. Several types of data are needed for this type of assessment. Effluent data, both quantity and quality, are needed to determine effluent characteristics and changes in effluent concentrations and loads. Discharge and water-quality data for the receiving stream, both upstream and downstream from the effluent-discharge point, are required to determine changes in stream concentrations and loads and to relate these changes to effluent characteristics. Water-quality data for the influent are needed to determine whether changes in effluent quality resulted from changes in wastewater-treatment practices or from changes in influent quality. As mentioned, discharge data associated with effluent and stream-water-quality data are needed to compute constituent mass loads and to determine constituent transport. Finally, biological-monitoring data and assessments of aquatic communities are needed to determine biological effects from changes in wastewater-treatment practices. Many types of aquatic flora and fauna could be monitored. Maintaining a consistent biological monitoring program in regard to locations, methods, and organisms sampled, however, is critical for the success of any biological monitoring program.

5. **Coordination of monitoring activities between agencies would improve the utility of data-collection efforts.**

Water-quality-monitoring programs differ widely in regard to constituents sampled, collection methods, analytical method, sample-collection frequencies, and sampling-site locations. In this assessment, the MWRDGC collected daily influent and effluent samples and monthly stream-water samples. The stream-water samples were collected in a stainless-steel bucket as grab samples from mid-channel at a depth of 3 ft. The IEPA operated its stream-monitoring program on an approximate 6-week interval and collected water samples by use of depth- and width-integrating techniques. Because of these differences, the data and the changes indicated by the data from these two programs were not always comparable. Although the objectives of specific monitoring programs differ, coordination of efforts between agencies could be of mutual benefit to the agencies involved and could produce valuable data sets useful for a variety of purposes. Improved inter-agency collaboration with regard to sample-collection and field-handling methods, sampling schedules, site locations, collection of streamflow data, and analytical methods could produce more complementary data sets. As seen in this assessment, such data sets would facilitate analyses of water-quality conditions and trends, such as determining the relations among changes in wastewater-treatment practices and changes in stream-water quality.

6. **Monitoring programs may need to be designed or modified to be capable of detecting changes resulting from specific changes in wastewater-treatment practices.**

Historically, monitoring programs were not designed to evaluate the effects of changes in wastewater-treatment practices on stream-water quality and ecosystem health. To quantify these relations, future monitoring programs might need to be designed, and existing programs might need to be modified, to evaluate the effects of specific changes in wastewater-treatment practices. For example, a few additional samples collected during storms would facilitate a complete analysis of the effects of the implementation of TARP on stream-water quality. TARP operates during storms that produce enough runoff to cause combined-sewer systems to overflow, and the effects of TARP would be most evident during and shortly after these storms. The current MWRDGC monitoring program, however, specifies collection of monthly stream-water-quality samples without provision for collecting samples during storms. In addition, MWRDGC stream-monitoring samples typically are collected during the day; water collected by the TARP system, however, generally is treated during the night. Because discharge data were not included in the stream-monitoring program, and because specific storm samples were not collected, it is difficult to identify those samples collected during periods when TARP was in operation. Without this information, only general changes in stream-water quality could be determined, and the full benefit of TARP might be only partly documented.

The ability of many monitoring programs to evaluate benefits to stream-water quality resulting from changes in wastewater-treatment practices could be improved by careful consideration of the monitoring program's components and how these components might determine the utility of the data. Some components to consider include sample-collection methods and frequencies, monitoring-site locations, analytical methods, and constituent lists. Most importantly, however, is the recognition that assessing the effects of changes in wastewater-treatment practices on stream-water quality should be a stated monitoring goal.

SUMMARY

Chlorination was discontinued in 1983 or 1984 at three large treatment plants operated by the Metropolitan Water Reclamation District of Greater Chicago –the Calumet Water Reclamation Plant, the Stickney Water Reclamation Plant, and the North Side Water Reclamation Plant. After the cessation of chlorination, densities of fecal coliform bacteria increased significantly in the effluents of these three treatment plants. Increases in densities of fecal coliform bacteria were detected at some downstream monitoring sites, but no farther than 6.8 mi downstream from effluent-discharge points.

Tunnel and Reservoir Plan (TARP) systems, designed to capture and treat overflows from combined sewers, were implemented in the service areas of the Calumet, Stickney, and North Side plants in

1985 or 1986. Changes in effluent quality and stream-water quality after the implementation of TARP differed between treatment plants, and few similarities were found. Factors possibly contributing to these differences include drainage basin characteristics, ambient stream-water quality, locations of the TARP systems in the treatment-plant service areas, locations of stream-monitoring sites, differences in influent quality, and percentages of the service areas served by the TARP systems. At the Calumet and North Side plants, other changes in wastewater-treatment practices were implemented shortly after the TARP systems became operable, and these changes precluded a determination of the effects from TARP alone.

The primary changes in the water quality of the effluent from the Calumet plant that were attributed to the implementation of TARP or concurrent improvements in aeration included increases in phosphorus and oil and grease and decreases in bacteria, suspended solids, COD, ammonia-N, and cyanide. Changes in water quality at one or more downstream monitoring sites included decreases in DO, ammonia-N, and phenol.

At the Stickney Water Reclamation Plant, changes in effluent characteristics resulting from the implementation of TARP included increases in concentrations of BOD_5, suspended solids, ammonia-N, and cyanide, and decreases in concentrations of DO and phenol. Changes in water quality downstream from the Stickney plant attributed to the implementation of TARP included decreases in ammonia-N, BOD_5, COD, suspended solids, oil and grease, and phenol.

