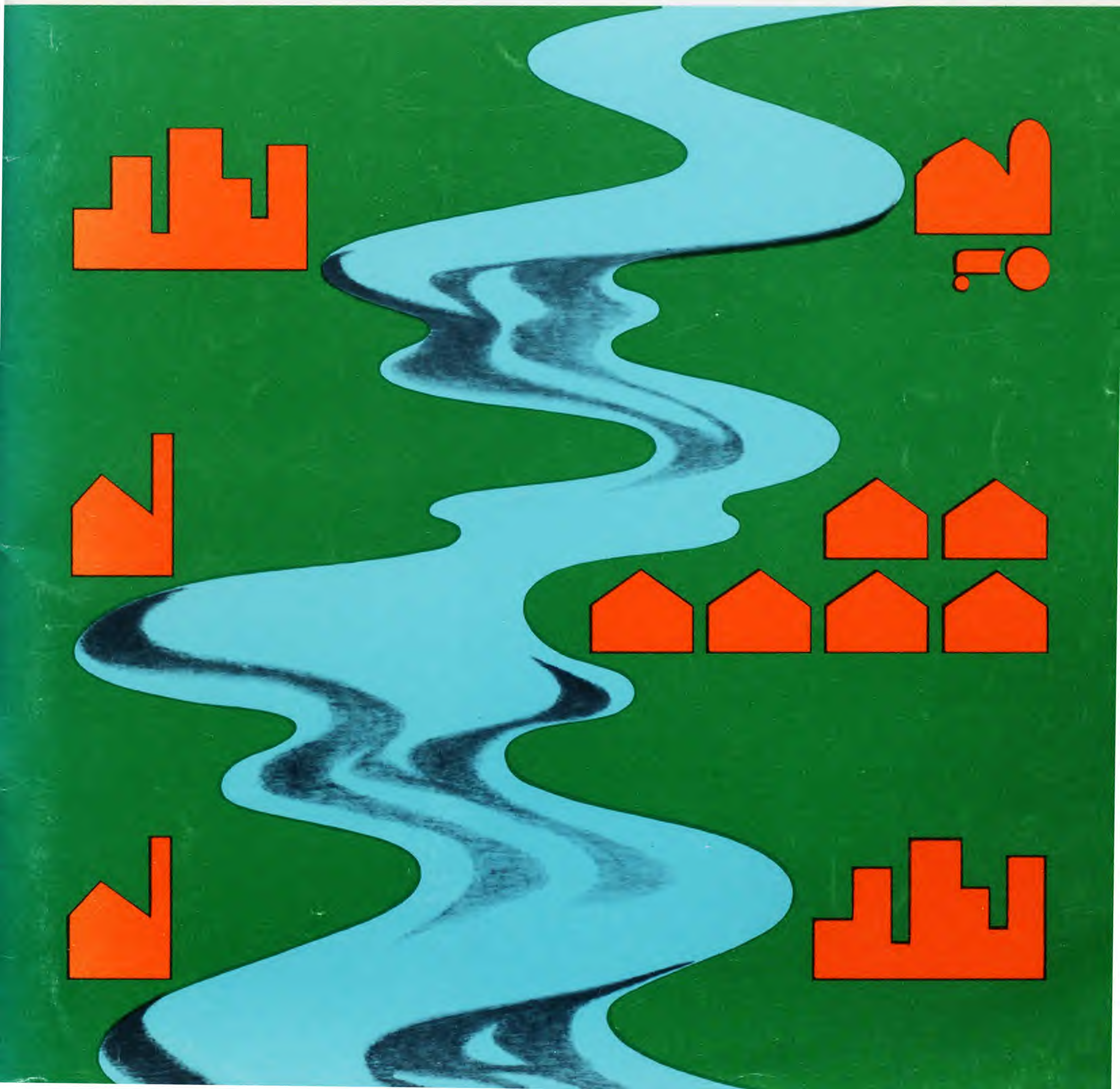
A river-quality assessment of the upper White River, Indiana

U.S. Geological Survey
Water-Resources Investigations
10-75



BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.

4. Title and Subtitle

A river-quality assessment of the upper White River, Indiana

5. Report Date June 1975

6.

7. Author(s)

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8. Performing Organization Rept. No. WRI 10-75

9. Performing Organization Name and Address

U.S. Geological Survey
1819 N. Meridian Street
Indianapolis, Indiana 46202

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

U.S. Geological Survey
1819 N. Meridian Street
Indianapolis, Indiana 46202

13. Type of Report & Period Covered

Final

14.

15. Supplementary Notes

16. Abstracts

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17. Key Words and Document Analysis. 17a. Descriptors

*water pollution sources, *nutrients, *pesticide residues, *biological communities, *physical properties, *biological properties, *chemical properties, municipal wastes, industrial wastes, reservoirs, thermal stratification, bottom sediments, land use, sewage effluents, Indiana, esthetics, aquatic microbiology

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	UNCLASSIFIED	
	20. Security Class (This Page) UNCLASSIFIED	22. Price

A RIVER-QUALITY ASSESSMENT OF THE

UPPER WHITE RIVER,

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 10-75

1975

UNITED STATES DEPARTMENT OF THE INTERIOR

Rogers C. B. Morton, Secretary

GEOLOGICAL SURVEY

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CONTENTS

ILLUSTRATIONS

TABLES

PREFACE

Various aspects of the quality of the White River have been studied since Indianapolis was founded in 1821. Each study defined, in varying degrees of detail, the chemical, physical, or biological conditions of the river as related to specific water problems at the time. This report is the product of a pilot study designed to demonstrate the feasibility of assembling the mass of available data, and expanding the concept of a water-quality study to that of a river-quality assessment. In a river-quality assessment it is recognized that the physical, chemical, biological, esthetic, and cultural characteristics of a river are all interrelated and are the net result of a wide variety of factors such as the physical setting, climate, land and cultural resources, water resources, and pollution. The purpose of such an assessment is to provide a useful management tool by describing the present quality of the river and attempting to establish trends that can be used for predictive purposes.

METRIC TABLE

The following factors may be used to convert the English units published herein to the International System of Units (SI).

Multiply English units	By	To obtain SI units
	Length	
inches	25.4	millimetres (mm)
feet	.3048	metres (m)
miles	1.609	kilometres (km)
	Area	
acres	.4047	hectares
square miles (mi^2)	2.590	square kilometres (km^2)
	Volume	
gallons (gal)	3.785	litres (l)
million gallons (10^6 gal)	3785	cubic metres (m^3)
cubic feet (ft^3)	.02832	cubic metres (m^3)
acre-feet (acre-ft)	1233	cubic metres (m^3)
	Flow	
cubic feet per second (ft^3/s)	28.32	litres per second (l/s)
cubic feet per second (ft^3/s)	.02832	cubic metres per second (m^3/s)
gallons per minute (gal/min)	.06309	litres per second (l/s)
million gallons per day (Mgal/d)	.04381	cubic metres per second (m^3/s)
	Mass	
pounds (lb)	.4536	kilograms (kg)
ton (short)	.9072	tonne (t)
	Temperature	
degrees Fahrenheit (°F)-32	.556	degrees Celsius (°C)

A RIVER-QUALITY ASSESSMENT OF THE UPPER WHITE RIVER, INDIANA

by William J. Shampine

ABSTRACT

This report attempts to interrelate the physical, chemical, biological, esthetic, and cultural aspects of the upper White River (above Centerton, Ind.) by assessing the mass of available data. Relatively few new data were collected.

The White River can be subdivided into five distinct river-quality sections. Section 1, above Winchester, drains a rural area and is affected by agricultural land use, although the river quality generally is good. Section 2, between Winchester and Muncie, is affected by urbanization at Winchester and Muncie. The river quality generally is good, although stretches near the cities occasionally have problems. Section 3, Muncie to Anderson, is polluted by urban effluent. Section 4, Anderson to Indianapolis, is further polluted (particularly at Anderson), but the river tends to recover considerably at Indianapolis, and becomes relatively clean. Section 5, below Indianapolis, is polluted. The river continues to be polluted below the project boundary.

The river is affected most severely in the Indianapolis area. For example, in October 1972 the nitrogen load increased from 5.45 tons per day (4.94 tonnes per day) above Indianapolis to 18.43 tons per day (16.72 tonnes per day) below the city. Ten micrograms per kilogram of DDD, 20 micrograms per kilogram of chlordane, and 20 micrograms per kilogram of polychlorinated biphenyls were extracted from the sediments in the White River below Indianapolis. The median coliform bacteria count below Indianapolis is 360,000 colonies per 100 millilitres of water. The only benthic invertebrates found in the White River below Indianapolis are pollution-tolerant species, and very few fish are found. Conditions are similar, but to a somewhat lesser degree, below Muncie.

INTRODUCTION

Physical Setting

The upper White River basin extends over an area of about 2,444 square miles (6,330 square kilometres) in central Indiana (fig. 1). The bedrock in the basin was deposited from about 500 to 300 million years ago, during the Paleozoic Era, and consists of sandstone, limestone, dolomite, and shale. Of the marine sedimentary rocks, the layers of limestone and dolomite are the best aquifers (water-bearing formations).

From about 300,000 to 12,000 years ago glaciers moved through the basin. These glaciers modified the land surface by smoothing out some of the rugged hills and filling some of the valleys with till. When the glaciers had finally retreated, the bedrock was covered by till and stratified layers of clay, silt, and sand and gravel. These deposits range in thickness from a few feet to about 300 feet (91 metres). The buried layers of outwash sand and gravel are good sources of water.

The surface features of the basin were left relatively flat with gently rolling till plains broken occasionally by stream valleys. The White River, the major stream, is about 170 miles (274 kilometres) long and flows in a westerly direction toward Noblesville, then southwesterly to its confluence with the Wabash River in southwestern Indiana. The major tributraries to the upper White River are Buck, Killbuck, Pipe, Duck, Cicero, Fall, Eagle, and White Lick Creeks. These tributaries and the general drainage pattern of the basin are shown in figure 9.

