EFFECTS OF ADVANCED TREATMENT OF MUNICIPAL WASTEWATER ON THE WHITE RIVER NEAR INDIANAPOLIS, INDIANA: TRENDS IN WATER QUALITY, 1978-86

U.S. GEOLOGICAL SURVEY

Open-File Report 88-335

Prepared in cooperation with the

CITY OF INDIANAPOLIS DEPARTMENT OF PUBLIC WORKS

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CONVERSION FACTORS AND ABBREVIATIONS

For use of readers who prefer to use metric (International System) units, rather than the inch-pound terms used in this report, the following conversion factors may be used:

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
square foot (ft^2)	0.0929	square meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.0283	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
pound (lb)	0.4536	kilogram
pound per day (lb/d)	0.4536	kilogram per day
quart (qt)	0.9464	liter

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

$$°F = (1.8 \times °C) + 32$$

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ABSTRACT

The City of Indianapolis has constructed state-of-the-art advanced municipal wastewater-treatment systems to enlarge and upgrade the existing secondary-treatment processes at its Belmont and Southport treatment plants. These plants became operational in 1983.

A nonparametric statistical procedure--a modified form of the Wilcoxon-Mann-Whitney rank-sum test--was used to test for trends in time-series water-quality data from four sites on White River and from the Belmont and Southport wastewater-treatment plants. Time-series data representative of pre-advanced (1978 through 1980) and post-advanced (1983 through 1986) wastewater-treatment conditions were tested for trends and the results indicate substantial changes in water quality of treated effluent and of White River downstream from Indianapolis after implementation of advanced-wastewater treatment. Water quality during 1981 through 1982 was highly variable due to plant construction. Therefore, this time period was excluded from the analysis. Water quality at sample sites located upstream from the wastewater-treatment plants was relatively constant during the period of study (1978 through 1986).

Analysis of data from the two plants and downstream from the plants indicates statistically significant decreasing trends in concentrations of total ammonia, 5-day biochemical-oxygen demand, fecal-coliform bacteria, total phosphate, and total solids at all sites where sufficient data were available for testing. Because of in-plant nitrification, increases in nitrate concentration were statistically significant in both the plants and in White River. The decrease in ammonia concentrations and 5-day biochemical-oxygen demand in White River resulted in a statistically significant increasing trend in dissolved-oxygen concentration because of reduced oxygen demand for nitrification and biochemical oxidation processes. Following implementation of advanced-wastewater treatment, the number of river-quality samples that failed to meet the water-quality standards for ammonia and dissolved oxygen that apply to White River decreased substantially.

INTRODUCTION

Background of Study

The Clean Water Act of 1972 established rigorous effluent quality standards for industrial and municipal wastewater. In response to the Act, and to subsequent Federal and State regulations, the City of Indianapolis constructed state-of-the-art advanced wastewater-treatment (AWT) systems to enlarge and upgrade the two existing secondary wastewater-treatment plants. The new AWT plants began operation in January 1983. The plants have ozonation of the final effluent rather than chlorination, and an oxygen-nitrification system. The ozone-production system and oxygen-nitrification system are presently among the largest systems in the world of this type used for wastewater treatment. The new AWT plants are designed to process up to 245 million gallons of effluent per day (368 ft^3/s [cubic feet per second]) at a quality that approaches drinking-water standards.

The study area is in the middle of the White River drainage basin. The basin drains a 2,655 mi^2 (square mile) area in central Indiana (fig. 1). The river flows generally west and southwest to its confluence with the Wabash River. Land use in the drainage basin is about 68 percent agriculture, 19 percent urban, 7 percent forest, and 6 percent other land uses (U.S. Soil Conservation Service, 1968). Several major population centers, including Muncie, Anderson, Noblesville, Indianapolis, and Martinsville discharge effluents into the White River. According to studies by Shampine (1975) and the Indiana Heartland Coordinating Commission (1976), the water quality of the river was affected most by the Indianapolis area. Most water-quality problems in White River downstream from the Indianapolis area were attributed to stormwater runoff from both combined sanitary and storm and separated storm sewers and to effluent from the city's wastewater-treatment plants.

The U.S. Geological Survey, in cooperation with the City of Indianapolis, Department of Public Works, began studying the effects of municipal wastewater on the water quality of White River downstream from Indianapolis in October 1981. Since that time, the study has included: (1) collection of data used to calibrate and verify two dissolved oxygen (DO) models; (2) collection of biological samples to determine changes in aquatic flora and fauna; (3) collection of water-quality data at a fixed-station monitoring network; and (4) collection of continuous DO monitoring data to evaluate the effects of combined storm and sanitary and storm sewer flows on the DO dynamics of the White River during various flow conditions. This report describes trend analyses of water-quality data from the fixed-station monitoring network. For the purpose of this report, the period of study before January 1981 is defined as pre-AWT and the period of study after January 1983 is defined as post-AWT. During the period from January 1981 to January 1983, water-quality conditions were variable because of plant construction; therefore, the data were not used in the analyses.

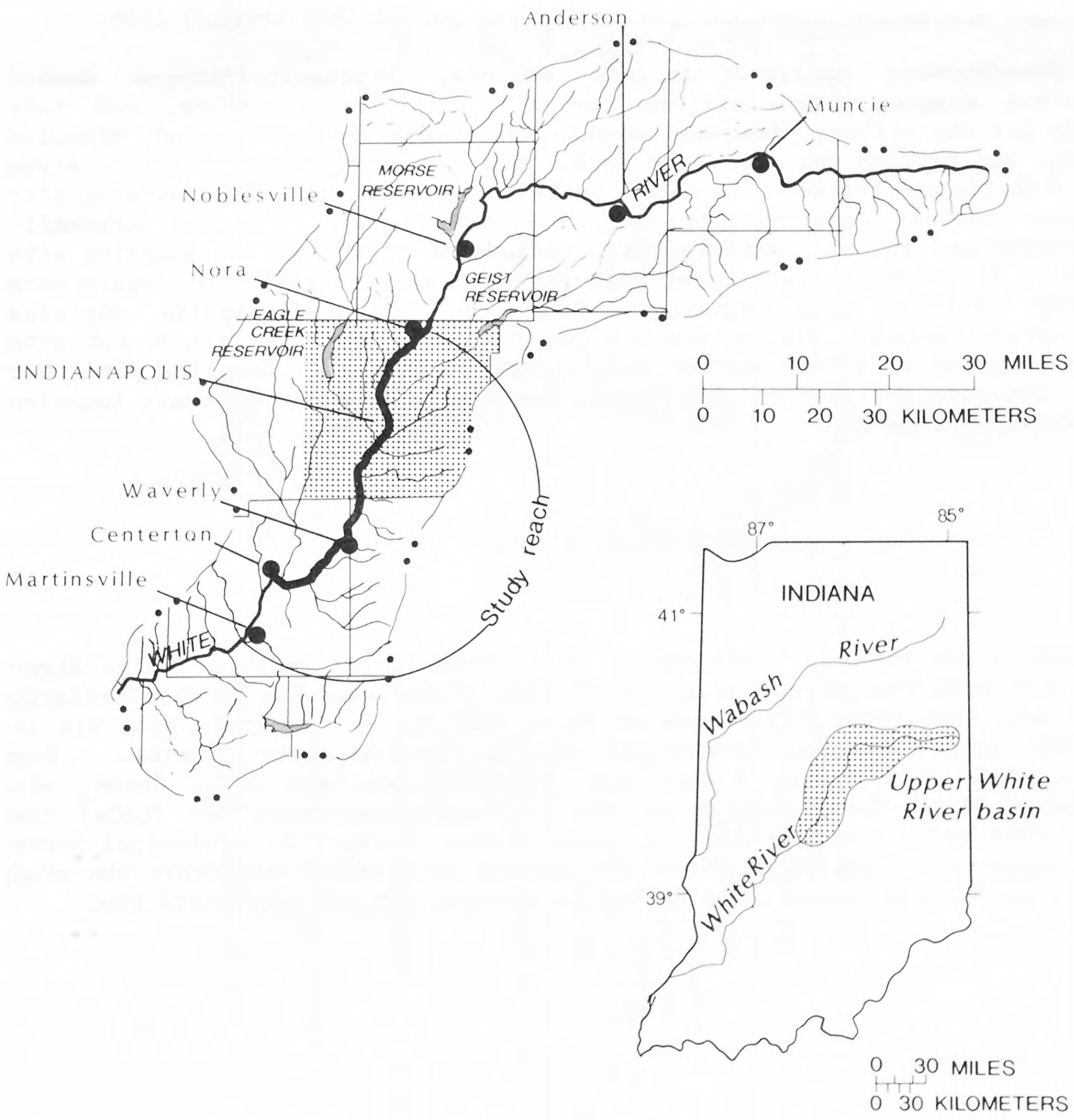


Figure 1.-- Upper White River basin and study area.

Purpose and Scope

The purpose of this report is to describe changes in the water quality of White River that occurred after the implementation of AWT. This report includes analyses of data collected from three locations on the White River between 1978 and 1986 by the City of Indianapolis, Department of Public Works, and the U.S. Geological Survey, and data from one location on the White River between 1958 and 1986 by the Indiana State Board of Health. This report also includes analyses of daily effluent data from the Belmont and Southport municipal wastewater-treatment plants for the period 1978 through 1986.

Constituents analyzed include ammonia, biochemical-oxygen demand, dissolved oxygen, fecal-coliform bacteria, nitrate, phosphate, and total solids for the effluent data and ammonia, biochemical-oxygen demand, dissolved oxygen, and nitrate for the river data. The data were statistically analyzed for significant changes in water quality and trends. The water-quality analyses reflect water-quality conditions over a wide range of streamflow conditions and seasonal differences. Periods of record at the sampling sites on White River are variable, but adequate data are available to compare water quality upstream and downstream from the two Indianapolis municipal wastewater-treatment plants and to compare water quality before and after implementation of AWT by use of statistical techniques. Sampling sites with data that were analyzed in this report are listed in table 1; their locations are shown on figure 2.

DESCRIPTION OF STUDY AREA

The study area for this report is a 48-mi (mile) reach of White River, extending from 82nd Street on the north side of Indianapolis to near Centerton (fig. 2). The major influences on water quality in the study area are the Belmont and Southport municipal wastewater-treatment plants. Four tributaries, Fall Creek, Pogues Run, Pleasant Run, and Eagle Creek, also influence White River because of the combined sewer overflows (CSOs) that enter them and ultimately flow to White River. Three U.S. Geological Survey continuous-record gaging stations are located on White River within the study area: one at 82nd Street, one at Morris Street, and one near Centerton.

Table 1.--Location of and period of record for municipal wastewater effluents and sampling sites on White River

[DPW, Department of Public Works; ISBH, Indiana State Board of Health; USGS, U.S. Geological Survey; n.d., no data]

Sampling site name	Sampling site number (fig. 2)	Location (river mile)	DPW Period of record	ISBH Period of record	USGS Period of record
White River at 82nd Street[1]	1	247.87	n.d.	01/58 to 12/86	n.d.
White River at Morris Street[1]	2	230.30	01/78 to 12/86	n.d.	08/82 to 12/86
Belmont plant effluent	3	[2]226.70	01/78 to 12/86	n.d.	n.d.
Southport plant effluent	4	[3]221.90	01/78 to 12/86	n.d.	n.d.
White River at Waverly	5	212.20	01/78 to 07/82	n.d.	08/82 to 12/86
White River near Centerton[1]	6	199.31	01/78 to 07/82	n.d.	08/82 to 12/86

[1]USGS continuous-record gaging station.
[2]Present location of effluent discharge; prior to 1983 located at river mile 227.50.
[3]Present location of effluent discharge; prior to 1983 located at river mile 222.11.