Combined-sewer overflows captured by TARP from the service area of the North Side plant are conveyed to the Stickney plant for treatment. Therefore, it was presumed that the implementation of TARP presumably did not affect the effluent quality of the North Side plant. Several changes in water quality downstream from the treatment plant, however, were attributed to the implementation of TARP. These changes included decreases in concentrations of many constituents and increases in concentrations of phenol and bacteria densities.

Additional primary- and secondary-treatment units were added to the Calumet plant in 1984. These additional units provided for a longer activated-sludge residence time and resulted in decreases in effluent ammonia-N concentrations; however, decreases in ammonia-N concentrations for the influent to the treatment plant also were indicated and may have contributed to the decreases of ammonia-N concentrations in effluent. Regardless of the cause for the decreases in effluent ammonia-N concentrations, corresponding decreases were indicated at the stream-monitoring site 1.5 mi downstream. Ammonia-N concentrations at stream-monitoring sites farther downstream did not change significantly.

The analysis of the James C. Kirie plant focused on differences in stream-water quality from periods before and after the treatment plant began operation in 1980. The associated TARP system began concurrently. Changes in water quality found only at the downstream monitoring site included increases in concentrations of chloride, ammonia-N, phosphorus, and cyanide. Changes common to the upstream and downstream monitoring sites included decreases in densities of fecal coliform bacteria, decreases in concentrations of COD, BOD_5, and suspended solids, and an increase in phenol concentrations. It is not possible, given the available information, to determine if these common changes resulted from the operation of TARP. Because virtually all of these changes involved decreases in concentrations, however, TARP is the presumed cause for these changes.

No major changes were made in wastewater-treatment practices at the John E. Egan plant during 1978-88. A trend analysis was used to identify trends in constituent concentrations and bacteria densities and to determine relations between trends in effluent and stream-water quality. Most of the statistically significant trends in the effluent from the John E. Egan plant were decreases, with the exceptions of increases in discharge and concentrations of COD and phosphorus. The most pronounced changes downstream resulting from trends in effluent quality were increases in concentrations of phosphorus and phenol and decreases in concentrations of COD and suspended solids. Upstream trends for other constituents were attenuated, but not reversed, by trends in the John E. Egan effluent.

Although the data sets used for this study were adequate for their intended purposes, a few enhancements to the monitoring programs would increase the usefulness of data collected in the future for additional purposes. Records of discharge at the stream-monitoring sites would facilitate analyses of (1) the constituent loads and mass transport in the stream systems, (2) variations in stream-water quality for different flow regimes, and (3) the dilution capacities of the receiving streams.

Water-quality samples specifically targeted for providing information on the effects of individual changes in wastewater-treatment practices would enhance the utility of the monitoring data. The effects of some changes in wastewater-treatment practices, such as the implementation of TARP, are most evident at specific times or under certain conditions. Routine sample collection might not provide the necessary information to fully assess the effects of some major changes in wastewater-treatment practices, and the benefits of these changes to stream-water quality may not be fully determined.

Biological analyses can show effects of changes in stream-water quality in ways chemical data cannot because aquatic organisms integrate the effects of water quality over time. For this study, fish-community assemblage data were available from several agencies, but the usefulness of the information was limited because of differences in collection methods and site locations and because of intermittent sample collection.

The results of this study indicated several implications for large-scale water-quality assessments. Wastewater-treatment practices, and changes in these practices, can affect stream-water quality in various ways. Available information from existing ambient monitoring programs might not be adequate to determine the relations between wastewater-treatment practices, effluent quality, and stream-water quality. Stream-discharge data are an important, but commonly omitted, component of ambient monitoring programs. Coordination between agencies operating water-quality-monitoring programs would enhance the utility of available data sets to assess changes in stream-water quality. The goals of existing monitoring programs might need to be modified, and additional monitoring may be required to allow the determination of the effects of wastewater-treatment processes on local and regional stream-water quality and ecosystem health.

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GLOSSARY

Activated sludge. Masses of microorganisms used to aerobically degrade and stabilize wastewater.

Average design capacity. The average amount of wastewater the wastewater-treatment plant is designed to process.

Effluent. Treated wastewater that is discharged from a wastewater-treatment plant.

Imhoff tank. A two-story tank incorporating the removal and digestion of settleable solids and the venting of gases generated in the digestion process.

Influent. Wastewater entering a wastewater-treatment plant, usually from a municipal collection system.

Maximum design capacity. The maximum amount of discharge the wastewater-treatment plant is designed to process.

Nitrification. The conversion of ammonia-nitrogen to nitrite-nitrogen and eventually to nitrate-nitrogen.

Pretreatment. Treatment of wastewater after a commercial or industrial use and before discharge to the municipal wastewater-collection system.

Primary treatment. The initial treatment at a wastewater-treatment plant, usually consisting of separate screening and sedimentation units designed to remove floatable and settleable solids.

Secondary treatment. Aerobic biological treatment and sedimentation, used sometimes in conjunction with biological and chemical processes designed to remove organic material.

Sludge. The solids removed from wastewater during treatment.

Tertiary treatment. Additional biological, chemical, or physical processes designed to remove specific compounds or constituent groups not effectively removed in secondary treatment.

Water year. The 12-month period, October 1 through September 30. The water year is designated by the calender year in which it ends and which includes 9 of the 12 months.