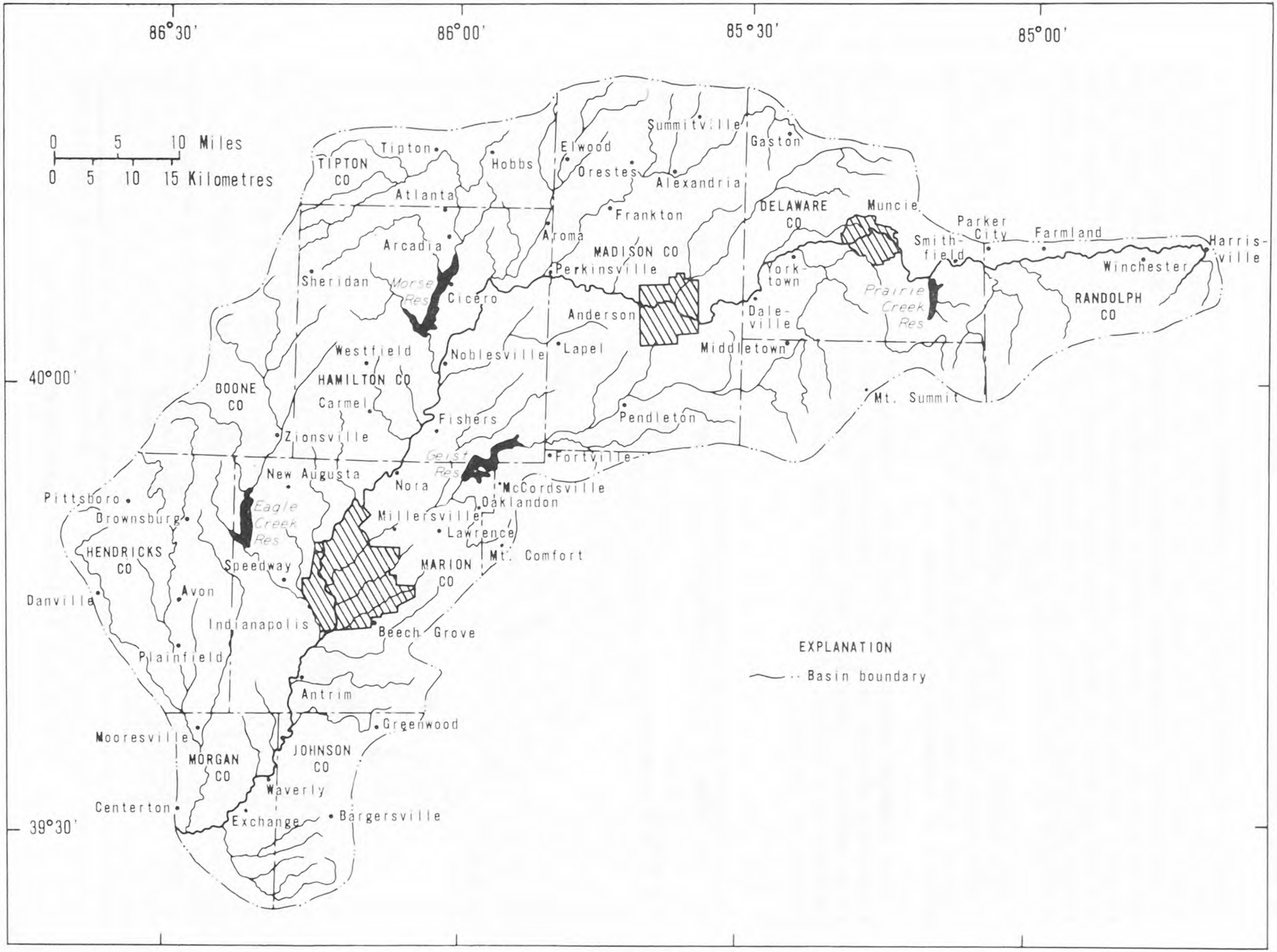


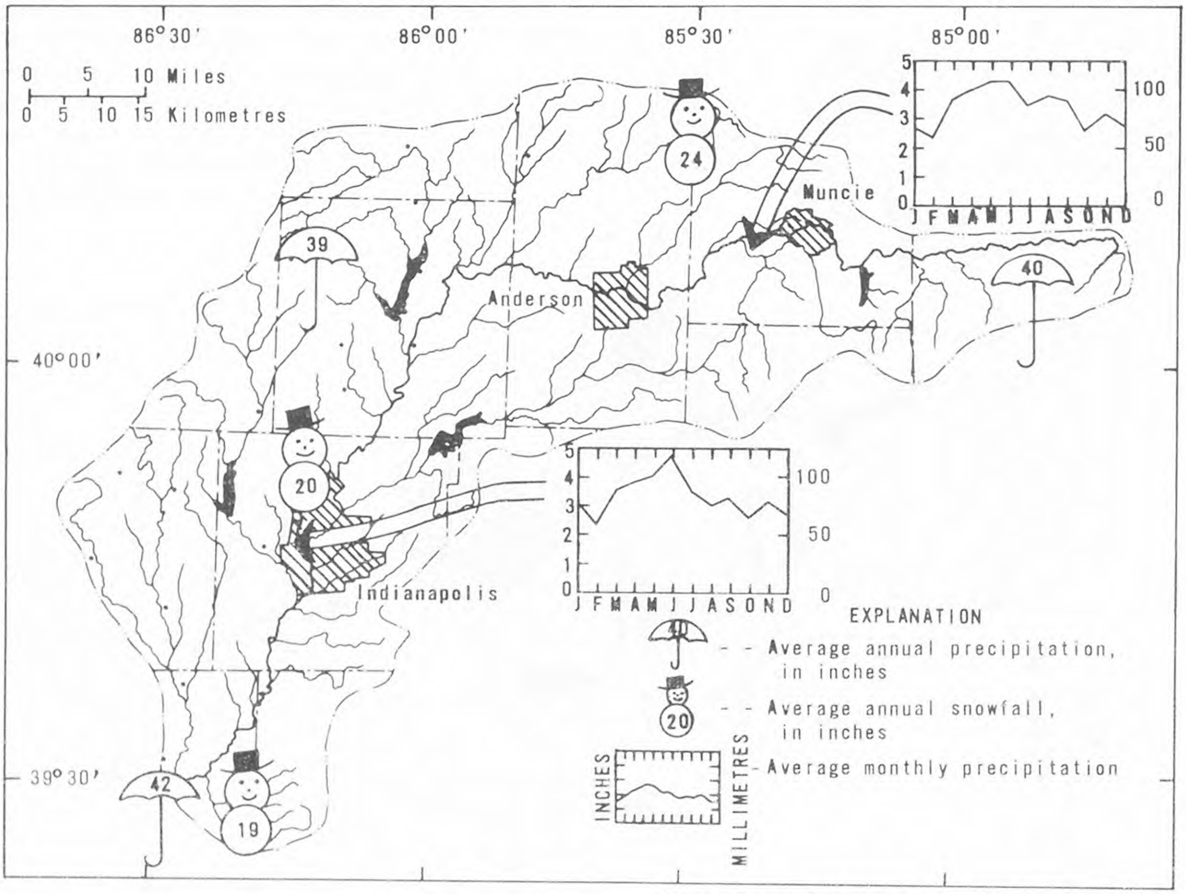
Figure 1.-- Upper White River basin

Climate

The climate is the humid, continental, warm-summer type characterized by definite winter and summer seasons accompanied by large annual temperature ranges. The cooler months are characterized by dull, gray, overcast skies and drizzly rain or snow. This broad, general type of precipitation is the result of masses of warm, moisture-laden air from the Gulf of Mexico moving northward and contacting cooler northern air.

Precipitation during the summer occurs sporadically and is of the thunderstorm type, when heavy downpours may occur over small areas. This type of storm can cause flash flooding in localized areas and can wash large amounts of sediment into a stream.

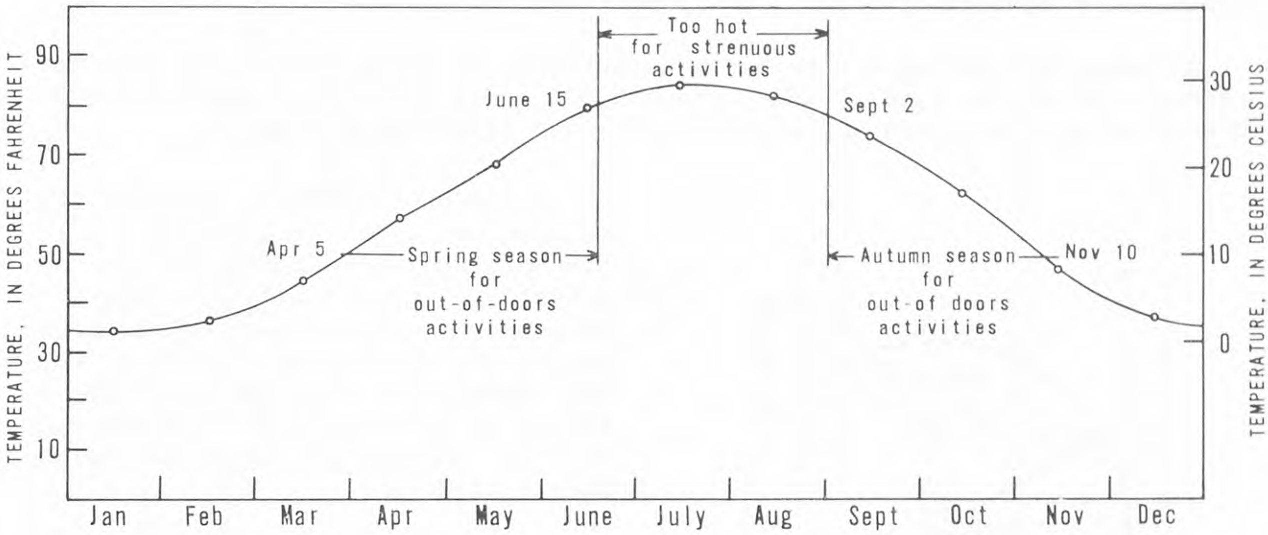
The average annual precipitation is about 40 inches (1,020 mm), and is relatively uniform (fig. 2). Variations in the monthly precipitation tend to be moderate. February and October characteristically have the lowest rainfall (2.2 inches, or 560 mm), and June usually has the highest (4.5 inches, or 114 mm).



Data from U.S. Department of Commerce, 1972

Figure 2.-- Selected climatological features

Temperatures for most outdoor recreation in the upper White River basin are ideal during 5 months of the year (fig. 3). July and August are generally too hot for strenuous outdoor recreation except for those associated with open water, such as swimming or water skiing.



Data from U.S. Army Corps of Engineers, 1971 d

Figure 3.-- Mean daytime temperatures

In January the daily temperature variations average from 21°F (-6°C) to 37°F (3°C). In July the average will be from 64°F (18°C) to 86°F (30°C).

Land and Water Use

The 1970 population of the basin was about 1.1 million. About 75 percent lived in the Indianapolis area and 90 percent within the urban areas of Indianapolis, Muncie, and Anderson (U.S. Bureau of the Census, 1971). Eight municipalities have a current population in excess of 10,000.

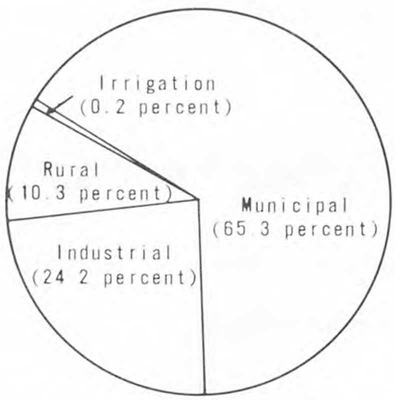
The basin has a diversified economic base in which both agriculture and manufacturing play important roles. Because of its location amid several major population centers and along major national transportation routes, it is in a favorable marketing position for its agricultural products. In addition, the multi-million dollar agricultural sector represents an important market for many of the goods and services produced by other industries and businesses. The multi-million dollar industrial sector is centered in

Indianapolis, Muncie, and Anderson and includes manufacturing, mining, construction, finance and insurance, wholesale and retail trade, transportation and communication, and professional services.

A report by the Soil Conservation Service (1968) shows that in 1967 cropland accounted for 62 percent of the land and 6 percent was pasture. Urban areas constituted 19 percent; forest, 7 percent; and water surface, roads, idle agricultural land, investment tracts, and mines, 6 percent.

Although all mining in the basin is surface, or strip mining, it does not affect much of the land. Only about 5,000 acres (2,000 hectares) has been disturbed by clay, sand and gravel, peat, and limestone mining.

In 1970 daily water use was 149 million gallons (5.64×10^5 m^3). Most of this water (97.3×10^6 gal or 3.68×10^5 m^3) was used for domestic purposes and was supplied by the municipal water companies (fig. 4). The industrial category in figure 4 refers to self-supplied systems and not to industrial concerns using municipal water.



Total use: 149 Mgal/d (6.53 m^3/s)

Figure 4.-- Water use in 1970

Most of the municipal water systems in the basin use ground water (fig. 5). The exceptions are: (1) Muncie, all surface water; (2) Indianapolis, 95 percent surface water; and (3) Speedway, 52 percent surface water. Even though these three municipalities are the only ones using surface water, they account for 75 percent of the total water used.

ACKNOWLEDGMENTS

The author acknowledges, with gratitude, the individuals who have assisted in the collection, tabulation, and processing of data for this report. Particular thanks are given Robert A. Pettijohn and Leslie D. Arihood of the U.S. Geological Survey, and to Robert Becker of the Indianapolis Water Company.