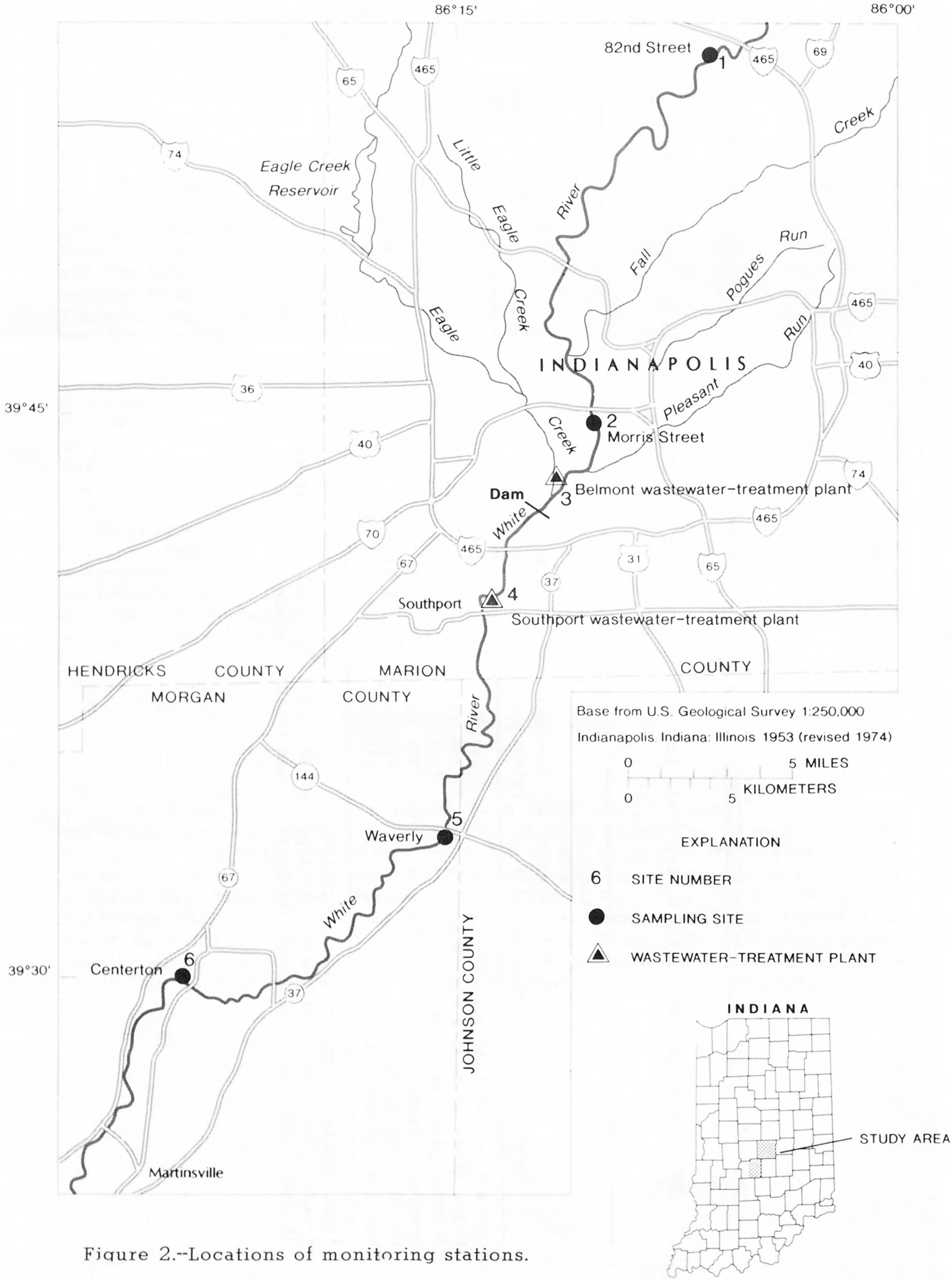


Figure 2.--Locations of monitoring stations.

DATA COLLECTION

Water was collected by the U.S. Geological Survey from at least five points on the cross section, using the equal-width-increment technique. The water was composited in a churn, thoroughly mixed, and a sample drawn off and analyzed for total concentrations of ammonia, 5-day biochemical-oxygen demand (BOD_5), nitrate, organic nitrogen, and orthophosphate. A sample to be analyzed for fecal-coliform bacteria was collected from the center of flow in a sterilized biochemical-oxygen demand (BOD) bottle. BOD_5 was analyzed according to techniques described by the American Public Health Association and others (1976). Nutrient analyses were done according to techniques described by Skougstad and others (1979). Techniques for analysis of fecal-coliform bacteria are described by Greeson and others (1977). The dissolved-oxygen concentration was measured at each point on the cross-section, and the measurements were averaged for each site. Field instruments were calibrated each day according to the manufacturer's specifications. Water samples were collected by other agencies from the center of flow and analyzed, using standard methods described by the American Public Health Association and others (1976). Nitrogen species are reported in concentrations as nitrogen. Phosphorus species are reported in concentrations as phosphorus.

For the sampling sites at White River at 82nd Street, Morris Street, and near Centerton, flow was obtained directly from the U.S. Geological Survey gage. River stage was measured at the time of sampling and a corresponding flow was selected from the rating table for that site. For the sampling site at White River at Waverly, where no gaging stations existed, several flow measurements were made over a wide range in stage, and a correlation was developed between the flow at this site and the flow at the U.S. Geological Survey gage near Centerton. Flow was then estimated for the ungaged site for the date of sample collection, based on discharge near the Centerton gage for that date. Flow from the Belmont and Southport treatment plants was measured by continuous-recording flow meters operated by plant personnel.

DATA SUMMARY

Flow Data

A summary of the flow data that are discussed in this report is listed in table 2. The data were divided to represent sampling conditions prior to and following implementation of advanced wastewater treatment.

Table 2.--Summary of instantaneous flow data for municipal wastewater effluents and sampling sites on White River

[ft^3/s, cubic foot per second; Post-AWT, period of study after implementation of advanced wastewater treatment; Pre-AWT, period of study before implementation of advanced wastewater treatment]

Sampling site name	Sampling site number (fig. 6)	River mile	Period of record[1] (month/year)	Number of observations	Mean flow (ft^3/s)	Median flow (ft^3/s)	Interquartile range[2] (ft^3/s)	Maximum flow (ft^3/s)	Minimum flow (ft^3/s)
White River at 82nd Street	1	247.87	01/58 - 12/86	497	1,140	502	786	23,100	104
			Pre-AWT						
White River at 82nd Street	1	247.87	01/78 - 12/80	35	1,390	640	1,420	9,980	237
White River at Morris Street	2	230.30	01/78 - 12/80	143	1,810	956	1,300	20,000	180
Belmont plant effluent	3	227.50	01/78 - 12/80	[3]1,033	143	140	39	226	68
Southport plant effluent	4	222.11	01/78 - 12/80	[3]1,061	79	79	20	124	24
White River at Waverly	5	212.20	01/78 - 12/80	145	2,550	1,400	1,780	18,600	371
White River near Centerton	6	202.64	01/78 - 12/80	142	2,860	1,650	2,070	21,100	446
			Post-AWT						
White River at 82nd Street	1	247.87	01/83 - 12/86	38	2,010	714	975	23,100	176
White River at Morris Street	2	230.30	01/83 - 12/86	47	1,570	757	1,540	16,700	103
Belmont plant effluent	3	[4]226.70	01/83 - 12/86	[3]1,458	145	140	38	255	71
Southport plant effluent	4	[4]221.90	01/83 - 12/86	[3]1,459	117	113	24	299	42
White River at Waverly	5	212.20	01/83 - 12/86	48	1,970	1,320	1,970	9,630	190
White River near Centerton	6	202.64	01/83 - 12/86	48	2,290	1,540	2,260	11,200	236

[1]Period of record includes the time period for which flow data correspond to the collection of a water-quality sample. Period of record does not include, in the case of a continuous-record gaging station, the complete record of daily mean flows.
[2]Interquartile range is the difference between the 75th and 25th percentiles.
[3]Flow data provided by Department of Public Works.
[4]Effluent outfalls for both the Belmont and Southport wastewater-treatment plants were relocated during the construction.

The relation of flow to time at four river sites is shown in figure 3: White River at 82nd Street and at Morris Street (upstream from both plants), and White River at Waverly and near Centerton (downstream from both plants). The relation of flow to time at the Belmont and Southport wastewater-treatment plants is shown in figure 4. The data for the period 1981 through 1982 are not shown because of the effects that plant construction had on the quality of the effluents.

Flow from the Southport plant increased because of increased design capacity and a connector system that allows Belmont to transfer sewage to Southport. Wastewater that previously had been routed to the Belmont plant, but was in excess of the plant's capacity, had to be stored or bypassed to White River. The expansion of the Southport plant and construction of the new connector system allow the excess wastewater to be bypassed to the Southport plant for treatment. Thus, there has been an increase in flow from the Southport plant; no change in treated flow from the Belmont plant; elimination of the bypass flow; but no detectable change in flow in the river downstream from the plants.

Flow-duration tables of daily mean flow were calculated for White River at 82nd Street and at Morris Street, using daily values for the period of record from 1931 through 1984. Duration curves were drawn using the information from the tables. The curves are shown in figure 5. The maximum, minimum, and median flows at which water-quality samples were collected and analyzed also are shown in figure 5. The maximum flows at which water-quality samples were collected are near the maximum flows recorded for the gages. The minimum flows sampled are near the minimum recorded flows and are only about twice the calculated 7-day, 10-year low flow for both gages. Median flows at which water-quality samples were collected and analyzed were equaled or exceeded during the period of record 35 to 50 percent of the time. The data discussed in this report are representative of nearly the entire range of flow at the gaging stations at 82nd Street and Morris Street.

The two duration curves cross at the lower end of the curves. The more typical curve is that shown for the 82nd Street gage. Between the two gages, river water is diverted for use as a municipal-water supply. The diverted water enters White River again as treated effluent from the Belmont wastewater-treatment plant downstream from the Morris Street gage and, therefore, is never measured at the Morris Street gage.

Discharges from both treatment plants represent a large percentage of the total flow in White River downstream from the plants. For example, if median flows at the Belmont and Southport plants are compared with the change in median flows between Morris Street and Waverly, about 42 percent of the flow entering White River is treated effluent. When the same comparison is made using minimum values of flow, 100 percent of the increase in flow between Morris Street and Waverly is treated effluent. These numbers are based on monthly medians, rather than on an analysis of daily mean flow values, but the comparison does show that treated effluent is a significant percentage of flow in the White River downstream from Indianapolis.

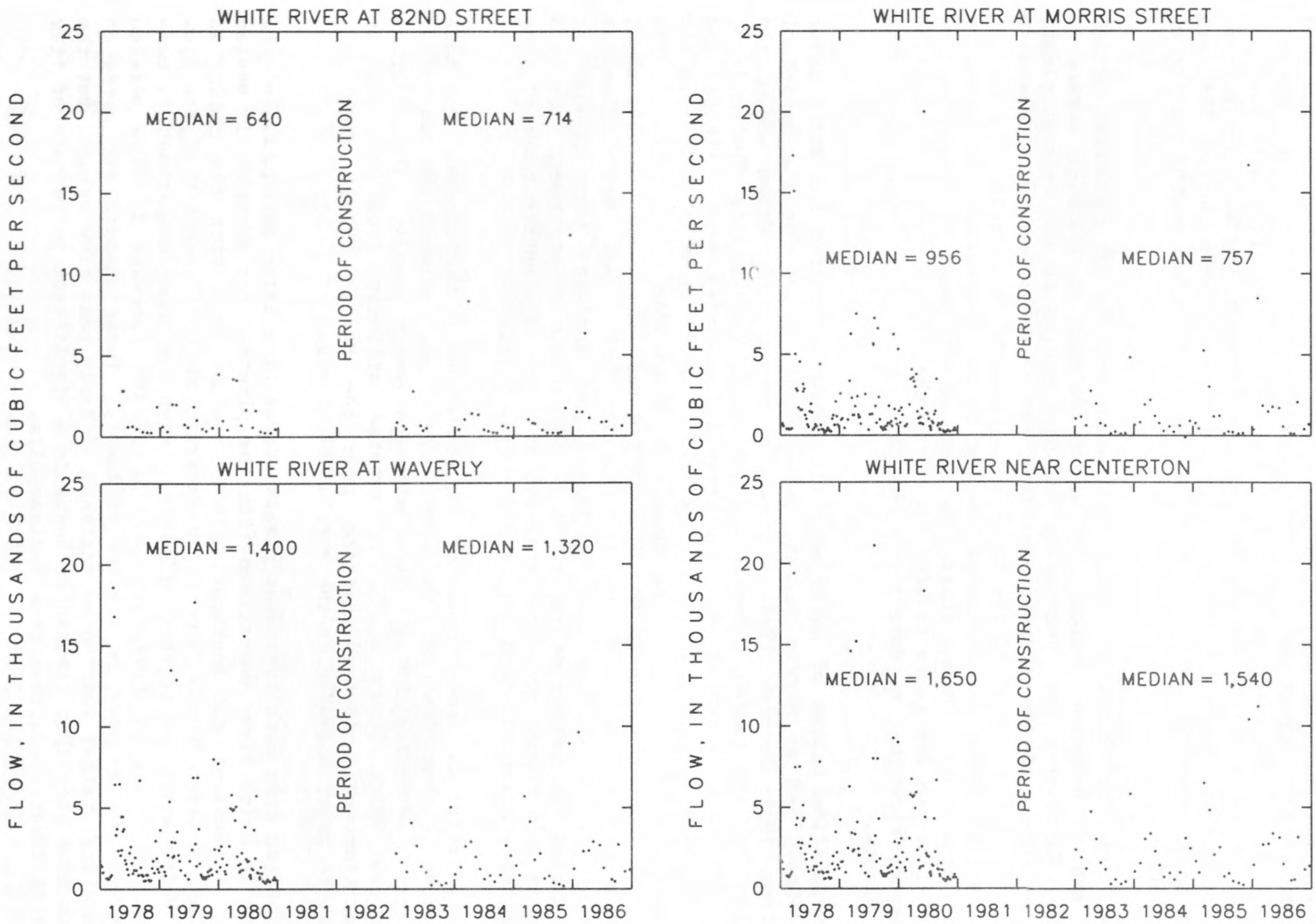


Figure 3.--Comparison of flow in White River at 82nd Street, at Morris Street, at Waverly, and near Centerton before and after construction, 1978-86 .

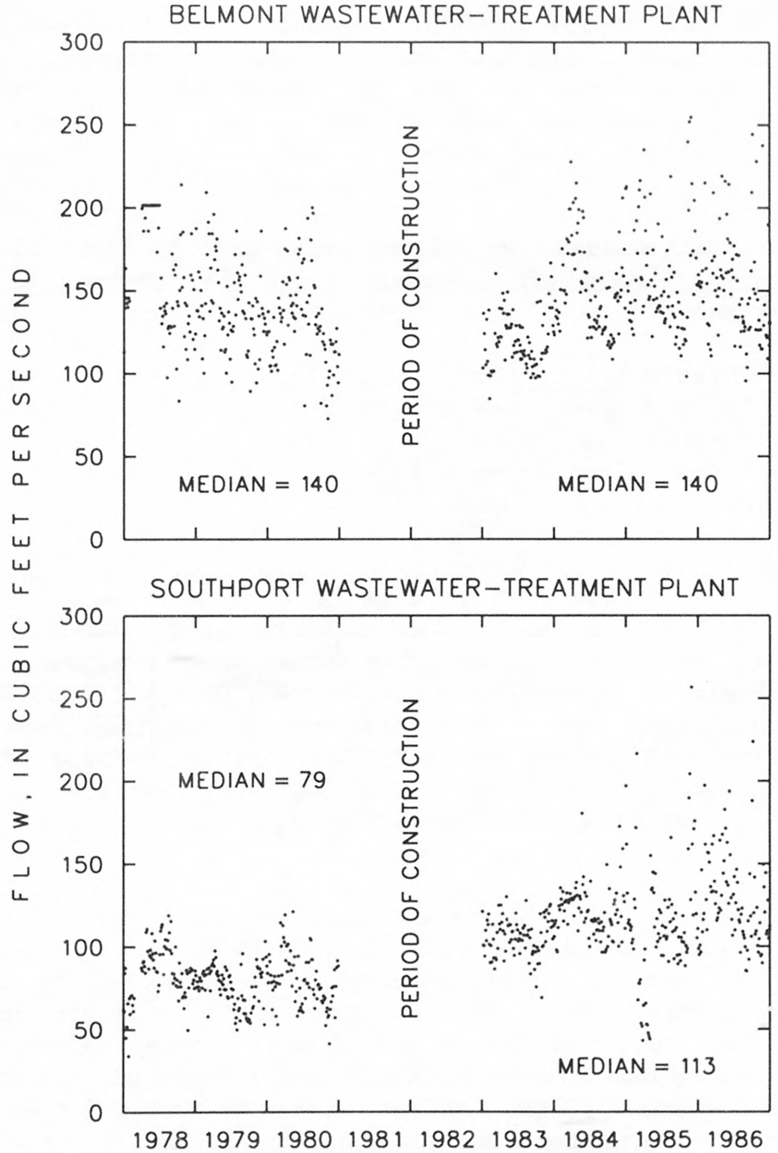


Figure 4.--Comparison of flow at the Belmont and Southport municipal wastewater-treatment plants before and after construction, 1978-86.

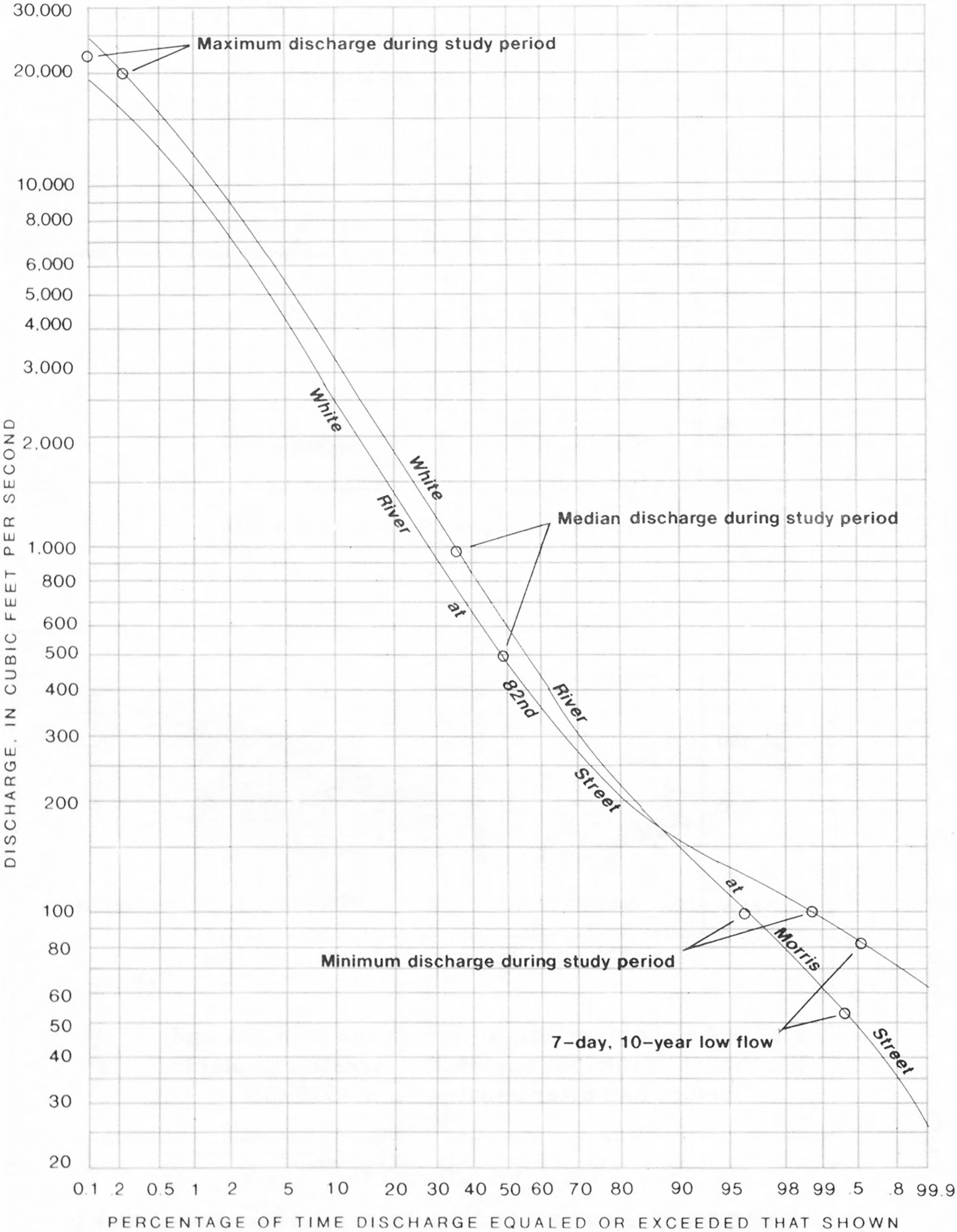


Figure 5.-- Flow-duration curves of daily mean flows for White River at 82nd Street and at Morris Street, 1931-84.

Daily Effluent-Quality Data

A summary of effluent-quality data from the Belmont and Southport wastewater-treatment plants discussed in this report is listed in table 3. The relation of concentrations of ammonia, BOD_5, fecal-coliform bacteria, nitrate, phosphate, and total solids in the Belmont and Southport wastewater-treatment plant effluents to time are shown in figures 6 and 7. The methods of Gilliom and Helsel (1986) were used to estimate summary statistics for nutrient data for which observations with concentrations less than the detection limit were found. All observations less than the highest detection limit used during the period of record for this study were considered to be nondetected concentrations. The highest detection limit used for ammonia, nitrate, and phosphate was 0.1 mg/L (milligrams per liter).

In the Belmont plant effluent, BOD_5 concentrations ranged from 1 to 101 mg/L with a median of 24 mg/L, and loads from 660 to 87,200 lb/d (pounds per day), with a median of 18,600 lb/d, prior to AWT. Concentrations ranged from 1 to 65 mg/L, with a median of 5 mg/L, and loads from 597 to 52,200 lb/d, with a median of 3,670 lb/d, since implementation of AWT.

A similar reduction in BOD_5 occurred in the Southport effluent. Concentrations ranged from 1 to 99 mg/L, with a median of 13 mg/L, and loads from 284 to 26,400 lb/d, with a median of 5,550 lb/d prior to AWT. Concentrations ranged from 1 to 70 mg/L, with a median of 3 mg/L, and loads from 241 to 48,000 lb/d, with a median of 1,620 lb/d, since implementation of AWT. The average decrease in the load of BOD_5 was 70 percent in the Belmont effluent and 60 percent in the Southport effluent. The decrease was greater in the Belmont effluent than in the Southport effluent because of the wastewater that was diverted from the Belmont plant to the Southport plant for treatment.

Only limited nutrient data are available for the Belmont plant; no nutrient data are available for the Southport plant prior to the implementation of AWT. Ammonia concentrations in the Belmont wastewater-treatment plant prior to AWT ranged from 5.9 to 23.4 mg/L, with a median of 14.3 mg/L. Loads ranged from 2,600 to 14,700 lb/d, with a median of 8,480 lb/d. After implementation of AWT, ammonia concentrations ranged from <0.1 to 23.1 mg/L, with a median of <0.1 mg/L. Loads ranged from 23 to 15,000 lb/d, with a median of 52 lb/d. Phosphate concentrations in the Belmont wastewater-treatment plant prior to AWT ranged from 1.0 to 10.8 mg/L, with a median of 5.0 mg/L. Loads ranged from 593 to 5,960 lb/d, with a median of 2,990 lb/d. After implementation of AWT, phosphate concentrations ranged from 0.1 to 10.7 mg/L, with a median of 3.1 mg/L. Loads ranged from 114 to 6,370 lb/d, with a median of 2,430 lb/d.

The median effluent concentrations and loads of all constituents discussed in this report were reduced by the AWT process, except for nitrate. Nitrate was expected to increase following implementation of AWT because the ammonia-removal process installed was designed to have nitrification occurring in the plants. Median nitrate concentrations in the Belmont wastewater-treatment plant effluent increased from <0.1 mg/L prior to AWT, to 11.0 mg/L after AWT was implemented. The median load increased from 30 lb/d to 8,620 lb/d.

Table 3.--Summary of water-quality data for Belmont and Southport municipal wastewater-treatment plants, 1978-86

[All data collected and analyzed by the Department of Public Works; BOD_5, 5-day biochemical-oxygen demand; col/100 mL, colonies per 100 milliliters; col/d, colonies per day; lb/d, pound per day; mg/L, milligram per liter; n.d., no data; Post-AWT, period of study after implementation of advanced wastewater treatment; Pre-AWT, period of study before implementation of advanced wastewater treatment; <, less than]

Property or constituent	Units	Belmont effluent: Number of observations	Belmont effluent: Mean	Belmont effluent: Median	Belmont effluent: Interquartile range[1]	Belmont effluent: Maximum	Belmont effluent: Minimum	Southport effluent: Number of observations	Southport effluent: Mean	Southport effluent: Median	Southport effluent: Interquartile range[1]	Southport effluent: Maximum	Southport effluent: Minimum
Pre-AWT													
Ammonia as N	mg/L	91	14.3	14.3	4.7	23.4	5.9	0	n.d.	n.d.	n.d.	n.d.	n.d.
BOD_5	mg/L	1,018	28	24	19	101	1	1,046	14	13	9	99	1
Fecal-coliform bacteria	col/100 mL	386	8,670	50	192	451,000	0	448	374	38	82	17,900	0
Nitrate as N	mg/L	91	.2	<.1	<.1	1.25	<.1	0	n.d.	n.d.	n.d.	n.d.	n.d.
Phosphate as P	mg/L	91	5.1	5.0	2.7	10.8	1.0	0	n.d.	n.d.	n.d.	n.d.	n.d.
Total solids	mg/L	1,030	33	26	23	195	1.0	1,058	14	13	9	153	1
Post-AWT													
Ammonia as N	mg/L	1,458	1.7	<.1	1.5	23.1	<.1	1,457	1.2	<.1	<.1	35.6	<.1
BOD_5	mg/L	1,459	7.9	5.0	6.0	65	1.0	1,457	3.6	3.0	2.0	70	1.0
Fecal-coliform bacteria	col/100 mL	830	259	32	124	33,600	0	812	349	14	48	96,000	0
Nitrate as N	mg/L	1,448	11.3	11.0	5.9	29.6	<.1	1,457	12.6	12.5	5.9	32.4	<.1
Phosphate as P	mg/L	1,417	3.4	3.1	1.8	10.7	.1	1,414	2.8	2.7	1.4	7.3	.6
Total solids	mg/L	1,459	7.6	5.0	6.0	114	<1	1,456	4.8	3.0	3.0	142	<1
Pre-AWT													
Ammonia as N	lb/d	91	8,320	8,480	3,140	14,700	2,600	0	n.d.	n.d.	n.d.	n.d.	n.d.
BOD_5	lb/d	1,017	21,500	18,600	16,100	87,200	660	1,045	6,100	5,550	4,360	26,400	284
Fecal-coliform bacteria	$col/d \times 10^{10}$	386	31,100	195	676	1,460,000	0	448	790	70	154	49,900	0
Nitrate as N	lb/d	91	63	30	6.4	741	20	0	n.d.	n.d.	n.d.	n.d.	n.d.
Phosphate as P	lb/d	91	2,970	2,990	1,840	5,960	593	0	n.d.	n.d.	n.d.	n.d.	n.d.
Total solids	lb/d	1,029	25,300	20,500	19,100	147,000	750	1,057	6,050	5,460	4,270	44,300	298
Post-AWT													
Ammonia as N	lb/d	1,456	1,130	52	1,200	15,000	23	1,456	687	33	16	23,200	11
BOD_5	lb/d	1,456	6,210	3,670	5,160	52,200	597	1,456	2,310	1,620	1,260	48,000	241
Fecal-coliform bacteria	$col/d \times 10^{10}$	830	910	120	43	71,600	0	812	10,600	38	135	287,000	0
Nitrate as N	lb/d	1,446	8,474	8,620	3,440	16,900	27	1,456	7,680	7,710	3,000	16,400	18
Phosphate as P	lb/d	1,415	2,540	2,430	1,110	6,370	114	1,413	1,720	1,680	714	4,760	327
Total solids	lb/d	1,456	6,120	3,730	5,460	91,400	0	1,457	3,090	1,990	2,010	98,700	0

[1]Interquartile range is the difference between the 75th and 25th percentiles.