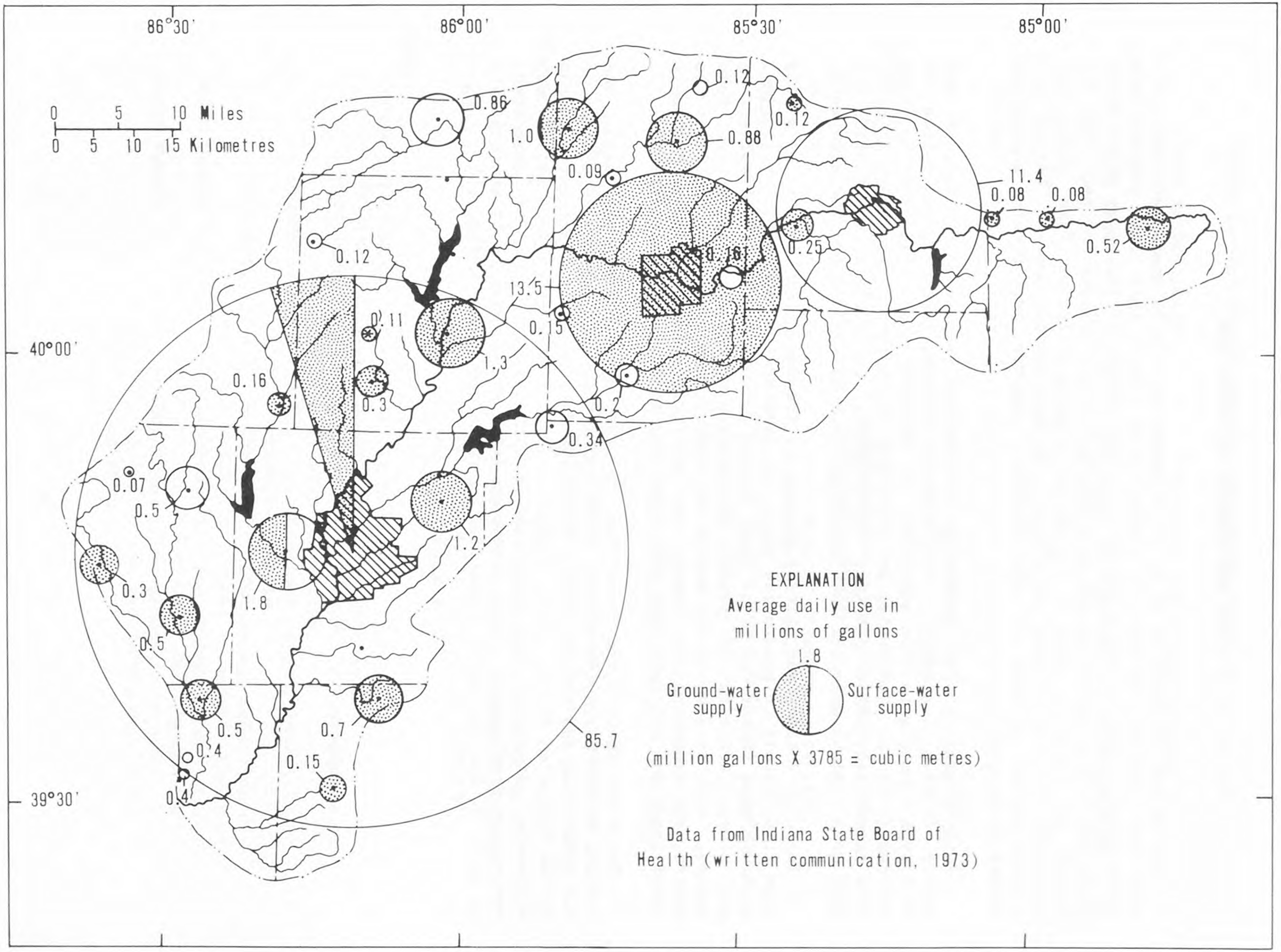


Figure 5.-- Quantity and source of municipal water supplies

TYPES AND SOURCES OF POLLUTION

One of the by-products of a functioning society is waste material. Almost any activity of man will create some waste that may pollute his environment. Some of the types of pollution found in the upper White River basin and a description of the possible hydrologic effects of each type are listed in table 1. Some of the wastes causing pollution find their way untreated to the streams and rivers. In many places, however, wastes are treated before release to the rivers. However, even treated wastes can stress river quality.

Agricultural wastes generally are derived from nonpoint sources and rarely receive treatment. Pollution by diffuse, land-oriented wastes of this type commonly is more dependent on weather than pollution by point sources (such as industrial and municipal discharges). For example, heavy rain immediately after plowing, fertilizing, or pesticide application may wash more noxious material into waterways than it would some time afterward.

The wide variety and varying degrees of treatment of industrial wastes make it difficult to generalize about the problems of industrial pollution. Although most industries treat their wastes to some degree, the treatment is not always adequate to prevent degradation of the receiving water. Some wastes, such as some of the metals and organic compounds, are difficult to remove, are expensive to treat, and are troublesome because of their persistence and the fact that they often are toxic in low concentrations.

There are about 9,000 industries in the upper White River basin. The Indiana Stream Pollution Control Board has inventoried about 10 percent of the industries and has wastewater discharge data on about 1 percent (Indiana Stream Pollution Board, oral commun., 1973). However, the relatively few wastewater discharge data available do account for most of the total wastewater discharged. These discharge data are summarized by municipality in table 2, and the major industrial outfalls are shown on figure 6.

Table 1.--Hydrologic effects of various types of pollution

Types of Pollution	Possible Hydrologic Effects
Agriculture	
Nutrients from fertilizers	Enrichment of streams; overabundance of aquatic vegetation.
Pesticides	Toxic to aquatic organisms; disruption of the natural food chains.
Sediment	Esthetically displeasing; reduction of numbers and kinds of aquatic organisms, may damage bridge structures by scour or fill; may fill reservoirs.
Industrial	
Inorganic chemicals	Large concentrations can restrict use for public supply.
Metals	Toxic to aquatic organisms; restrict use for public supply.
Organic chemicals	Toxic to aquatic organisms; taste and odor problems; esthetically displeasing.
Thermal	Reduces the assimilative capacity of streams; supports biological activity during the winter.
Turbidity	Esthetically displeasing; reduction of numbers and kinds of aquatic organisms.
Mining	
Sediment	Esthetically displeasing; reduction of numbers and kinds of aquatic organisms.
Metals	Toxic to aquatic organisms; restrict use for public supply.
Urban	
Sewage - Bacteria	Health hazard.
Metals	Toxic to aquatic organisms.
Nutrients	Enrichment of streams; overabundance of aquatic vegetation.
Organic loading	Depletes dissolved oxygen; restricts aquatic organisms.
Turbidity	Esthetically displeasing; reduction of numbers and kinds of aquatic organisms.
Solid wastes	Esthetically displeasing; odors; contaminates ground water and adjacent streams.
Storm runoff	Increased flood hazard; road salt, fertilizers, and pesticides may affect water quality.

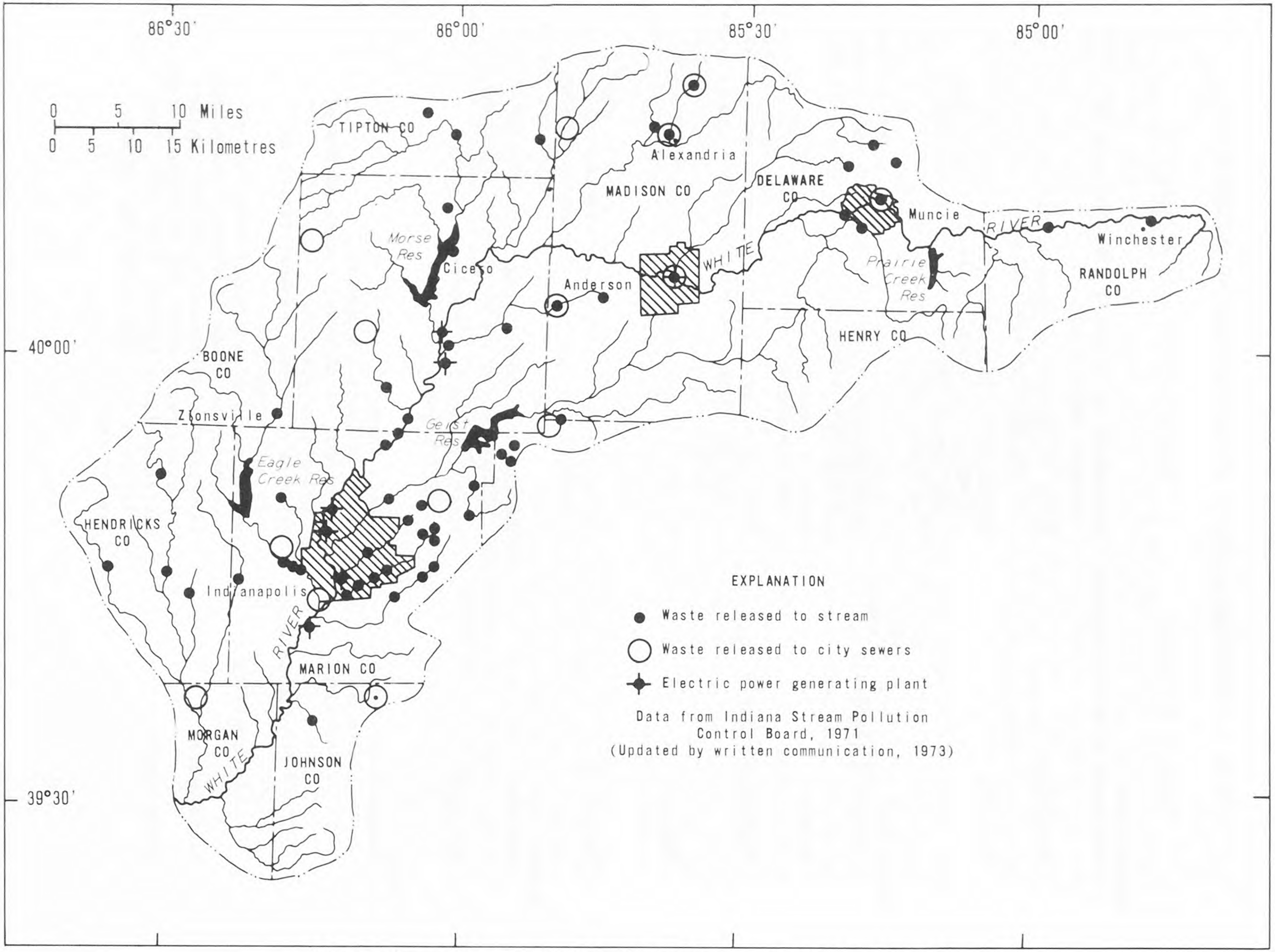


Figure 6.-- Major industrial wastewater discharge points

Table 2.--Industrial waste data by municipality

(Data from Indiana Stream Pollution Control Board, 1971, updated 1973, written communication)

City	Receiving Stream	Waste flow (Mgal/d)	Waste load BOD lb/d
Alexandria			
	Pipe Creek		
	Mud Creek	0.25	100
	City sewer		
	Soil	.02	
Anderson			
	Stoney Creek	50.40	
	City sewer		
	Stanley ditch		
Arcadia			
	Soil		
Avon			
	White Lick Creek	.13	15
Beech Grove			
	Lick Creek	.10	10
Carmel			
	Carmel Creek	.02	10
Elwood			
	Pollywog Creek	.05	100
	City sewer		
Farmland			
	White River		
Fortville			
	City sewer	.02	
	Flat Fork	.01	
Greenwood			
	City sewer		
Hobbs			
	Cicero Creek	.05	50
Indianapolis			
	City sewer	4.05	575
	Eagle Creek	6.93	360
	Pleasant Run	.15	
	White River	227.11	60
	Bean Creek	1.80	50
	White Lick Creek		
	Pogue's Run	.86	
Lapel			
	City sewer	.03	
	Stoney Creek		

Table 2.--Industrial waste data by municipality--Continued

(Data from Indiana Stream Pollution Control Board, 1971, updated 1973, written communication)

City	Receiving Stream	Waste flow (Mgal/d)	Waste load BOD lb/d
Lawrence			
	City sewer		
	Indian Creek	0.02	
McCordsville			
	Fall Creek	.20	
Mt. Comfort			
	Indian Creek	.05	
Mt. Summit			
	White River	.90	200
Mooresville			
	City sewer		
Muncie			
	City sewer	.46	
	White River	.33	50
	Jakes Ditch		
	Muncie Ditch	.01	
	Killbuck Creek		
	Buck Creek		
New Augusta			
	Little Eagle Creek	.50	180
Noblesville			
	White River	38.80	25
Orestes			
	Lilly Creek	.06	0
Sheridan			
	City sewer		
Speedway			
	City sewer		
Summitville			
	Mud Creek	.02	
	City sewer		
Tipton			
	Buck Creek	.38	0
Winchester			
	White River	.05	
	Trib. to White River		
Zionsville			
	Eagle Creek	.15	67
	Trib. to Eagle Creek		

The largest producers of industrial wastewater (by volume) in the upper White River are the seven electric power generation plants, whose main waste product is heat. Large volumes of water are pumped from the White River and used as cooling water in the powerplants. After varying periods of storage, the cooling water is returned to the river, commonly at a higher temperature. Unlike most pollution, heat can have beneficial as well as detrimental effects. For example, winter discharge of heated water may enable some aquatic organisms to survive the otherwise fatal winter temperature, and it may keep the river from freezing over, thus increasing reaeration potential.

The upper White River basin has 33 sand and gravel, clay, and limestone strip mines (Indiana Geol. Survey, written commun., 1973). These mines may add fine sediment to an adjacent stream.

Sewage is one of the most common forms of pollution in an urban environment. Although all the municipalities in the upper White River basin treat sewage by secondary methods, except Yorktown, which has a primary treatment system, even treated sewage can cause a variety of serious problems (table 1).