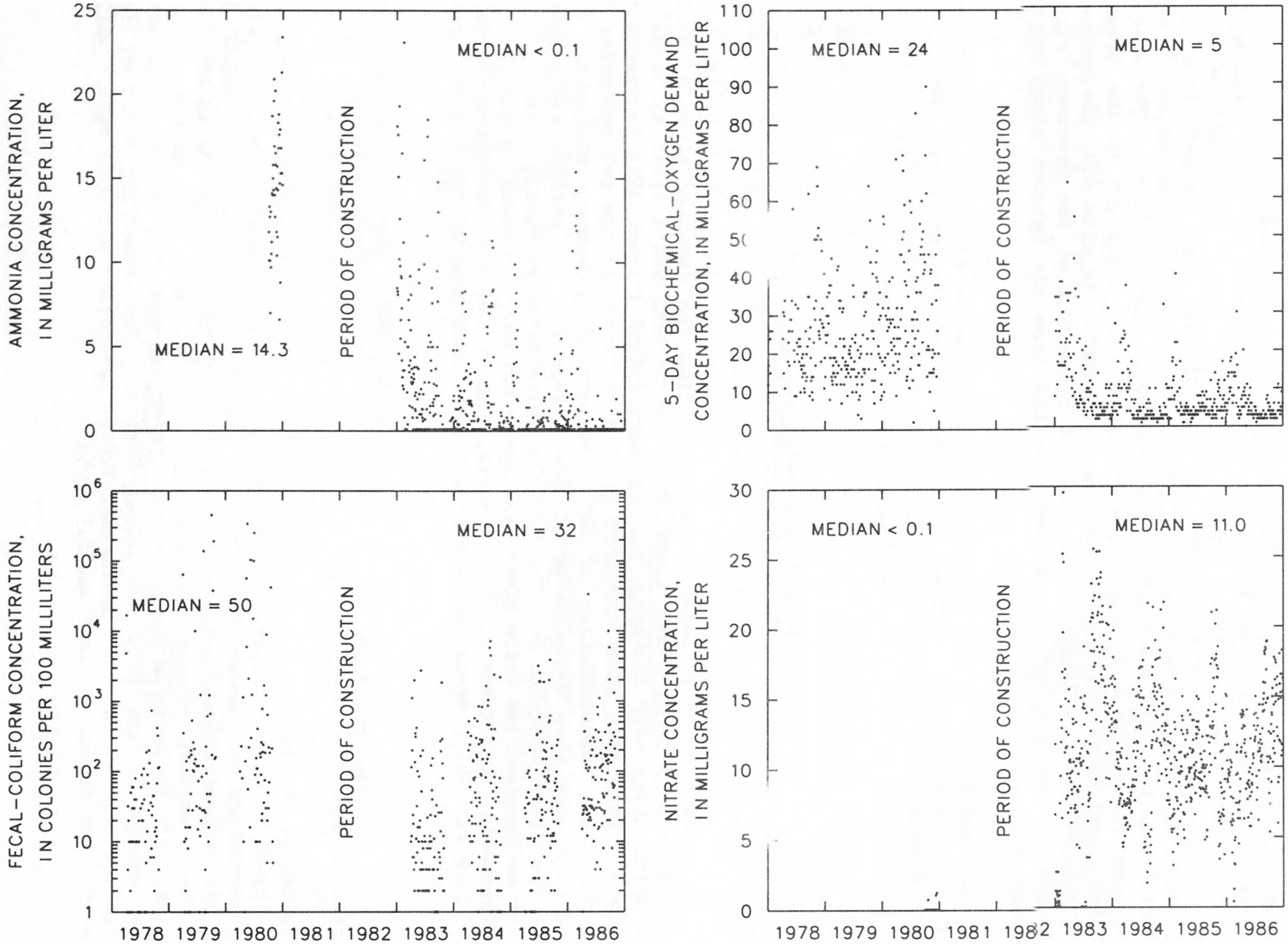
Substantial decreases were also observed in total solids. In the Belmont plant effluent, total-solids concentrations ranged from 1 to 195 mg/L, with a median of 26 mg/L prior to implementation of AWT and ranged from 0 to 114 mg/L, with a median of 5 mg/L after implementation of AWT. Total-solids loads in the Belmont effluent ranged from 750 to 147,000 lb/d, with a median of 20,500 lb/d prior to implementation of AWT and ranged from 0 to 91,400 lb/d, with a median of 3,730 lb/d after implementation of AWT. Similar results were observed in the Southport plant effluent. The average decrease in the load of total solids was about 75 percent in the Belmont effluent and 50 percent in the Southport effluent. As with BOD, the decrease in total solids was larger at the Belmont plant than at the Southport plant, because of the wastewater that was diverted from the Belmont plant to the Southport plant.

The number of fecal-coliform colonies also decreased in the effluent from both treatment plants. The median number of colonies decreased from 50 to 32 col/100 mL (colonies per 100 milliliters) in the Belmont plant effluent and from 38 to 14 col/100 mL in the Southport plant effluent.

Monthly River-Quality Data

A summary of river-water-quality data from the sampling sites at White River at 82nd Street, White River at Morris Street, White River at Waverly, and White River near Centerton for the period 1978 through 1986 is listed in table 4. Data from each site were divided to represent the periods prior to and following implementation of AWT. Water-quality summary statistics for long-term data from White River at 82nd Street for the period 1958 through 1986 are given in table 5. The data for White River at Morris Street, White River at Waverly, and White River near Centerton were collected by the City of Indianapolis, Department of Public Works, and by the U.S. Geological Survey. The data for White River at 82nd Street were collected by the Indiana State Board of Health.

The relation of concentrations of ammonia, BOD_5, dissolved oxygen, and nitrate to time at White River at 82nd Street and White River at Morris Street is shown in figures 8 and 9. The data for White River at Waverly and the data for White River near Centerton are shown in figures 10 and 11. As illustrated in figures 8 and 9, there was little, if any, change in the water quality of White River upstream from the wastewater-treatment plants following implementation of advanced-wastewater treatment. The apparent change in ammonia concentrations observed in White River at Morris Street is an artifact of the laboratory change that was made in 1982 when data collection and analysis at the White River at Morris Street, at Waverly, and near Centerton were assumed by the U.S. Geological Survey. The detection limit of the procedure used by the U.S. Geological Survey laboratory was 0.01 mg/L, while the previous detection limit was 0.1 mg/L.



AMMONIA CONCENTRATION, IN MILLIGRAMS PER LITER
MEDIAN = 14.3
PERIOD OF CONSTRUCTION
MEDIAN < 0.1
5-DAY BIOCHEMICAL-OXYGEN DEMAND CONCENTRATION, IN MILLIGRAMS PER LITER
MEDIAN = 24
PERIOD OF CONSTRUCTION
MEDIAN = 5
FECAL-COLIFORM CONCENTRATION, IN COLONIES PER 100 MILLILITERS
MEDIAN = 50
PERIOD OF CONSTRUCTION
MEDIAN = 32
NITRATE CONCENTRATION, IN MILLIGRAMS PER LITER
MEDIAN < 0.1
PERIOD OF CONSTRUCTION
MEDIAN = 11.0
1978 1979 1980 1981 1982 1983 1984 1985 1986

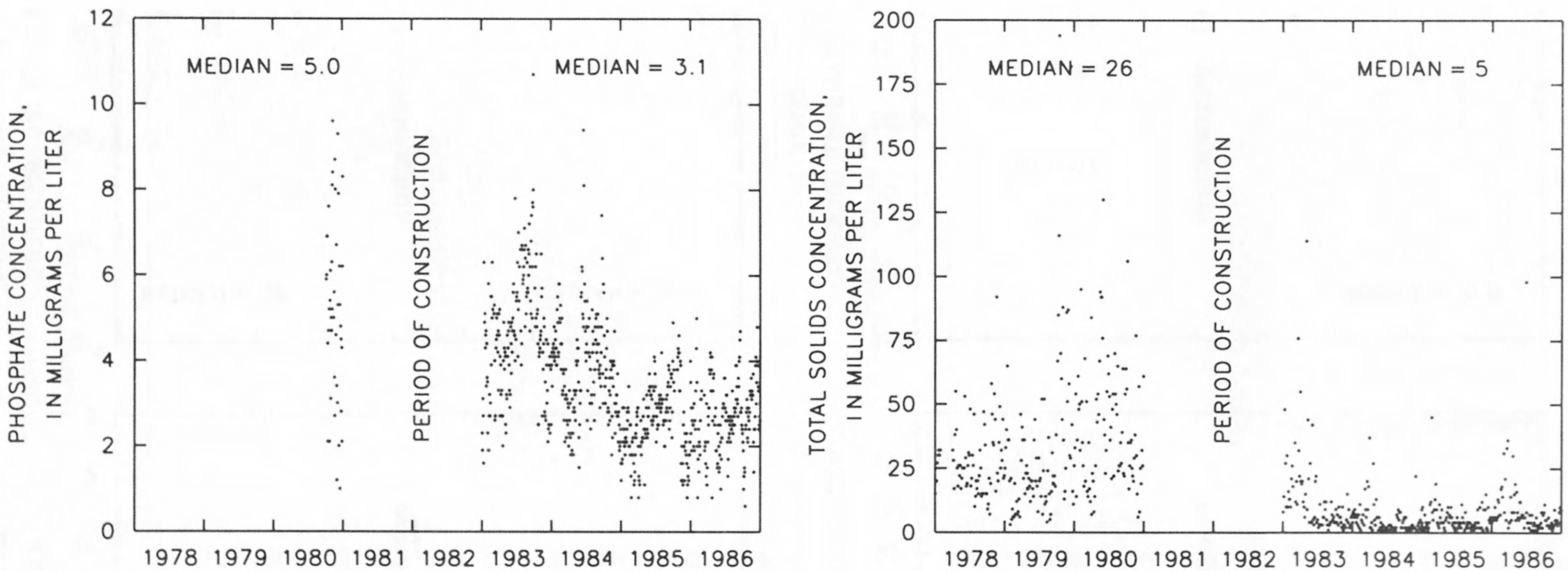
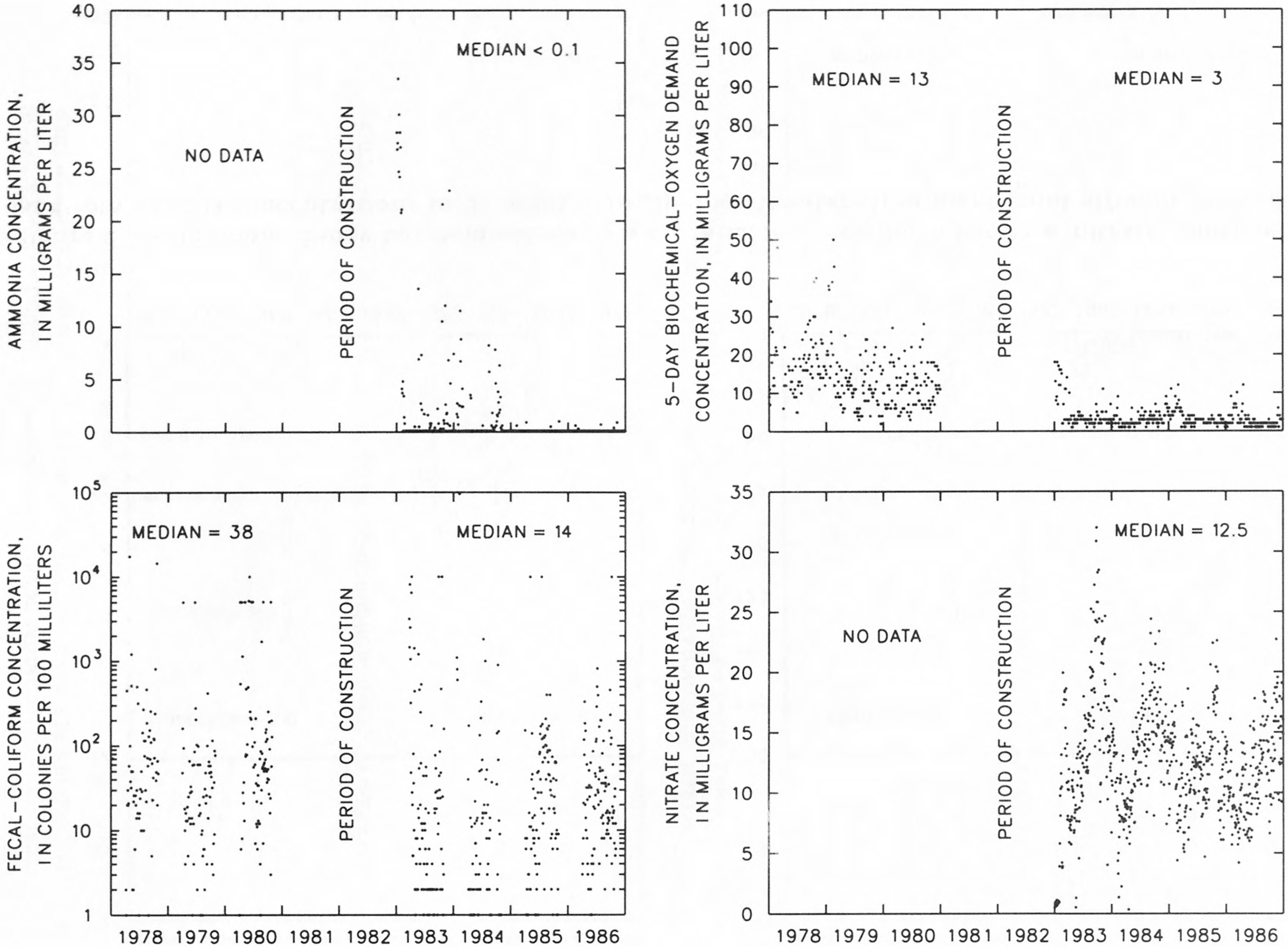


Figure 6.--Ammonia, 5-day biochemical-oxygen demand, fecal-coliform bacteria, nitrate, phosphate, and total-solids concentrations in Belmont municipal wastewater-treatment plant effluent, 1978-86.


AMMONIA CONCENTRATION, IN MILLIGRAMS PER LITER
NO DATA
PERIOD OF CONSTRUCTION
MEDIAN < 0.1
5-DAY BIOCHEMICAL-OXYGEN DEMAND CONCENTRATION, IN MILLIGRAMS PER LITER
MEDIAN = 13
PERIOD OF CONSTRUCTION
MEDIAN = 3
FECAL-COLIFORM CONCENTRATION, IN COLONIES PER 100 MILLILITERS
MEDIAN = 38
PERIOD OF CONSTRUCTION
MEDIAN = 14
NITRATE CONCENTRATION, IN MILLIGRAMS PER LITER
NO DATA
PERIOD OF CONSTRUCTION
MEDIAN = 12.5
1978 1979 1980 1981 1982 1983 1984 1985 1986
1978 1979 1980 1981 1982 1983 1984 1985 1986

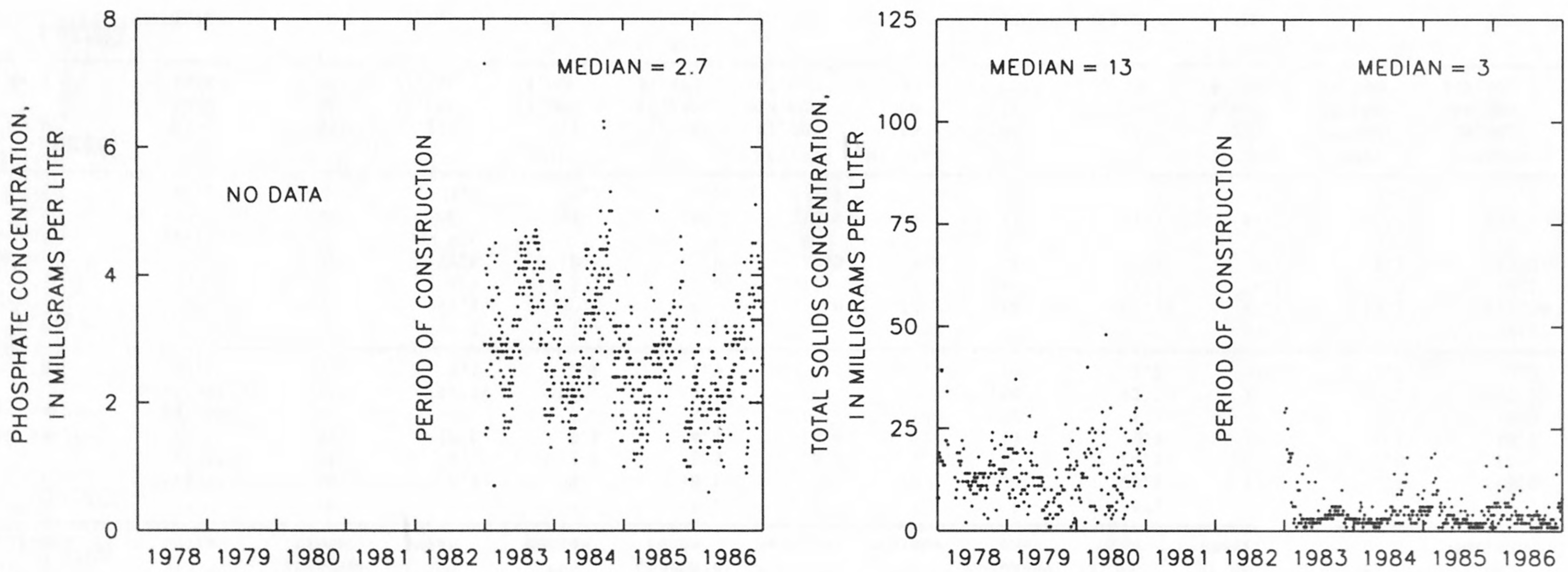


Figure 7.--Ammonia, 5-day biochemical-oxygen demand, fecal-coliform bacteria, nitrate, phosphate, and total-solids concentrations in Southport municipal wastewater-treatment plant effluent, 1978-86.

Table 4.--Summary of water-quality data for White River upstream and downstream from the municipal wastewater-treatment plants, 1978-86

[BOD_5, 5-day biochemical-oxygen demand; lb/d, pound per day; mg/L, milligram per liter; Post-AWT, period of study after implementation of advanced wastewater treatment; Pre-AWT, period of study before implementation of advanced wastewater treatment; <, less than]

Property or constituent	Units	White River at 82nd Street						White River at Morris Street					
		Number of observa-tions	Mean	Median	Inter-quartile range	Maximum	Minimum	Number of observa-tions	Mean	Median	Inter-quartile range	Maximum	Minimum
Pre-AWT													
Ammonia as N	mg/L	35	0.22	0.1	0.1	1.1	0.1	108	<0.1	<0.1	<0.1	1.0	<0.1
BOD_5	mg/L	35	3.1	2.7	1.5	8.8	1.0	136	4.2	4.0	2.0	12	1.0
Dissolved oxygen	mg/L	35	10.0	9.8	4.0	14.0	5.7	143	9.8	9.8	4.4	14.8	1.0
Dissolved oxygen	percent saturation	35	92	90	12	136	70	143	92	92	14	167	7.8
Nitrate as N	mg/L	35	3.1	2.6	1.9	5.5	1.5	18	2.7	3.1	1.9	5.3	.8
Post-AWT													
Ammonia as N	mg/L	37	.14	.1	0	.9	<.1	48	.16	.12	.17	.59	<.1
BOD_5	mg/L	33	4.1	3.2	3.0	12	1.0	48	4.4	4.6	2.5	8.2	.9
Dissolved oxygen	mg/L	39	11.0	10.5	2.9	18.5	6.6	48	9.8	9.8	3.1	15.7	3.8
Dissolved oxygen	percent saturation	39	106	93	29	218	64	48	91	87	20	149	47
Nitrate as N	mg/L	37	3.1	3.2	3.0	6.8	.1	48	2.9	3.1	3.5	5.6	<.1
Pre-AWT													
Ammonia as N	lb/d	35	2,140	748	1,600	37,700	128	108	960	232	537	35,400	49
BOD_5	lb/d	35	31,000	11,000	27,200	473,000	1,280	136	40,400	19,100	33,600	466,000	1,990
Nitrate as N	lb/d	35	27,700	11,000	33,400	167,000	2,040	18	27,000	19,300	44,600	105,000	1,450
Post-AWT													
Ammonia as N	lb/d	36	1,540	356	672	24,900	95	47	1,360	480	917	19,800	33
BOD_5	lb/d	32	44,500	12,600	15,000	535,000	2,800	47	36,200	16,900	26,100	405,000	1,780
Nitrate as N	lb/d	36	45,100	13,400	27,700	436,000	105	47	31,400	11,000	38,500	229,000	58

Table 4.--Summary of water quality data for White River upstream and downstream from the municipal wastewater-treatment plants, 1978-86--Continued

Property or constituent	Units	White River at Waverly						White River near Centerton					
		Number of observa-tions	Mean	Median	Inter-quartile range	Maximum	Minimum	Number of observa-tions	Mean	Median	Inter-quartile range	Maximum	Minimum
Pre-AWT													
Ammonia as N	mg/L	135	2.5	2.0	2.1	8.8	<0.1	135	1.7	1.1	2.2	7.4	<0.1
BOD_5	mg/L	137	8.0	7.0	3.5	26	3.0	136	7.1	7.0	3.0	19	3.0
Dissolved oxygen	mg/L	145	6.7	6.4	5.4	13.2	1.0	141	7.1	6.7	4.6	13.9	1.0
Dissolved oxygen	percent saturation	145	62	66	33	103	12	141	66	65	26	111	12
Nitrate as N	mg/L	19	2.2	2.5	1.7	4.7	.4	19	2.3	2.6	1.7	4.7	.7
Post-AWT													
Ammonia as N	mg/L	48	.40	.24	.36	1.7	<.1	48	.29	.15	.32	1.5	<.1
BOD_5	mg/L	48	5.1	4.8	2.3	10	1.9	48	4.8	4.6	2.5	8.3	1.4
Dissolved oxygen	mg/L	48	10.1	10.3	3.8	14.6	4.5	48	10.4	10.6	3.7	14	5.5
Dissolved oxygen	percent saturation	48	97	96	16	158	55	48	100	95	20	160	62
Nitrate as N	mg/L	48	5.1	4.9	1.1	9.5	1.7	48	4.7	4.6	1.1	15	<.1
Pre-AWT													
Ammonia as N	lb/d	135	17,200	15,600	8,100	80,000	965	135	13,200	11,800	12,800	92,600	372
BOD_5	lb/d	137	98,500	65,500	73,000	765,000	7,390	136	103,000	66,000	82,600	655,000	8,840
Nitrate as N	lb/d	19	35,600	22,500	52,300	138,000	740	19	41,400	27,800	57,300	156,000	1,730
Post-AWT													
Ammonia as N	lb/d	48	3,660	2,060	4,130	24,600	170	48	3,290	1,360	4,220	20,200	78
BOD_5	lb/d	48	53,100	36,600	50,400	366,000	4,200	48	58,000	39,000	57,800	420,000	5,220
Nitrate as N	lb/d	48	45,800	33,700	39,600	239,000	8,400	48	50,300	33,300	40,900	266,000	254

Table 5.--Summary of long-term water-quality data for White River at 82nd Street upstream from the municipal wastewater-treatment plants, 1958-86

[Water-quality data collected by Indiana State Board of Health; BOD_5, 5-day biochemical-oxygen demand; lb/d, pound per day; mg/L, milligram per liter; <, less than]

Property or constituent	Units	Number of observa-tions	Mean	Median	Inter-quartile range[1]	Maximum	Minimum
			Concentration				
Ammonia as N	mg/L	131	0.22	0.10	0.2	1.1	<0.1
BOD_5	mg/L	465	4.2	3.5	2.7	24	.1
Dissolved oxygen	mg/L	485	9.9	9.8	3.6	18.5	1.9
Dissolved oxygen	percent saturation	481	93	88	22	218	23
Nitrate as N	mg/L	453	2.4	2.2	1.6	8.6	<.1
			Load				
Ammonia as N	lb/d	130	1,920	560	1,360	37,700	91
BOD_5	lb/d	464	27,200	9,880	14,700	1,110,000	165
Nitrate as N	lb/d	452	20,400	5,440	15,000	436,000	43

[1]Interquartile range is the difference between the 75th and 25th percentiles.