Much of the organic material in the effluent from a sewage-treatment plant is biodegradable (decomposable into simpler forms by bacteria), and, as such, exerts an oxygen demand on the water. The oxygen demand can be great enough to consume all the oxygen dissolved in the water. When this occurs the water is biologically unhealthy and esthetically displeasing. Biochemical oxygen demand (BOD) is one common measure of the oxygen-using characteristics of a wastewater. BOD loads from some municipal effluents are given in table 3.

A problem associated with sewage disposal is the use of combined sewer systems, where sanitary-sewer effluent is combined with that of storm sewers. This type of system is more difficult to control than separate systems. For example, during a storm, water carried by storm sewers may overload a treatment plant, causing raw sewage to be discharged to a stream. This is a significant concern in the upper White River basin because 16 of 35 municipalities have combined sewer systems (table 3).

Paved surfaces and concrete, canalized drains prevent rain from infiltrating the ground, thus increasing and accelerating storm runoff from urban areas, and increasing the possibility of flooding. Further, litter, road salt, fertilizers, and pesticides washed from the land surface may create a BOD load in storm water comparable to similar volumes of sewage-treatment-plant effluent.

Table 3.--Municipal waste data

(Data from Indiana Stream Pollution Control Board, 1967, updated 1973, written communication)

Municipality	Population Served	Type Treatment	Waste Flow (Mgal/d)		Waste Load		Receiving Stream
			Design	Present	BOD (lb/d)	Suspended Solids (lb/d)	
Alexandria	5,097	T - Co	1.00	0.75	50		Pipe Creek
Anderson	76,114	A,C - Co	22.70	16.00	2,300		White River
Arcadia	1,338	T,C - Se		.15	13	14	Cicero Creek
Atlanta	600	L,C - Se[1]		.04	13	15	
Bargersville	873	T,L - Se	.14	.04	3	4	Mid.Fk. Stotts Cr.
Beech Grove	13,468	A,C - Se	1.20	1.48	222	716	Lick Creek
Brownsburg	5,186	A,C - Co[1]	.50	.55	64		White Lick Creek
Carmel	6,568	A,C - Se	.30	.52	82	74	Cool Creek
Cicero	1,378	A,C - Co[1]		.13	9	13	Cicero Creek
Danville	3,771	T - Se[1]	.75	.60	90	65	White Lick Creek
Elwood	11,196	A - Co	1.73	1.73	170		Duck Creek
Farmland	1,262	T,C - Se		.10			Trib. to White River
Fortville	2,460	T,C - Co	.40	.35	67		Trib. to Fall Creek
Frankton	1,796	T - Se	.15	.03	24		Pipe Creek
Gaston	928	T,C - Co	.10	.20	20		Pipe Creek
Greenwood	11,408	A,C - Se[1]	1.00	1.00	170	150	Pleasant Run Creek
Indianapolis	744,624						
North plant		A,C - Co[1]	120.00	110.00	30,000	26,000	White River
South plant		A - Co	28.00	36.00	3,300	3,600	White River
Lapel	1,725	A - Co	.18	.11	30		Stoney Creek
Lawrence	16,646	A,C - Se	1.80	1.80	300	300	Trib. to Fall Creek
Middletown	2,046	T,C - Co	.45	.45	35		Fall Creek
Mooresville	5,800	T - Se[1]	.50	.52	173		White Lick Creek
Muncie	69,080	A - Co	20.00	14.10	2,300		White River
Noblesville	7,548	A - Co	.80	.71	59	47	White River
Parker City	1,179	T,C - Se		.05			Trib. to White River
Pendleton	2,243	A,C - Se	.21	.19	40		Fall Creek
Pittsboro	867	T,C - Se	.20	.09	18	15	White Lick Creek
Plainfield	8,211	A,C - Co[1]	1.50	.80	40		White Lick Creek
Sheridan	2,137	A - Co	.40	.30	50	58	Little Cicero Creek
Speedway	15,056	T,C - Se	4.00	3.20	480	640	Eagle Creek
Summitville	1,104	L - Co[1]		.05			Mud Cr., Pipe Creek
Tipton	5,176	T,C - Se	.90	.80	140		Cicero Creek
Westfield	1,837	L - Se[1]	.20	.15	50	58	Cool Creek
Winchester	5,493	T,C - Se	.88	.65	90		White River
Yorktown	1,673	P,C - Co	.37	.28	175		White River
Zionsville	1,854	T,C - Se	.50	.25	37		Eagle Creek

A = activated sludge
C = chlorination
Co = combined storm-sanitary sewer system
L = lagoon
P = primary
Se = separate system
T = trickling filter
1 = mixture, indicated system predominates

Solid waste disposal is another problem associated with urban development. A common practice is to bury the wastes in landfills, which are potential sources of pollution. Water percolating through a landfill will pick up both inorganic and organic constituents. The resulting leachate can then pollute ground-water reservoirs or discharge into nearby streams. There are 17 active landfill sites in the basin (fig. 7) and many inactive sites. Most municipalities have had at least one site in the past (Indiana Board of Health, oral commun., 1973).

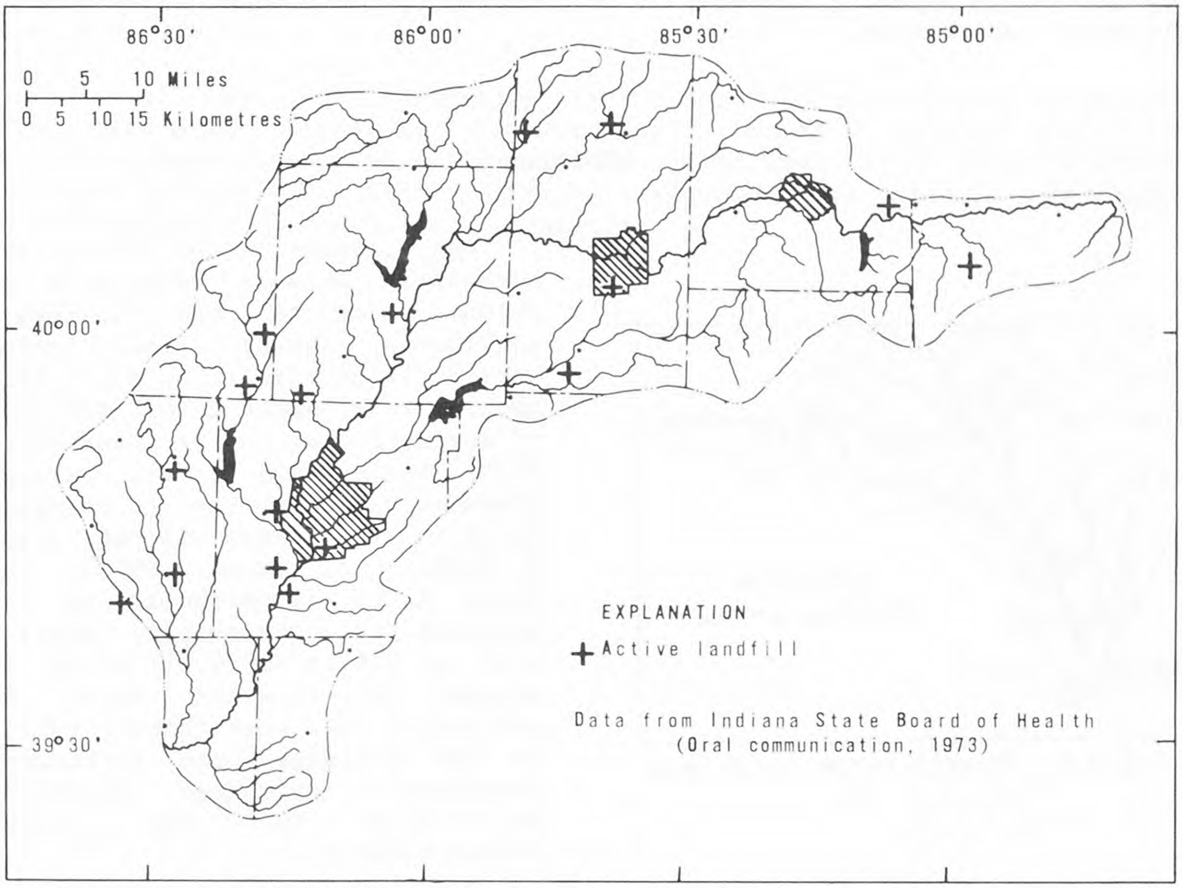


Figure 7.-- Location of active landfill sites

Physical

One of the most obvious physical characteristics affecting river quality is discharge. Either extreme of discharge can cause problems. On occasion, discharge will be so low that water demands cannot be met; on other occasions it will be so high that flooding causes property damage and loss of life. Other related physical characteristics include traveltime of dissolved constituents, movement of sediment in the water and on the bottom, and water temperature.

Flow

Many streams in the basin are perennial because discharge of ground water to them provides a continuous (base) flow during periods of no rain (fig. 8). As a general rule, about 25 mi^2 (65 km^2) of drainage area in the upper White River basin will provide enough ground-water discharge to maintain water in the stream all year (Paul B. Rohne, oral commun., 1973). The White River is perennial as far upstream as Harrisville, where a flow of 0.6 ft^3/s (0.017 m^3/s) is equaled or exceeded about 90 percent of the time (Rohne, 1972). As the drainage area increases, ground-water discharge increases the flow in the river proportionately.

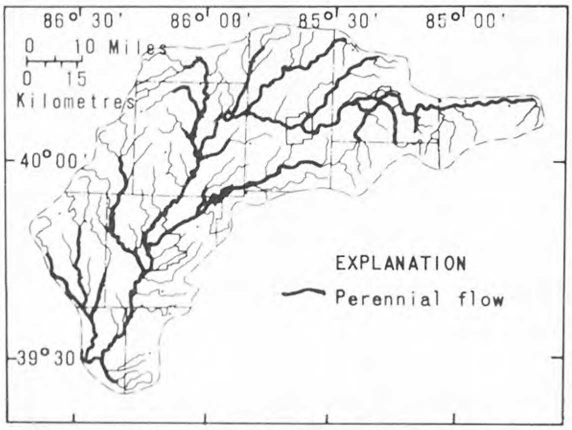


Figure 8.-- Perennial streams in the basin

Surface runoff from precipitation contributes a volume of water to a river over and above base flow. The size and relief of the drainage area largely control the distribution of this additional volume of water. For example, a heavy rain above Winchester, where the drainage area is small, will cause a surge in river flow, which subsides in about 3 days. A heavy rain above Centerton, where the drainage area is large, will cause a surge that lasts several days.

Another effect of increased drainage area on streamflow is demonstrated by greater flow extremes downstream, as shown on figure 9. Discharge extremes can be useful in evaluating potential flow problems during extremely dry years, such as 1941, and extremely wet years, such as 1964.

In addition to natural controls, such as amount of precipitation and size of drainage area, riverflow is also commonly controlled by water-supply intakes, reservoirs with controlled outlets, and flood-control levees. Major cities such as Indianapolis and Muncie can utilize most of the water in the White River during very low flow. For example, during the drought year of 1941 as much as 83 percent of the water in the White River was diverted by Indianapolis; however, most of it was returned downstream as treated sewage.

Three of the four reservoirs in the basin, Prairie Creek, Morse, and Geist, were built primarily for water supply. Water is released daily from each to augment streamflow for downstream diversion. Eagle Creek Reservoir was built primarily for flood control, and water is released after heavy precipitation to maintain storage capacity.