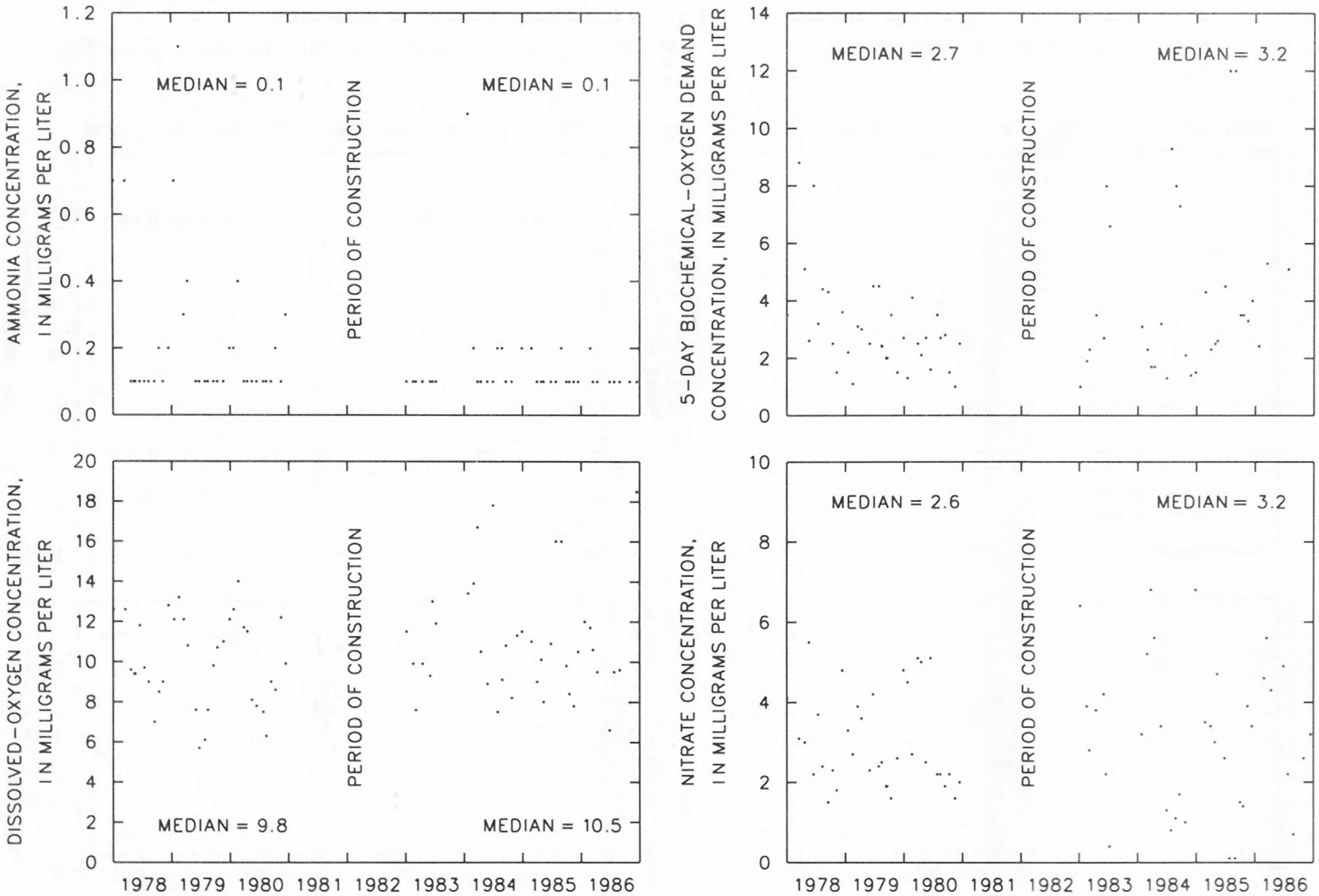


Figure 8.--Ammonia, 5-day biochemical-oxygen demand, dissolved-oxygen, and nitrate concentrations in White River at 82nd Street, 1978-86.

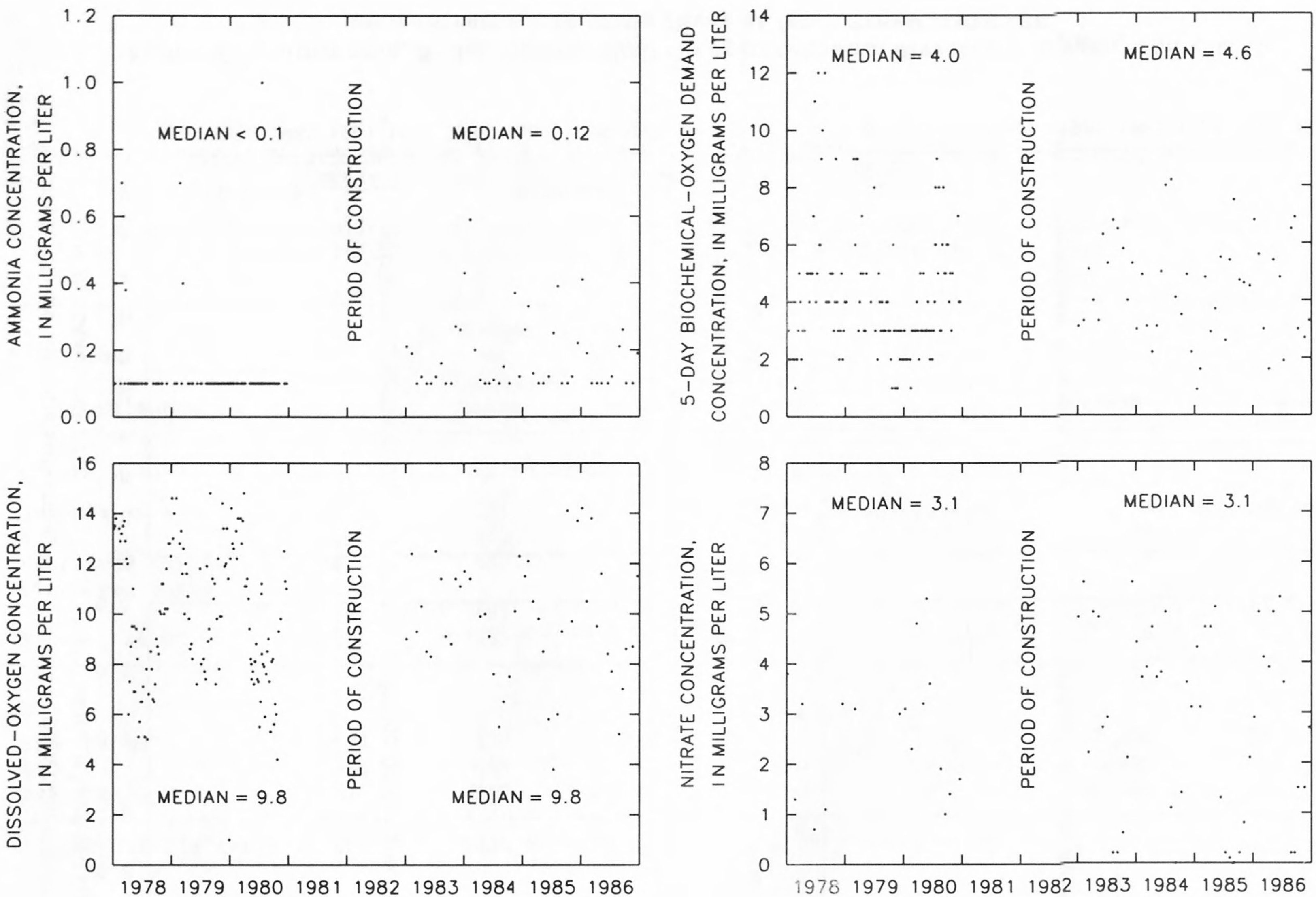


Figure 9.--Ammonia, 5-day biochemical-oxygen demand, dissolved-oxygen, and nitrate concentrations in White River at Morris Street, 1978-86.

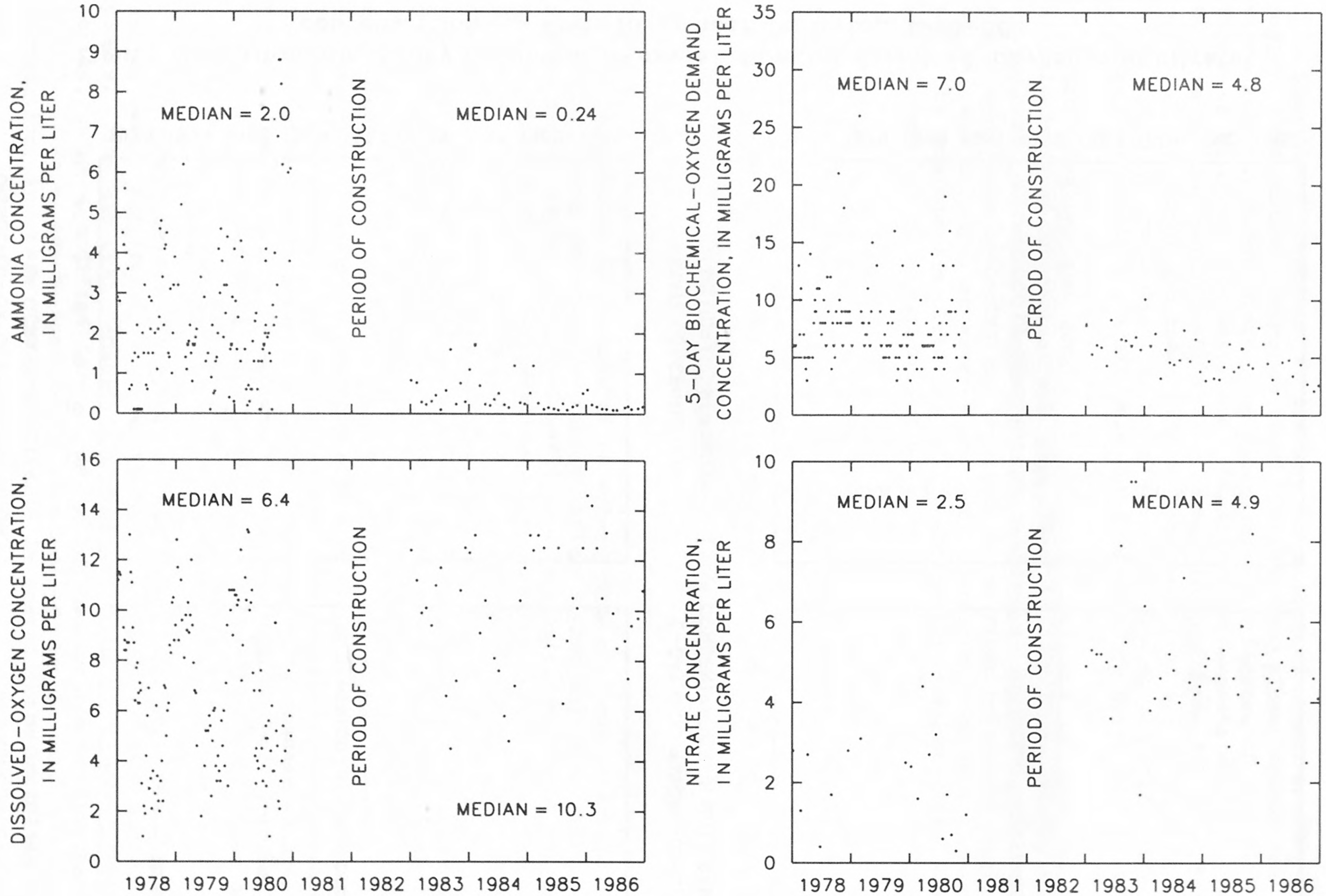


Figure 10.--Ammonia, 5-day biochemical-oxygen demand, dissolved-oxygen, and nitrate concentrations in White River at Waverly, 1978-86.

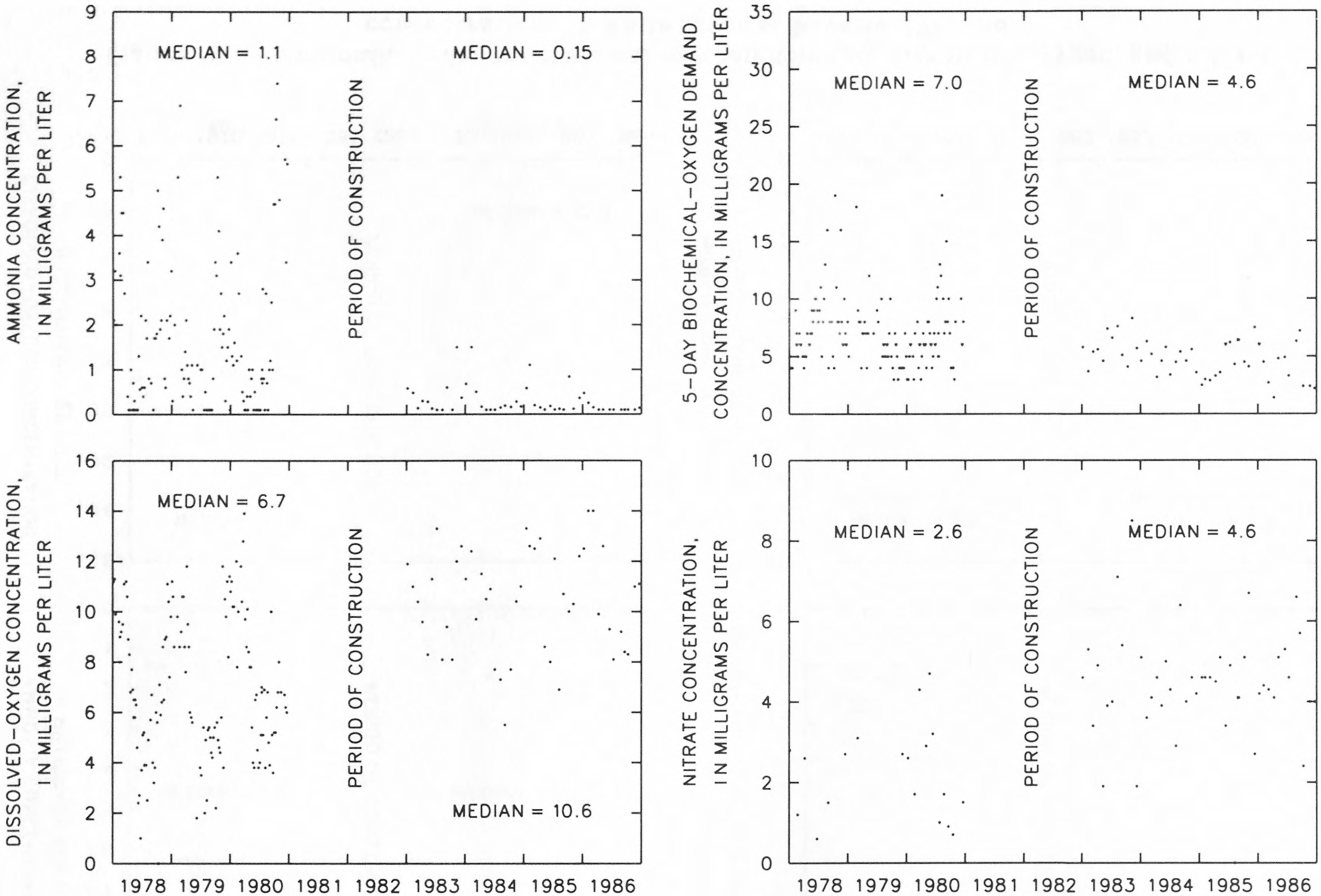


Figure 11.--Ammonia, 5-day biochemical-oxygen demand, dissolved-oxygen, and nitrate concentrations in White River near Centerton, 1978-86.

Sizeable differences in the concentrations of ammonia, BOD_5, dissolved oxygen, and nitrate were observed at the two sites downstream from the wastewater treatment plants, as illustrated in figures 10 and 11. In White River at Waverly, the median concentration of ammonia dropped from 2.0 to 0.24 mg/L, the median BOD_5 concentration dropped from 7.0 to 4.8 mg/L, the median dissolved-oxygen concentration increased from 6.4 to 10.3 mg/L, and the median nitrate concentration increased from 2.5 to 4.9 mg/L after AWT was implemented. Similar changes were observed in White River near Centerton.

Additionally, the ranges in the concentrations of ammonia, BOD_5, and dissolved-oxygen concentrations were less in the White River at the two downstream sites following implementation of AWT. The minimum dissolved-oxygen concentration observed in the river before the implementation of AWT was 1.0 mg/L at Waverly and near Centerton. After implementation of AWT, the minimum dissolved-oxygen concentrations observed were 4.5 mg/L at Waverly and 5.5 mg/L near Centerton.

TRENDS IN WATER QUALITY

Trend Analysis Techniques

A time series is a sequence of values of a particular variable collected over time, that may contain random variation and(or) deterministic trends. Deterministic trends may be classified as periodic, monotonic, or step, or a combination of these. Periodicities are repeating cycles in a time series, as typified by annual cycles in water-temperature data. Periodicities in hydrologic time-series data generally are the result of astronomic cycles. A monotonic trend is a systematic and continuous change in a variable over time. Monotonic trends in hydrologic time-series data are the result of natural or manmade changes in the hydrologic environment, such as ecological succession or increased urbanization. Examples of such trends are linear or exponential increases or decreases. A step trend is an abrupt and constant change. Step trends in hydrologic time-series data can be caused by catastrophic natural events (such as earthquakes or forest fires), or by manmade changes (such as construction of a dam or wastewater-treatment plant). More information about hydrologic time series may be found in Yevjevich (1972) and Salas and others (1980).

Two nonparametric procedures were used to test for trends in the time-series water-quality data from White River and the wastewater-treatment plants. The seasonal Kendall procedure tests for monotonic trends in time series, using a modified form of Kendall's tau derived by Hirsch and others (1982). This is a specialized application of Kendall's tau test for correlation, in which a random variable is tested for correlation with time.

The seasonal Kendall procedure is an alternative to linear-regression methods. The null hypothesis for this test is that the random variable is independent of time. The test assumes that the random variable is independently and identically distributed. In this application of Kendall's tau test, all possible pairs of data values are compared. If a later value (in time) is larger, a plus is recorded; if smaller, a minus is recorded. If no trend exists in the data, the probability of a later value being larger or smaller than any previous value is 0.50. In this case, the number of pluses should approximately equal the number of minuses. If the number of pluses greatly exceeds the number of minuses, the values later in the time series are more often larger than those earlier in the series, indicating an uptrend. If the number of minuses greatly exceeds the number of pluses, a downtrend is indicated. The problem of seasonality is considered by comparing only observations from the same season of the year. Thus, for monthly data with seasonality, January data are compared only with January data, and so on. An estimate of trend magnitude is obtained using the seasonal Kendall slope estimator (Hirsch and others, 1982). This estimate is taken to be the median of the slopes of the ordered pairs of data values compared in the seasonal Kendall test. A discussion of the seasonal Kendall test may be found in Hirsch and others (1982), Smith and others (1982), and Crawford and others (1983).

A simple nonparametric procedure for comparing two populations was proposed by Wilcoxon (1945). A mathematically identical procedure was proposed by Mann and Whitney (1947). This procedure is referred to as the Wilcoxon-Mann-Whitney rank-sum procedure, and is an alternative to the t-test. The seasonal Wilcoxon-Mann-Whitney rank-sum procedure is a specialized application of the Wilcoxan-Mann-Whitney procedure as presented by Bradley (1968). The null hypothesis for this test is that two populations comprised of data from two separate periods in a time series are identical. The test assumes that the two samples were randomly and independently collected; the two samples are mutually independent; and the random variables are continuous (some ties are allowed). This test also assumes that the probability distributions of the populations from which the samples were drawn are of the same form, but not necessarily normal. If the null hypothesis is true, no distinction can be made between the n observations in the first sample, or m observations in the second sample, all of which, in effect, were taken from a common population. Therefore, each of the possible combinations of n plus m observations taken from the common population were equally likely to have become the samples actually collected. For each of these possible combinations a value exists of the test statistic, W. This statistic is the sum of the ranks of the n observations within the combined (n plus m observations) sample. The smallest value in the combined sample receives a rank of 1; the next smallest value receives a rank of 2; and so on. The null hypothesis is rejected if the value of the test statistic, W, differs from the expected value of W by a preselected value, corresponding to a desired probability. Seasonality is handled in the same way as in the seasonal Kendall procedure. An estimate of the magnitude of the step trend is taken as the median of the difference between all pairs of seasonal values, one from each period, but of the same season. Instead of recording a plus or minus for each comparison, the difference between each pair is the step. The median of these differences is taken to be the change in units of measure per year as a result of the trend. A discussion of the seasonal Wilcoxon-Mann-Whitney rank-sum procedure may be found in Crawford and others (1983).

Trend-Analysis Results

River Quality Upstream from Treatment Plants

The seasonal Kendall procedure was used to test for monotonic trends in long-term data (1958 through 1986) in White River at 82nd street. The test was applied assuming monthly seasonality. Test results are listed in table 6. The time-series water-quality data were considered to have a significant trend if the calculated probability level was 0.05 or less, and a highly significant trend if the probability level was 0.01 or less. Results of the trend test for each parameter are given in two parts. The first part is the probability level and the level of significance (significant, highly significant, or no significant change). The second part is the magnitude and direction of the slope in units of measure per year.

The site at 82nd Street is upstream from most urban-affected tributaries, combined sewer overflows, and surface-water diversions. The data from this site were used to test for long-term (1958 through 1986) monotonic changes in background conditions not influenced by the city of Indianapolis. The seasonal Kendall procedure indicated highly significant trends in ammonia, flow, and nitrate. However, the rate of change in the constituents and flow was quite small (<0.01 mg/L per year for ammonia, 5.3 ft^3/s per year for flow, and 0.05 mg/L per year for nitrate). Thus, for practical purposes, there was no sizeable change in water quality over time in the White River upstream from Indianapolis.

The seasonal Wilcoxon-Mann-Whitney rank-sum procedure was used to test for step trends in data for the period 1978 through 1986. Results of this procedure are presented in table 7. Data from White River at 82nd Street showed no statistically significant change in concentrations or loads except for an extremely small (<0.01 mg/L) increasing trend in ammonia concentration. Data from White River at Morris Street represent changes in river quality resulting from many of the urban effects of Indianapolis, but do not represent changes resulting from treated municipal-wastewater effluents. The sampling site at Morris Street is downstream from many of the tributary inputs and CSOs to the White River and is affected by diversion for drinking-water supply.

Table 6.--Seasonal Kendall test results of water-quality trends in White River upstream from Indianapolis, 1958-1986

[Water-quality data collected by Indiana State Board of Health; BOD_5, 5-day biochemical-oxygen demand; ft^3/s, cubic foot per second; lb/d, pound per day; mg/L, milligram per liter; n.a., not applicable; *, significant difference at 0.05 probability level; **, significant difference at 0.01 probability level; <, less than]

	White River at 82nd Street					
	Concentration			Load		
Property or constituent	Units	Probability level	Median change (per year)	Units	Probability level	Median change (per year)
Flow	ft^3/s	0.003**	+5.3	n.a.	n.a.	n.a.
Ammonia as N	mg/L	.001**	<-.01	lb/day	0.001**	-28.6
BOD_5	mg/L	.102	-.02	lb/day	.102	-.02
Dissolved oxygen	mg/L	.557	.01	n.a.	n.a.	n.a.
Dissolved oxygen	percent saturation	.108	.15	n.a.	n.a.	n.a.
Nitrate as N	mg/L	.001**	.05	lb/day	.001**	102

Some of the loss from the diversion gradually is replaced by ground-water input to tributaries and to the main channel. All water-quality parameters tested for trend during the time series of 1978 through 1986 showed no statistically significant change in concentrations or loads, except for a small (0.06 mg/L) increasing trend in ammonia concentration. For the purposes of this report, the authors considered the water quality at sample sites located upstream from the wastewater-treatment facilities to be relatively stable over time, showing only small or no increasing or decreasing trends in constituent concentrations during the period of study.

Effluent Quality

The seasonal Wilcoxon-Mann-Whitney rank-sum procedure also was used to test for step trends in the effluent data from the Belmont and Southport wastewater-treatment plants. Results of this analysis are presented in table 8. As before, monthly seasonality was assumed. Nutrient data were limited at both plants, so the test could only compare data from October, November, and December. Results of the test indicate highly significant changes in the concentration and load of several parameters. More data were available for analysis from the Belmont site; however, where Southport data were available, results were similar, with the exception of discharge. No change was indicated in discharge at Belmont and a highly significant increasing step trend was indicated at Southport. The reason for this change was explained previously. Significant decreasing step trends were indicated in the ammonia data at Belmont (14.6 mg/L); the BOD_5 data (19 mg/L at Belmont and 10 mg/L at Southport); the phosphate data (1.8 mg/L at Belmont); and the total solids data (22 mg/L at Belmont and 10 mg/L at Southport). No significant change in fecal-coliform bacteria was observed in the Belmont effluent. A significant decrease (17 col/100 mL) was observed at Southport. Because of in-plant nitrification, a highly significant increasing step trend in nitrate concentration (14.5 mg/L at Belmont) was detected. Analysis of load data indicated similar results.

River Quality Downstream from Treatment Plants

The seasonal rank-sum procedure also was used to test for step trends in the data from White River at Waverly and near Centerton (downstream from the wastewater-treatment plants). Results of this analysis are presented in table 9. Results indicate highly significant decreasing step trends in the ammonia data (1.8 mg/L at Waverly and 0.9 mg/L near Centerton) and the BOD_5 data (2.5 mg/L at Waverly and 2.3 mg/L near Centerton). The increase in nitrate concentrations was also highly significant (2.4 mg/L at Waverly and 2.0 mg/L near Centerton). Test results also indicated a highly significant increasing step trend in dissolved-oxygen concentration (3.2 mg/L at Waverly and near Centerton) and dissolved oxygen in percent saturation (29 percent) at Waverly and near Centerton.