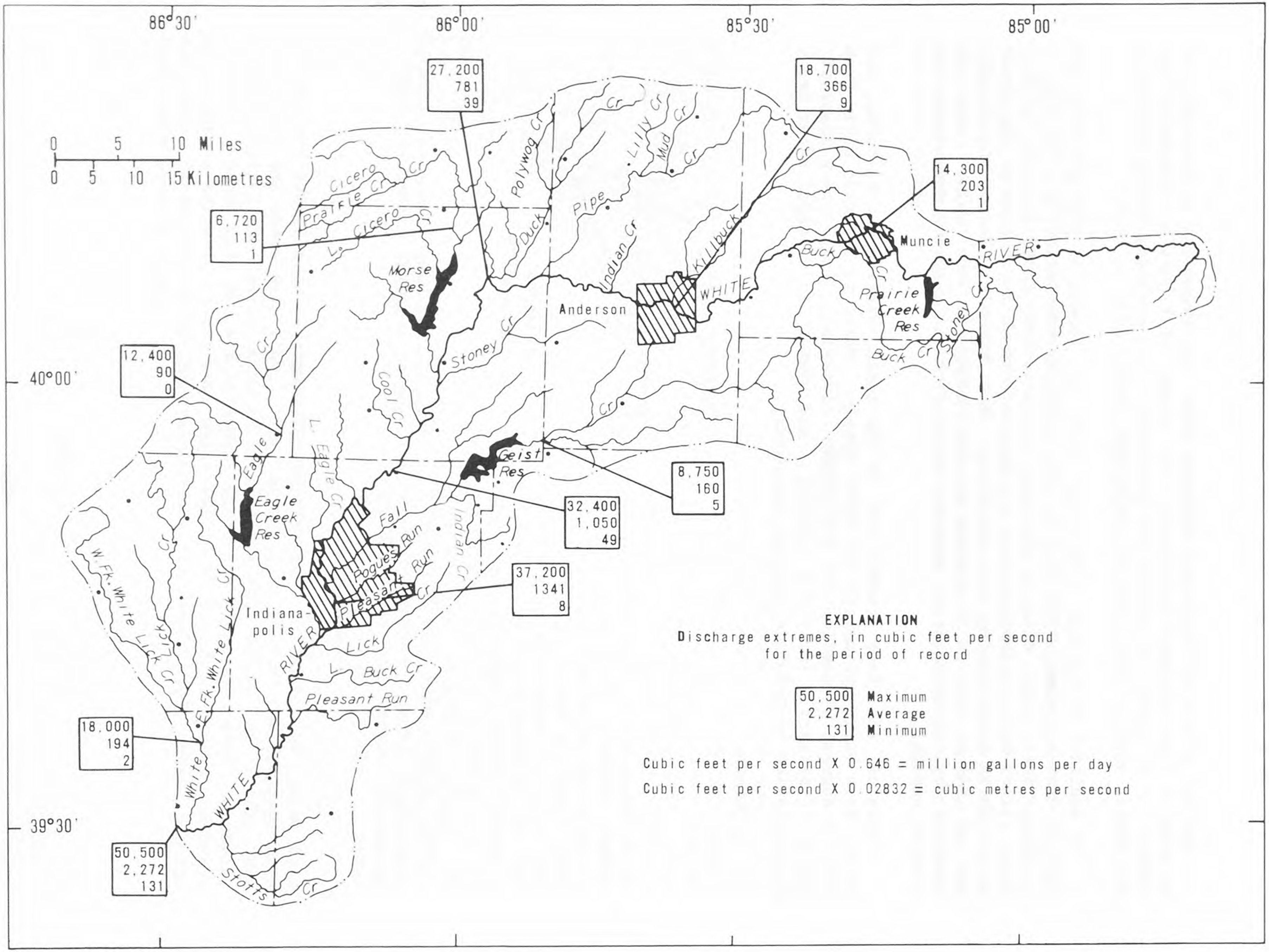


Figure 9.-- Extremes of discharge at selected sites

Traveltime

The traveltime of stream water varies substantially from place to place. The traveltime of the water in the upper part of the White River can be estimated for most flow conditions from figure 10. The data in figure 10

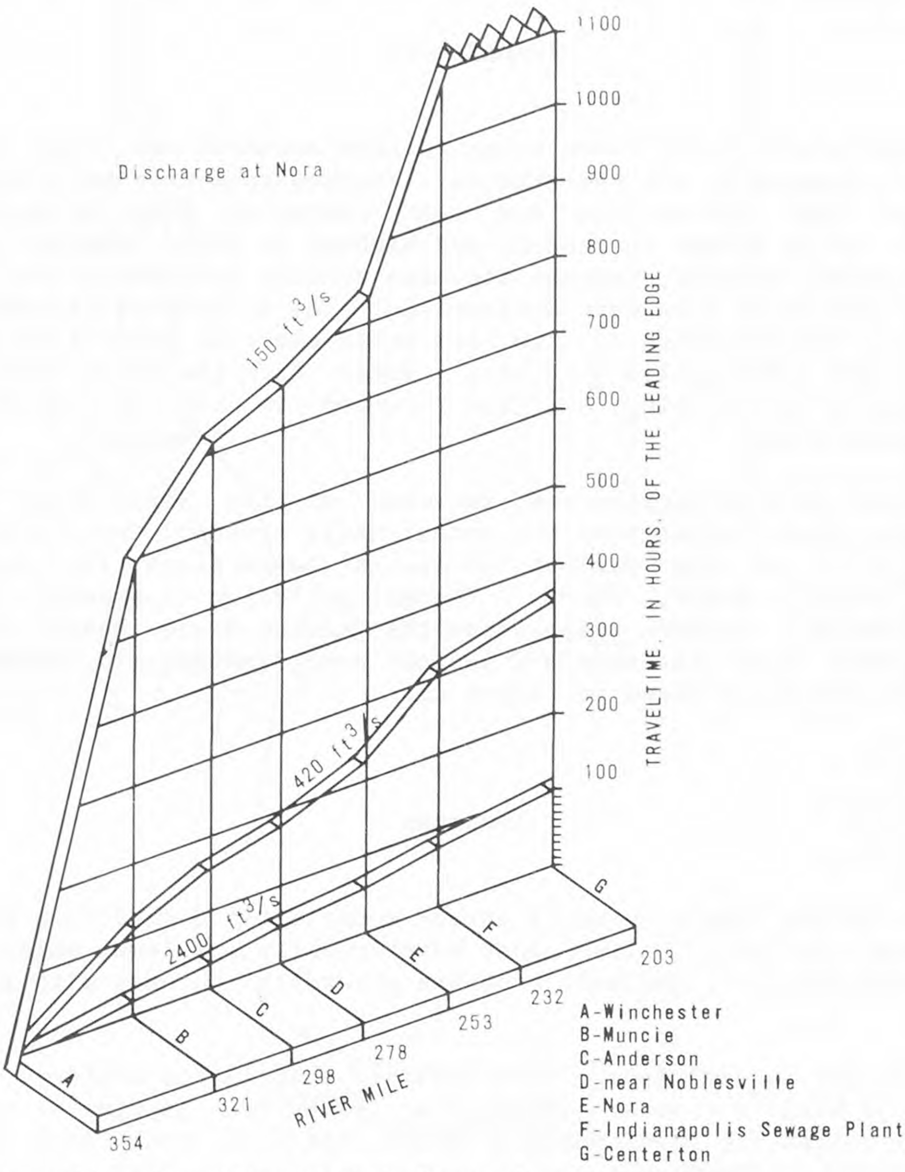


Figure 10.-- Traveltime of White River at selected flows

are valid for any reach of the river when the discharge at Nora is known. A discharge at Nora of 150 ft^3/s (4.2 m^3/s) is equaled or exceeded 90 percent of the time; 420 ft^3/s (12 m^3/s) is equaled or exceeded 50 percent of the time; and 2,400 ft^3/s (68 m^3/s) is equaled or exceeded 10 percent of the time. The data may be used as shown in the following example: When the discharge at Nora is 420 ft^3/s (12 m^3/s), the traveltime from Winchester to Nora is about 220 hours, and the traveltime from Winchester to Anderson is about 150 hours. Therefore, the traveltime from Anderson to Nora is 220 hours minus 150 hours, or, 70 hours. Traveltimes at other discharges and sites can be estimated by interpolating between two bracketing curves in figure 10.

Temperature

The temperature of the river water follows seasonal and diel cycles in response to changes in air temperature. Thermographs from monitors on the White River near Noblesville and near Centerton show the mean monthly temperature to be lowest in January and highest in July. The influence of man is apparent, however, because the mean monthly temperature is 6°F (3°C) higher near Centerton than near Noblesville. The difference probably can be attributed to the influence of the six steam-electric generating plants at Noblesville and Indianapolis (fig. 6). Water from the White River is used by these plants for cooling and is returned to the river at a slightly elevated temperature.

Historical data on temperature extremes of the White River (fig. 11) show that the river temperature has occasionally exceeded the State standard of 90°F (32°C) as the maximum allowable temperature (Indiana Stream Pollution Control Board, 1970). Thermal pollution apparently has been reduced, however, because data from the Indiana State Board of Health (1957-71) show that the standard has not been exceeded in recent years (1967-71) at the sites shown in figure 11.

Sediment

Streams in the basin usually appear muddy after a hard rain because of the sediment influx. Unlike most river-quality problems, which usually improve with dilution, sediment problems generally increase with increasing discharge.

Based on few observations, data indicate that little sediment is transported by the basin's rivers. More than 90 percent is clay or silt (less than 0.0625 millimetre in diameter). Water carrying such fine particles will look muddy, although the concentration and total load will be small. Sparse data show that sediment concentrations in the White River range from a maximum of 276 mg/l (milligrams per litre) near Noblesville to a maximum of 893 mg/l at Centerton. Fall Creek near Fortville has carried as much as 133 mg/l, and Eagle Creek at Zionsville has carried as much as 716 mg/l.

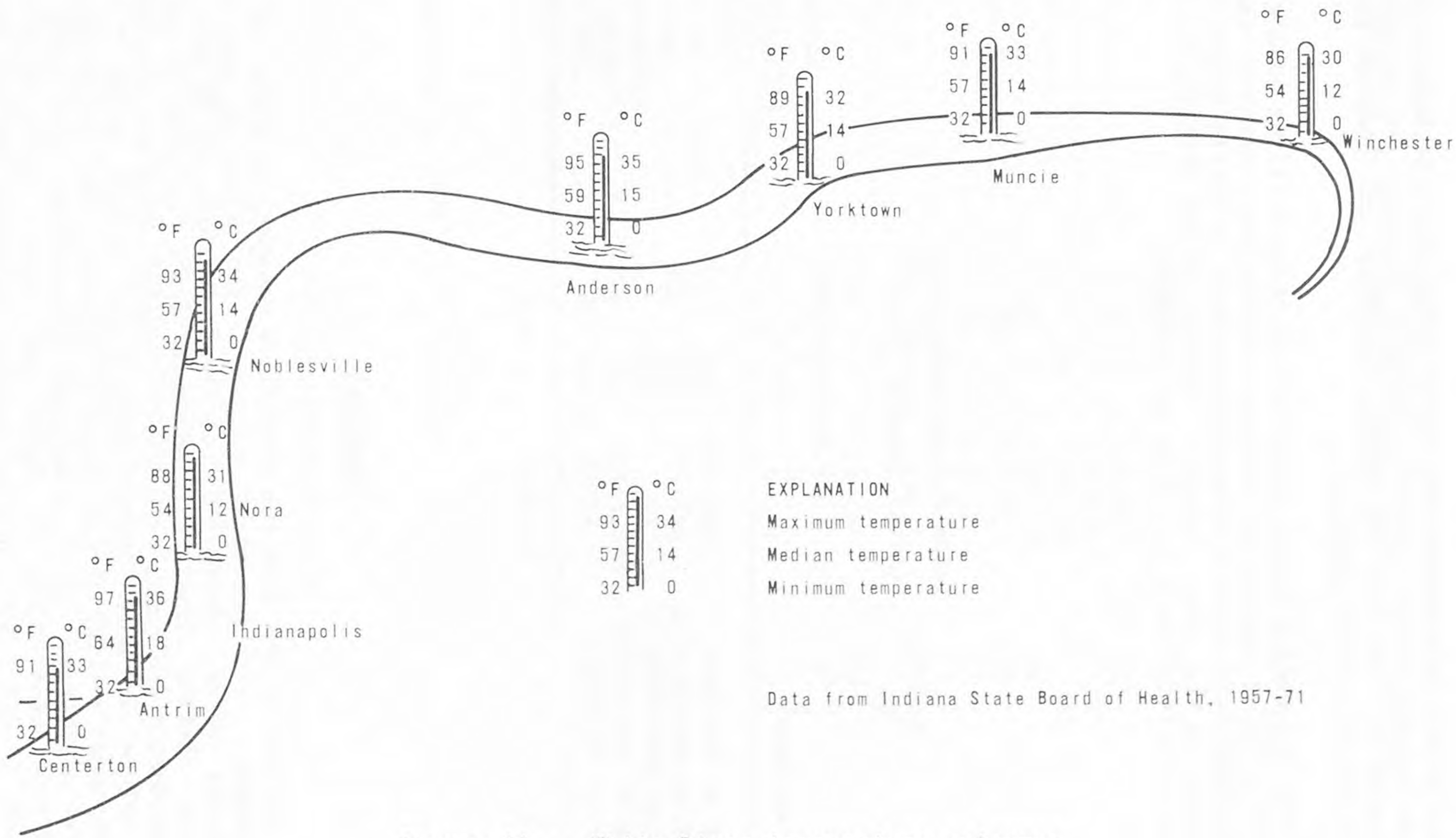


Figure 11.-- White River temperature extremes

Johnson (1971), who summarized the sediment data in Indiana, calculated a long-term average annual suspended-sediment discharge for selected Indiana streams (table 4). The data are sparse, however, and caution is necessary when using the calculated averages.