Table 7.--Seasonal Wilcoxon-Mann-Whitney rank-sum test results of water-quality trends in White River upstream from both municipal wastewater-treatment plants, 1978-86

[BOD_5, 5-day biochemical-oxygen demand; ft^3/s, cubic foot per second; lb/d, pound per day; mg/L, milligram per liter; *, significant difference at 0.05 probability level; **, highly significant difference at 0.01 probability level; <,less than]

Property or constituent	Units	White River[1] at 82nd Street		White River[2] at Morris Street	
		Probability level	Median change	Probability level	Median change
Flow					
	ft^3/s	0.152	-125	0.017*	-250
Concentration					
Ammonia as N	mg/L	.028*	<.01	.001**	.06
BOD_5	mg/L	.267	.5	.320	.4
Dissolved oxygen	mg/L	.712	-.1	.153	-.50
Dissolved oxygen	percent saturation	.668	.8	.184	-4.9
Nitrate as N	mg/L	.484	-.2	.470	.5
Load					
Ammonia as N	lb/d	.002**	-157	.327	58
BOD_5	lb/d	.267	.5	.075	-4,120
Nitrate as N	lb/d	.222	-2,317	1.000	352

[1]Water-quality data collected by the Indiana State Board of Health.
[2]Water-quality data collected by U.S. Geological Survey and Department of Public Works.

Table 8.--Seasonal Wilcoxon-Mann-Whitney rank-sum test results of water-quality trends in Belmont and Southport municipal wastewater-treatment plant effluents, 1978-86

[Water-quality data collected by Department of Public Works; BOD_5, 5-day biochemical-oxygen demand; col/100 mL, colonies per 100 milliliters; col/d, colonies per day; ft^3/s, cubic foot per second; lb/d, pound per day; mg/L, milligram per liter; n.d., no data; *, significant difference at 0.05 probability level; **, highly significant difference at 0.01 level]

Property or constituent	Units	Belmont Effluent		Southport Effluent	
		Probability level	Median change	Probability level	Median change
		Flow			
	ft^3/s	0.876	0.2	0.001**	36.6
		Concentration			
Ammonia as N	mg/L	.003**	-14.6	n.d.	n.d.
BOD_5	mg/L	.001**	-19	.001**	-10
Fecal-coliform bacteria	col/100 mL	.158	-19	.021*	-17
Nitrate as N	mg/L	.014*	14.5	n.d.	n.d.
Phosphate as P	mg/L	.014*	-1.8	n.d.	n.d.
Total solids	mg/L	.001**	-22	.001**	-10
		Load			
Ammonia as N	lb/d	.014*	-7,950	n.d.	n.d.
BOD_5	lb/d	.001**	-13,900	.001**	-3,470
Fecal-coliform bacteria	col/d X 10^{10}	.248**	-79	.063	-28
Nitrate as N	lb/d	.014*	9,950	n.d.	n.d.
Phosphate as P	lb/d	.014*	-693	n.d.	n.d.
Total solids	lb/d	.001**	-15,800	.001**	-3,680

Table 9.--Seasonal Wilcoxon-Mann-Whitney rank-sum test results of water-quality trends in White River downstream from the municipal wastewater-treatment plants, 1978-86

[Water-quality data collected by U.S. Geological Survey and Department of Public Works. BOD_5, 5-day biochemical-oxygen demand; ft^3/s, cubic foot per second; lb/d, pound per day; mg/L, milligram per liter; *, significant difference at 0.05 probability level; **, highly significant difference at 0.01 probability level]

Property or constituent	Units	White River at Waverly		White River near Centerton	
		Probability level	Median change	Probability level	Median change
		Flow			
	ft^3/s	0.126	-281	0.126	-321
		Concentration			
Ammonia as N	mg/L	.001**	-1.8	.001**	-.9
BOD_5	mg/L	.001**	-2.5	.001**	-2.3
Dissolved oxygen	mg/L	.001**	3.2	.001**	3.2
Dissolved oxygen	percent saturation	.001**	29	.001**	29
Nitrate as N	mg/L	.001**	2.4	.001**	2.0
		Load			
Ammonia as N	lb/d	.001**	-12,600	.001**	-8,350
BOD_5	lb/d	.001**	-28,400	.001**	-28,600
Nitrate as N	lb/d	.008**	13,300	.013*	12,000

The increasing and decreasing step trends in constituent concentrations are believed to represent real changes in water quality of the White River downstream from the plants, attributable to advanced wastewater treatment. It is possible, however, that the concentrations of some constituents are affected by flow. Concentrations of some constituents may increase with an increase in flow because of soil erosion and transport, or they may decrease with an increase in flow because of dilution. Concentrations also may increase during a low-flow period because of concentration effects. Applying a test for trend to this type of data could result in the determination of a statistically significant trend that may be all or partly the result of the flow conditions at the time of sampling. This was not considered likely in the test results from the White River sites because the tests for trend in flow at those sites indicated no significant change over time. Also, the test results for trends in loads indicated results similar to those for the concentration data. Furthermore, the tests that were used accounted for seasonal changes in flow.

Another way to summarize the river-water-quality data is to determine the number of times sample concentrations exceeded the water-quality standards that apply to White River. Water-quality standards imposed by Indiana Stream Pollution Control Board (330 IAC 1-1) state that fecal-coliform bacteria shall not exceed 2,000 col/100 mL in more than one sample per 4-week period to meet the partial-body-contact standard; concentrations of total ammonia shall not exceed 2.5 mg/L; and, the average daily dissolved-oxygen concentration in White River shall be at least 5.0 mg/L. The total number of observations for each parameter and the number of observations that exceeded the respective standard are shown in table 10. In the table, two standards are listed for ammonia, one for total ammonia, and one for un-ionized ammonia. The total ammonia standard was an attempt to protect fish populations from un-ionized-ammonia toxicity. But, because the concentration of total ammonia that is equivalent to the toxic level of un-ionized ammonia (0.05 mg/L) varies with pH and water temperature, the standard was changed to a concentration of un-ionized ammonia not to exceed 0.05 mg/L. The un-ionized ammonia can be converted to total ammonia, using equations that are dependent upon pH and water temperature. As the pH and water temperature increase, the concentration of total ammonia that is equivalent to 0.05 mg/L un-ionized ammonia decreases. Therefore, during summer low flows when water temperatures are high (>25 °C), and pH may be high (>7.5) because of algal photosynthesis, the concentration of total ammonia that is toxic to fish is less than 2.5 mg/L. Conversely, lower pH and water temperature values result in total ammonia concentrations equivalent to 0.05 mg/L un-ionized ammonia that are larger than 2.5 mg/L. Since most of the data discussed in this report were collected prior to the effective date of the new standard (March 2, 1984), the old standard of 2.5 mg/L should be applied here.

The total ammonia standard of 2.5 mg/L was not exceeded in the data collected at either upstream site. Before implementation of AWT, the standard was exceeded in 38 percent of the samples from Waverly, and in 25 percent of the samples collected near Centerton. After implementation of AWT, the standard was not exceeded at either downstream site. Results are similar when the un-ionized ammonia standard is used, except that fewer samples exceeded the standard (11 percent at Waverly and 9 percent near Centerton) prior to implementation of AWT. The fact that neither standard was exceeded in the data collected since implementation of AWT indicates a substantial improvement in river-water quality.

Table 10.--River-quality standards and number of times the observed data exceeded the standards in White River, 1978-86

[col/100 mL, colonies per 100 milliliters; mg/L, milligrams per liter; N1, total number of observations; N2, number of observations that exceeded the standard; n.d., no data; Post-AWT, period of study after implementation of advanced wastewater treatment; Pre-AWT, period of study before implementation of advanced wastewater treatment]

		82nd Street				Morris Street				Waverly				Centerton			
		Pre-AWT		Post-AWT		Pre-AWT		Post-AWT		Pre-AWT		Post-AWT		Pre-AWT		Post-AWT	
Parameter	Standard	N1	N2	N1	N2	N1	N2	N1	N2	N1	N2	N1	N2	N1	N2	N1	N2
Ammonia as N, total	2.5 mg/L	35	0	37	0	108	0	48	0	135	51	48	0	135	34	48	0
Ammonia as N, un-ionized	0.05 mg/L	35	0	37	0	108	1	48	0	135	15	48	0	135	12	48	0
Dissolved oxygen	5.0 mg/L	35	0	39	0	143	2	48	1	145	51	48	2	141	34	48	0
Fecal-coliform bacteria	2000 col/100 mL	35	9	38	9	n.d.	n.d.	48	15	n.d.	n.d.	48	25	n.d.	n.d.	48	19

Dissolved-oxygen concentrations were never less than the standard at 82nd Street; they were less than the standard at Morris Street in two samples before implementation of AWT, and in one sample after implementation. Downstream from the wastewater-treatment facilities, the DO concentrations were less than the standard in 35 percent of the samples collected at Waverly and in 24 percent of the samples collected near Centerton, before implementation of AWT. Following implementation of AWT, the standard was met in all samples collected near Centerton; it was not met in two samples (4 percent) collected at Waverly. Both samples (4.5 and 4.8 mg/L) were measured during summer lowflows (about 450 ft^3/s). The reduction in the number of times the dissolved-oxygen concentration failed to meet the standard indicates an improvement in river quality.

Fecal-coliform bacteria counts exceeded the standard in 26 percent of the samples at 82nd Street before implementation of AWT, and in 24 percent of the samples after implementation. No data were available from Morris Street prior to implementation of AWT, but the standard was exceeded in 31 percent of the samples after implementation. Downstream from the Belmont and Southport wastewater-treatment plants, no data were available from Waverly or Centerton prior to implementation of AWT, but the standard was exceeded in 52 percent of the samples collected after implementation at Waverly and in 40 percent of the samples collected near Centerton. Where Belmont and Southport treatment-plant-effluent data were available, they were compared with the river data during the periods when the standard was exceeded in the river. In only one occurrence at Waverly and one occurrence near Centerton after implementation of AWT, could the large fecal-coliform bacteria counts in White River be attributed to the treatment plants. Several tributaries to White River in Indianapolis have a history of combined sewer overflows; it is likely that they are the source of the high concentrations of fecal-coliform bacteria, rather then the two treatment plants. This analysis was based on the monthly river-quality samples, however, and the sample size is not adequate to determine sources of the fecal-coliform bacteria. Also, the data analyzed in this study do not represent the full range of concentration during storm runoff.

SUMMARY AND CONCLUSIONS

Monthly monitoring data from four sites on White River and daily samples from the Belmont and Southport municipal wastewater-treatment plants were analyzed for trends to determine if significant changes in river quality had occurred owing to implementation of advanced wastewater treatment. Two nonparametric-statistical procedures were used to test for trends in the time-series water-quality data. The seasonal Kendall procedure is an alternative to linear-regression methods; it was used to test for a monotonic trend (a systematic and continuous change). This procedure was used to test for long-term (1957 through 1986) trends in White River at 82nd Street, upstream from the treatment plants. The seasonal Wilcoxon-Mann-Whitney rank-sum procedure is an alternative to the t-test; it was used to test for a step trend (an abrupt and constant change) at all sites for the period 1978 through 1986.

Water quality at sample sites located upstream from the wastewater-treatment facilities was relatively constant during the period of study. Significant (probability level <0.05) increasing trends were indicated for ammonia in data from White River at 82nd Street and White River at Morris Street; however, the rate of change with time was small when compared to the change that occurred in the treatment-plant effluents and in White River downstream from the treatment plants.

Changes in effluent quality at the Belmont and Southport wastewater-treatment plants resulted in statistically significant changes in water quality in White River downstream from the plants, when pre- and post-AWT water-quality data were tested for trend. The test for step trends indicated highly significant decreases in concentrations and loads of BOD_5 and total solids in Belmont and Southport effluents, and in concentrations and loads of ammonia and phosphate in Belmont effluent (no data were available for Southport). Because of in-plant nitrification, a highly significant increase in nitrate concentration and load was indicated at the Belmont plant (no data were available for the Southport plant). The same trends occurred in White River downstream from the treatment plants. Statistically significant decreases in the concentrations and loads of ammonia and BOD_5 were observed in the White River at Waverly and near Centerton. Increases in nitrate concentrations and loads were also statistically significant at both of the downstream sites. The decrease in ammonia and BOD_5 concentrations and loads in White River following implementation of AWT resulted in a highly significant increase in dissolved-oxygen concentration and percent saturation because of reduced oxygen demand for nitrification and BOD processes at both of the downstream sites.

The number of times that river-quality samples exceeded the water-quality standards that apply to White River decreased substantially, following implementation of advanced wastewater treatment. Total ammonia concentrations exceeded the standard of 2.5 mg/L in 38 percent of the samples collected at Waverly and 25 percent of the samples collected near Centerton, downstream from the wastewater-treatment plants, before implementation of advanced wastewater treatment. Concentrations at these sites have not exceeded the standard in any samples collected since implementation of advanced wastewater treatment. Dissolved-oxygen concentrations were less than the 5.0 mg/L standard in 35 percent of the samples collected at Waverly and 24 percent of the samples collected near Centerton before implementation of advanced wastewater treatment. Dissolved-oxygen concentrations in White River at Waverly were observed to be less than the standard only twice since implementation of advanced waste treatment. Dissolved-oxygen concentrations were not observed to be less than the standard since implementation of advanced wastewater treatment.

Upstream water-quality conditions in White River were relatively constant over time. Statistically significant changes in river quality were indicated by tests of water-quality data from the treatment plants and in White River downstream from the plants. The number of times a water-quality standard was exceeded has been substantially reduced. The implementation of advanced wastewater-treatment systems at the Belmont and Southport wastewater-treatment plants has resulted in substantial changes in the quality of treated effluent and, therefore, in the quality of the White River downstream from Indianapolis.

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