The four reservoirs in the basin act as large settling basins for the scant sediment being carried by influent tributaries. Although there may be some small, localized deposition problems, there is little danger of filling the reservoirs in the near future. Because of the settling-basin effect, the reservoir outlets carry little or no sediment.

Table 4.--Sediment yield

(After Johnson, 1971)

Station Name	Drainage area (mi^2)	Yield [(Ton/yr)/mi]
White River at Muncie	241	82
White River nr Noblesville	828	60
Fall Creek nr Fortville	169	73
Eagle Creek at Zionsville	103	316
White River nr Centerton	2,444	134

Chemical

During periods of low flow the streamflow consists entirely of ground-water discharge. For practical purposes, the chemical quality of the shallow ground water, which is relatively stable, can be considered to represent the maximum mineralization that would be found in the streams without considering the human influence. Precipitation and overland runoff would only dilute the more highly mineralized ground water. Thus, the "natural" chemical quality of the basin's streams, as illustrated by the ground-water discharge, is a moderately mineralized, very hard, calcium bicarbonate type water (table 5). Cable and others (1971) show that both the sand and gravel, and shallow bedrock aquifers yield water with an average dissolved solids concentration of about 440 mg/l and a specific conductance averaging a little more than 700 micromhos.

Table 5.--Range and average of chemical parameters of ground water

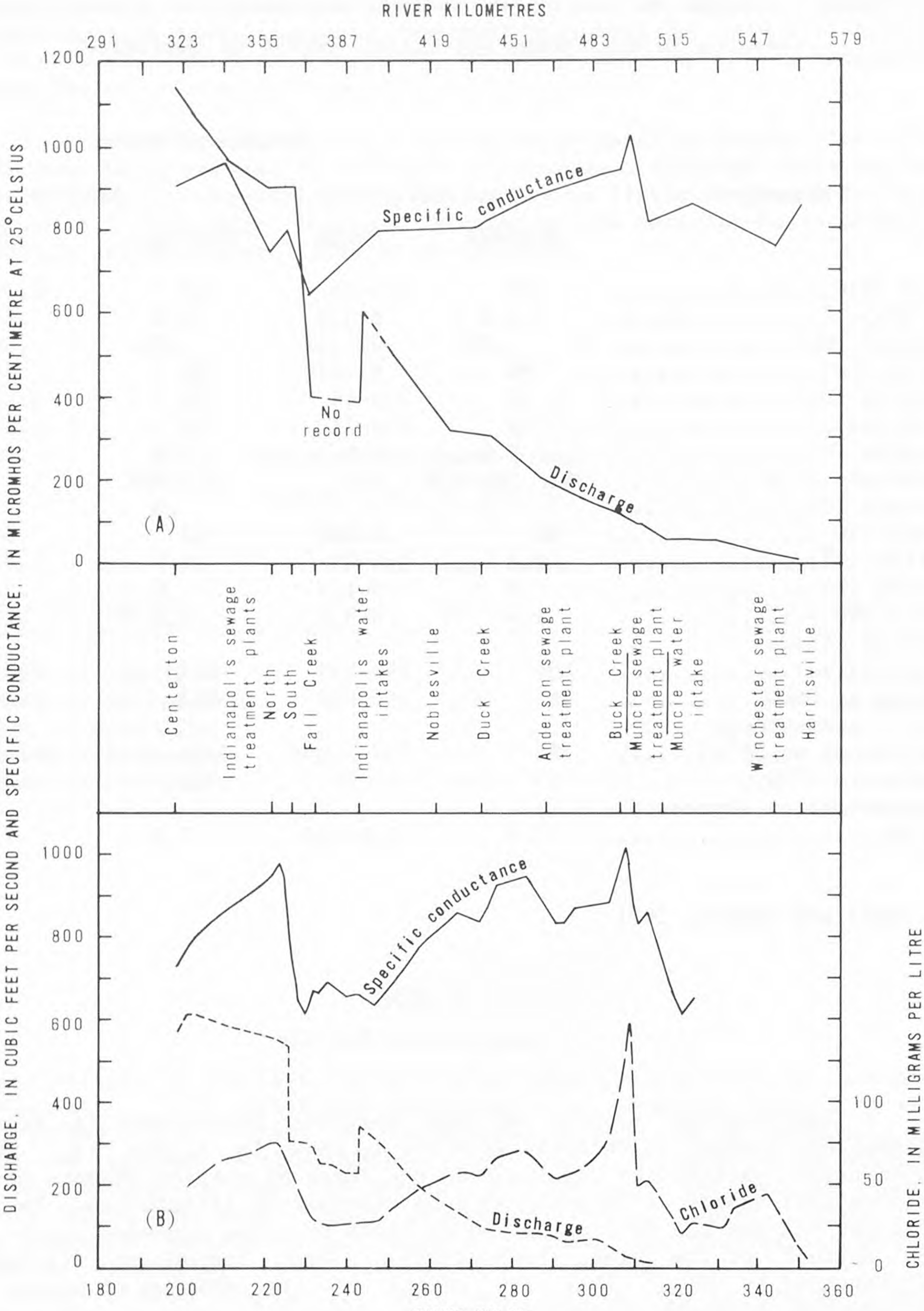
(Results in milligrams per litre, except as indicated)

Parameter	Source of water			
	Sand and gravel		Bedrock	
	Average	Range	Average	Range
Silica (SiO_2)..............	15	7.3-24	15	2.3-32
Iron (Fe)..................	1.5	0-5.0	1.6	.63-4.5
Manganese (Mn).............	.07	.00-.61	.03	.00-35
Calcium (Ca)...............	96	61-178	88	56-186
Magnesium (Mg).............	30	2.4-44	35	3.2-65
Sodium (Na)................	19	3.4-71	27	6.8-150
Potassium (K)..............	2.0	.2-9.1	1.9	.6-4.4
Bicarbonate (hc0).........	391	260-528	414	272-597
Carbonate (CO_3)...........	.0		.0	
Sulfate (SO_4).............	66	.0-268	60	.8-319
Chloride (Cl)..............	9.8	1.4-33	12	1.8-51
Fluoride (F)...............	.4	.0-1.4	.6	.2-1.0
Nitrate (NO_3).............	1.4	.0-9.7	2.2	.1-8.5
Dissolved solids (calculated).............	434	296-749	443	285-914
Hardness as $CaCO_3$..........	361	256-624	367	283-705
Specific conductance (micromhos at 25°C)......	726	507-1,090	705	451-1,320
Temperature (°C)...........	13	11-14	13	12-16
H+ concentration expressed as pH....................	7.4	6.9-8.0	7.5	7.2-8.3

From Cable and others, 1971

Longitudinal Profile

A longitudinal profile of the specific conductance (a measure of dissolved solids) of White River water is shown in figure 12. The wide downstream variability results from the input of varying amounts of highly mineralized wastes or dilution by less mineralized tributaries. The data in figures 12A and 12B were collected at flows that are exceeded about 45 and 80 percent of the time, respectively. With increasing discharge (as represented by fig. 12A) the effect of the addition of wastes is less pronounced, although the waste load is apparently great enough to maintain relatively high concentrations of dissolved solids.



(A) Data collected Oct 1972
(B) Data from Environmental Protection Agency, July 1965
(written communication, 1973)

Figure 12.-- Downstream variations in water quality

The first change in specific conductance shown on figure 12B is at about river mile 322 (river kilometre 518) and reflects the dilution effect of water being released from Prairie Creek Reservoir. Farther downstream, urban runoff and some industrial discharges in the Muncie area increase the specific conductance. Only a few miles farther downstream (river mile 310 or river kilometre 499), wastes from the Muncie sewage-treatment plant further increase the conductance. The dilution effect of Buck Creek (river mile 307 or river kilometre 494) also is readily apparent in figure 12B. After another slug of wastes from the Anderson area, the White River begins to recover by further dilution from tributaries, such as Duck Creek at river mile 273 (river kilometre 439), and from additional ground-water discharge. By the time the water has reached Indianapolis the specific conductance has again reached a value near that of the ground-water discharge.

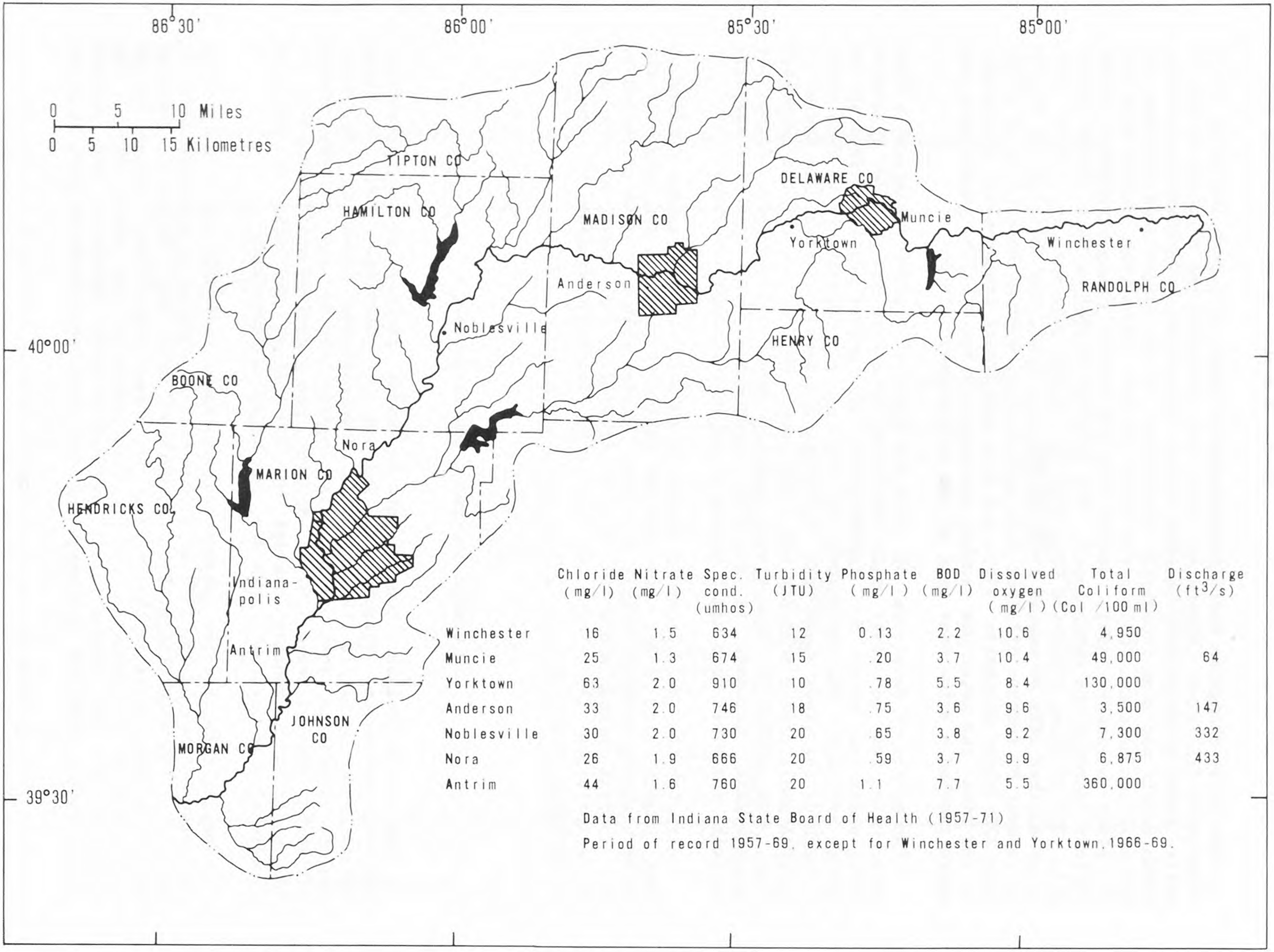
The effect of water use on flow and quality is shown dramatically from river mile 244 to river mile 226 (river kilometre 393 to river kilometre 364), where the water for Indianapolis is removed and later returned as sewage effluent. The variations in the specific conductance in this short stretch of the river above the Indianapolis sewage outfall are caused by several small creeks draining the urban area. Were it not for the decreased flow, the effect of these creeks probably would be marked. After the considerable increase in specific conductance below the Indianapolis outfall, the river once again begins to recover through dilution.

Although the data shown in figure 12 represent instantaneous conditions that change with time, the relative quality throughout the length of the river probably remains fairly constant. Median values of data collected by the Indiana State Board of Health (1957-71) show many of the same characteristics illustrated by the more detailed sampling of specific conductance (fig. 13).

Common Inorganic Constituents

The common inorganic constituents in water include sodium, potassium, calcium, magnesium, bicarbonate, sulfate, and chloride. None of these constituents occur in the basin in concentrations exceeding the water quality standards for public water supply set by the Indiana Stream Pollution Control Board (1970). However, the dissolved solids standard of 500 mg/l as a monthly average or 750 mg/l at any time is exceeded occasionally at Yorktown, Anderson, and below Indianapolis.

Samples taken for the measurement of common inorganic constituents were collected October 25-26, 1972 at a flow that is equaled or exceeded about 45 percent of the time (table 6). Comparison with the "natural" chemical concentrations, as estimated in table 5, shows significant changes in the concentration of chloride, sulfate, and sodium in the White River. The addition of the wastes from the Muncie area increased the sulfate concentration about 60 percent, the chloride concentration more than 200



	Chloride (mg/l)	Nitrate (mg/l)	Spec. cond. (umhos)	Turbidity (JTU)	Phosphate (mg/l)	BOD (mg/l)	Dissolved oxygen (mg/l)	Total Coliform (Col /100 ml)	Discharge (ft³/s)
Winchester	16	1.5	634	12	0.13	2.2	10.6	4,950	
Muncie	25	1.3	674	15	.20	3.7	10.4	49,000	64
Yorktown	63	2.0	910	10	.78	5.5	8.4	130,000	
Anderson	33	2.0	746	18	.75	3.6	9.6	3,500	147
Noblesville	30	2.0	730	20	.65	3.8	9.2	7,300	332
Nora	26	1.9	666	20	.59	3.7	9.9	6,875	433
Antrim	44	1.6	760	20	1.1	7.7	5.5	360,000	

Data from Indiana State Board of Health (1957-71)

Period of record 1957-69, except for Winchester and Yorktown, 1966-69.

Figure 13.-- Median values of selected river-quality factors

Table 6.--Common inorganic constituents

Name	River mile	Discharge (ft^3/s)	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Bicarbonate (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Spec. Cond. (micromhos)	Diss. Solids (mg/l)
White River nr Harrisville	355	3.8	100	37	8.5	2.7	390	68	18	709	440
White River below Muncie	310	84	100	38	45	5.3	362	110	60	900	569
White River at Waverly	211	963	90	31	42	5.7	310	90	70	826	507
White River at Centerton	199	1,140	93	31	36	5.1	314	86	58	794	502
Eagle Creek Reservoir	---	-----	55	22	10	2.7	196	45	25	458	276
Geist Reservoir	---	-----	66	30	13	2.3	264	61	24	559	339
Morse Reservoir	---	-----	71	25	9.2	2.2	242	48	26	528	360
Prairie Creek Reservoir	---	-----	36	23	4.0	2.9	156	47	13	357	215

Data collected Oct. 25-26, 1972.

percent, and the sodium concentration more than 400 percent over the values near Harrisville. Even in the rural area near Harrisville the chloride concentration had increased to 18 mg/l.

Solids dissolved in water vary seasonally in response to discharge variations. For example, chloride peaks during the low-flow periods in late summer and early fall and is at a minimum during the high-flow period in spring.

Some inorganic constituents can be related to discharge to the extent that a rating curve can be developed. Cable and others (1971) have prepared rating curves of this type for specific conductance, hardness, and chloride. These curves can be used to calculate the total amount of a constituent yielded by the basin. For example, the farmland above Winchester is yielding an average of 62 pounds of chloride per day per square mile (11 kilograms per day per square kilometre) of drainage area. This yield is 78 pounds (14 kg) at Muncie, 96 pounds (17 kg) near Noblesville, and 138 pounds (24 kg) at Centerton. The increase in load below Winchester is due primarily to wastes added by the municipalities. Most of the common inorganic constituents (such as listed in table 6) will react in a manner similar to chloride.

The seasonal effect on the concentration of the common inorganic constituents also is modified by land- and water-use patterns. For example, the water in the White River at Winchester represents natural drainage from a rural area. The chloride concentration is low and is relatively constant throughout the year, with monthly median values ranging from 11 to 23 mg/l. On the other hand, when the water is used and returned to the river, as demonstrated by data on the White River below Muncie, the concentration becomes greater and more variable, with monthly median values ranging from 18 to 117 mg/l.

Nutrients

Nitrogen and phosphorus are two commonly recognized nutrients for biological growth and, in sufficient concentrations, can cause a reaction in a river similar to spreading fertilizer on lawns. The nitrogen and phosphorus concentration added to the White River throughout its length are high enough to cause this type of biologic enrichment.

Nitrogen occurs in several different ionic states--ammonia, nitrite, nitrate, and organic nitrogen. Given time, however, most of the nitrogen in the form of ammonia and nitrite will oxidize to nitrate. This characteristic of nitrogen can be used to help determine the sources of nitrogen to a stream. The most common forms of nitrogen from sewage are nitrite, ammonia, and organic nitrogen and, as such, would be dominant in areas of recent urban pollution. Although total nitrogen would remain fairly constant, these forms would be converted to nitrate downstream. The residence time of agricultural fertilizers generally allows time for much of the nitrogen to convert to nitrate before entering the stream channel; thus, the nitrogen contribution from rural areas is primarily in the form of nitrate or organic nitrogen.

Phosphorus is another indicator of urban pollution. A high concentration of phosphorus is uncommon in natural waters, whereas it is a significant constituent of sewage.

The characteristics of nitrogen and phosphorus described above are reflected by the data in table 7 and can be used to help evaluate the nutrient contribution to the upper White River.

Table 7.--Nutrients at selected sites

Name	River mile	Nitrogen Species (mg/l as N) Ammonia	Nitrite	Nitrate	Organic	Total Phosphorus as P (mg/l)	Discharge (ft^3/s)	Total Nitrogen (tons/d)	Total Phosphorus (tons/d)
White River nr Harrisville	355	0.14	0.01	0.68	0.35	0.03	3.8	0.01	0.6 1/
White River nr Smithfield	329	2.2	.02	1.1	.38	.13	53	.53	.02
White River below Muncie	310	.85	.64	1.0	1.7	1.6	82	.93	.35
White River nr Noblesville	275	.13	.26	3.2	.87	.49	304	3.66	.40
White River nr Nora	249	.02	.10	3.2	.70	.39	502	5.45	.53
White River at Waverly	211	3.6	.29	1.8	1.4	1.3	963	18.43	3.38
White River at Centerton	199	.70	.36	2.9	.50	1.0	1,140	13.73	3.08
Eagle Creek Reservoir	---	.08	.03	1.4	.88	.02			
Geist Reservoir	---	.01	.03	.2	.93	.08			
Morse Reservoir	---	0	.16	4.9	1.1	.08			
Prairie Creek Reservoir	---	.19	.08	.1	.02	.05			

Data collected October 25-26, 1972.

1/ pounds per day

In October 1972 the rural drainage area above Harrisville was yielding water containing nitrogen primarily in the form of nitrate and organic nitrogen, and relatively little phosphorus (table 7). The next station listed in table 7 shows a large increase in the concentrations of ammonia and phosphorus, which indicates a contribution from an urbanized area, probably Winchester. The high concentration of nitrite in the sample below Muncie is indicative of a recent nutrient contribution and reflects the proximity of that sample site to the Muncie sewage-treatment plant. Data collected at the Waverly site (below Indianapolis) also indicate a recent source of urban pollution. Conversion of nitrogen species to the more stable form of nitrate is illustrated by the concentration changes between Waverly and Centerton.

The addition of wastes throughout the length of the upper White River causes the nutrient load (in tons per day) in the river to increase downstream; however, the load seems to reach a peak just below Indianapolis. The decrease in load between Waverly and Centerton may reflect the beginning of the river to recover through biologic uptake of some of the nutrients. The load calculations also show that Indianapolis is the most significant contributor of nutrients to the upper White River.

Seasonal concentrations of phosphorus occur in a manner similar to that of chloride, but the nitrogen concentrations do not. The nitrate values are highest during the winter and spring and are at a minimum during the low flow, heavy plant growth periods of summer and early fall. Apparently nitrate is getting into the river water from solution of some of the stream bottom materials, or, possibly, the overland flow from precipitation is washing nitrate from the soil in the rural areas during the periods when it is not all being used by actively growing vegetation.

Minor Elements

Metals such as iron, cadmium, chromium, lead, mercury, and strontium, normally occur in water in very small concentrations and are grouped here into a classification called minor elements. Minor element data are important because many of the minor elements are toxic at very low concentrations. High concentrations of minor elements usually indicate pollution -- commonly industrial pollution. For example, a water sample collected by the U.S. Environmental Protection Agency in June 1967 (written commun., 1973) from Eagle Creek at Kentucky Avenue (an area of heavy industry) contained 0.04 mg/l cadmium, 0.6 mg/l copper, 1.5 mg/l lead, 0.05 mg/l nickel, and 2.1 mg/l zinc. These values considerably exceed "natural" levels in unpolluted waters and also exceed the State water-quality standards (Indiana Stream Pollution Control Board, 1970) of 0.01 mg/l for cadmium and 0.05 mg/l for lead.

In contrast to the Eagle Creek sample, another sample collected at the same time from the White River above Winchester contained 0.01 mg/l cadmium, 0.03 mg/l copper, 0.04 mg/l lead, 0.02 mg/l nickel, and 0.27 mg/l zinc. Effluent from the Indianapolis sewage-treatment plant contained 0.03 mg/l cadmium, 0.04 mg/l copper, 0.1 mg/l lead, 0.1 mg/l nickel, and 0.14 mg/l zinc.

The above data show that the water-quality standard of 0.01 mg/l for cadmium is exceeded in most of the White River tributaries in Indianapolis and in the White River below Indianapolis. They also show that the standard for lead (0.05 mg/l) is exceeded in the White River below Anderson and in most of the tributaries in Indianapolis.

Bottom Materials

In general, the sediments and stream bottom materials have a high affinity for nutrients, minor elements, and pesticides. Consequently, the concentration of these constituents that are associated with the sediments and bottom materials is considerably higher than that dissolved in the water. This phenomenon can reduce undesirable concentrations of dissolved materials in the stream. However, it also enables the stream bottom to act as a source of toxic materials long after the dissolved phase has moved downstream. Table 8 lists the concentrations of minor elements that were extracted from bottom sediments collected on October 25-26, 1972. The increases in concentration over the dissolved phase are striking. For example, in the "clean water" area near Harrisville, lead is more concentrated by a factor of 675, nickel by 450, and cadmium by 100. The relatively high arsenic value may be a reflection of rural usage of inorganic chemical poisons.

The data in table 8 illustrate the usefulness of analyses of bottom materials as an indicator of past pollution. For example, the total nitrogen concentration dissolved in the water in the October 1972 sample was 1.18 mg/l of nitrogen, whereas at that time there was 1,170 mg/l of nitrogen associated with the bottom sediments. For a high concentration of nitrogen such as this to be found in association with the bottom materials, there presumably must have been either a high concentration dissolved in the water at some time in the past or some mechanism present whereby the constituent can be concentrated. Similarly, the high concentrations of metals associated with the bottom sediments at Nora indicate an upstream input of metal-containing wastes at some time in the past. Most of the samples listed in table 8 indicate the historical presence of some waste products that were not found in the dissolved phase at the time of sampling.

Some of the highest concentrations extracted from the bottom sediments were from samples collected distant from an obvious potential source of pollution. However, these data were collected after a period of high flow, and may be reflecting the normal downstream movement of the sediments.

Pesticides are another group of chemicals that commonly are found in association with the sediments. Like the minor elements, these organic compounds have received a lot of attention in recent years. Pesticides do not occur naturally, thus, any residue detected in the waterways are the result of some action by man. The two major sources of pesticides to the waterways are runoff from agricultural areas and runoff from residential areas through the municipal sewer systems. Similarly, polychlorinated biphenyl compounds (PCB's) do not occur naturally and commonly result from industrial wastes.

Characteristic of compounds with an affinity for bottom materials, no pesticides were found dissolved in the water in the basin's major streams. Significant concentrations were found in association with the sediments, however, indicating the historical presence of pesticides (table 9). Concentrations of the chlorinated hydrocarbons DDD, Dieldrin, and Chlordane and the concentration of PCB's were particularly significant in the upper White River basin.

Table 8.--Minor element and nutrient concentrations extracted from bottom sediments

(1/ Equivalent to parts per million or milligrams per litre)
(Data collected Oct. 25-26, 1972)

Location	Iron	Manganese	Copper	Nickel	Lead	Zinc	Cadmium	Cobalt	Chromium	Aluminum	Mercury	Arsenic	Strontium	Total Nitrogen (N)	Total Phosphorus (P)
	micrograms per gram 1/														
White River above Harrisville	3,360	223	5	9	27	18	1	5	3	1,170	0.04	6	109	1,170	500
White River near Smithfield	682	330	2	3	13	4	1	5	1	160	.02	2	75	290	210
White River near Nora	6,050	353	35	108	159	110	4	10	63	1,950	.03	1	43	770	740
White River at Waverly	849	104	7	12	13	20	1	4	6	212	.05	0	68	340	240
White River at Centerton	2,250	222	13	13	27	33	2	8	12	887	.04	1	95	520	480
Duck Creek near Aroma	2,870	220	6	40	22	20	1	5	20	359	.02	6	68	220	310
Fall Creek near Fortville	4,910	390	10	10	42	35	2	7	11	1,730	.07	13	56	1,560	460
Fall Creek at Millersville	1,630	368	4	7	17	11	1	7	2	299	.06	2	106	320	290
Eagle Creek at Zionsville	1,650	275	4	6	20	13	1	5	2	436	.05	1	74	400	270

Dieldrin seems to be the dominant insecticide found in the streams draining predominantly rural areas, whereas concentrations of DDD, Chlordane, and PCB's probably are from industrial sources. Each of the organic compounds mentioned above are found in the sediments of Geist, Morse, and Eagle Creek reservoirs, as each reservoir drains both rural and urban areas. Although Prairie Creek reservoir does not drain an urban area, DDD is the dominant insecticide found in the bottom sediments.

Few data are available to evaluate the problem potential of pesticides in the upper White River basin. It is known, however, that small concentrations of insecticides, such as found in the basin, will enter the food chain of the aquatic organisms and can be concentrated to undesirable levels.

Oxygen

Dissolved oxygen is one of the most complex chemical characteristics of the river because of the many influencing factors, such as biological productivity, water temperature, waste loads, water turbulence, weather, and sunshine. Plants, both micro-and macroscopic, probably have the greatest effect on the oxygen concentration.

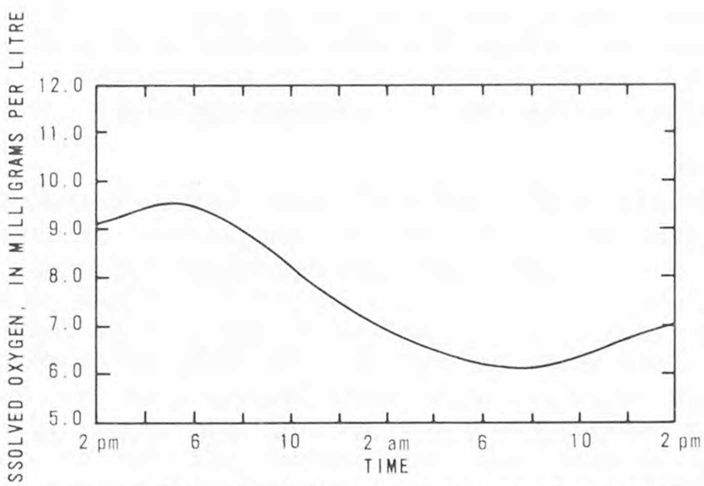


Figure 14.-- Diel dissolved oxygen fluctuation in the White River near Noblesville, Oct. 27-28, 1972

The dissolved-oxygen concentration often will change rapidly during a day. The 3.5 mg/l diel fluctuation shown in figure 14 is the result of photosynthetic activity by algae and other plant growth in the river. During the day, when the sun is shining, plants produce oxygen; thus, the dissolved oxygen usually will be at a peak concentration in the late afternoon. At night, in the absence of sunlight, the plants do not produce oxygen but rather utilize it. Thus, the dissolved oxygen will be at a minimum just before dawn.

Table 9.--Pesticide and chlorinated hydrocarbon concentrations extracted from bottom sediments, October 25-26, 1972

Sample Site	Aldrin	DDD	DDE	DDT	Dieldrin	Endrin	Heptachlor	Lindane	Chlordane	PCB
	(Concentrations in ug/kg)									
White River nr Harrisville	0.0	0.9	0.0	0.0	1.2	0.0	0.0	0.0	1	0
White River ab. Yorktown	.0	3.6	.0	.0	.8	.0	.0	.0	10	30
Pipe Creek nr Frankton	.0	7.0	.0	.0	1.2	.0	.0	.0	7	20
Cicero Creek nr Arcadia	.0	.0	.0	.0	2.8	.0	.0	.0	0	0
Fall Creek nr Fortville	.0	.6	.0	.0	.2	.0	.0	.0	2	0
Eagle Creek at Zionsville	.0	.0	.0	.0	2.1	.0	.0	.0	0	0
White River at Waverly	.0	10	.0	.0	.5	.0	.0	.0	20	20
White Lick Creek nr Mooresville	.0	.0	.0	.0	1.4	.0	.0	.0	0	TRACE 1/
White River nr nr Centerton	.0	.0	.0	.0	.1	.0	.0	.0	TRACE 2/	10
Geist Reservoir nr Oaklandon	.0	2.3	.0	.0	1.5	.0	.0	.0	8	10
Morse Reservoir nr Noblesville	.0	2.0	.0	.0	4.6	.0	.0	.0	15	20
Eagle Creek Reservoir nr Indianapolis	2.1	.7	.0	.0	2.6	.0	.0	.0	10	10
Prairie Creek Reservoir nr Muncie	.0	6.0	.0	.0	.5	.0	.0	.0	7	0

1/ Trace PCB is less than 5 ug/kg.
2/ Trace Chlordane is less than 1 ug/kg.

The effect of sunshine on photosynthesis also can be seen in figure 14. October 27, 1972, was a bright, sunny day and the dissolved oxygen rose to 9.6 mg/l, whereas October 28, 1972 was an overcast, rainy day and the dissolved oxygen rose only to about 7 mg/l.

The solubility of oxygen also varies with temperature, pressure, and dissolved solids. At a pressure of 760 millimetres fresh water can contain 14.6 mg/l of oxygen at 32°F (0°C), 10.2 mg/l at 59°F (15°C), and 7.7 mg/l at 86°F (30°C). Thus, even unpolluted waters will contain much less dissolved oxygen during the summer than during the winter.

The degree of oxygen saturation can be calculated by relating the actual concentration to the concentration derived from solubility calculations. For example, the dissolved oxygen shown in figure 14 was measured at a water temperature of 45°F (7.5°C), when the solubility of oxygen is 12 mg/l. Thus, the dissolved oxygen in the water varies from 80-percent saturation to 52 percent saturation. Under some conditions the water can become temporarily supersaturated with oxygen and contain more oxygen than the theoretical value derived from solubility calculations.

The dissolved-oxygen concentration varies seasonally in response to temperature variations (among other things). In the relatively clean water in the White River at Winchester it ranges from about 6 to 14 mg/l, with a median of 10.6 mg/l. In spite of the large fluctuation, the dissolved oxygen concentration is near saturation most of the year. In the polluted water in the White River at Antrim the dissolved-oxygen concentration ranges from 0 to 15.8 mg/l, with a median of 5.5 mg/l. At this site, where pollution as well as temperature is a significant factor affecting oxygen concentration, the dissolved-oxygen concentration ranges from 0- to 120-percent saturation.

The oxygen-demanding wastes being released into the White River cause significant downstream variations in the dissolved-oxygen concentration (fig. 15). The dissolved-oxygen concentration depression during low flow is very sharp below Muncie, Anderson, and Indianapolis (such as shown in fig. 15 by flow that is exceeded 90 percent of the time). Some idea of the relative waste load can be surmised from the fact that the oxygen depression below Indianapolis is much greater than below the other cities and that it took longer for the river to recover the lost oxygen. Higher discharges will reduce the effect of the waste load and tend to maintain a higher overall dissolved-oxygen concentration.

Fish and most other animals living in the river require certain minimum levels of dissolved oxygen at all times. In spite of a high average oxygen concentration fish will die if the concentration is below this minimum for part of the time. Data from the Indiana State Board of Health show that during 1965 to 1969 the dissolved-oxygen concentration in the White River at Centerton was 1 mg/l or less for at least 1 day per month, 6 months out of each year (fig. 16). The frequency and severity of this oxygen deficiency increases with nearness to the source of pollution at Indianapolis.

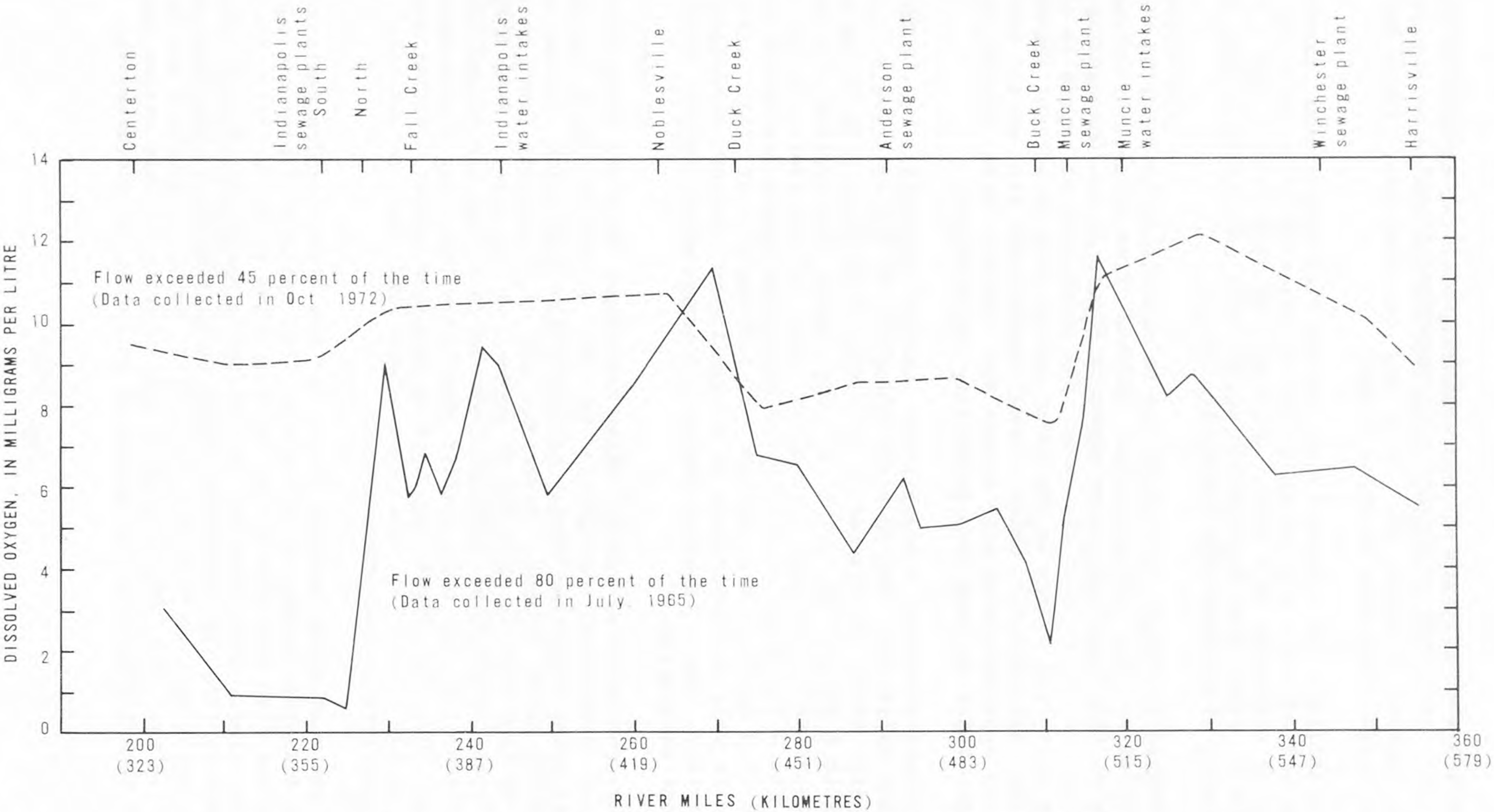
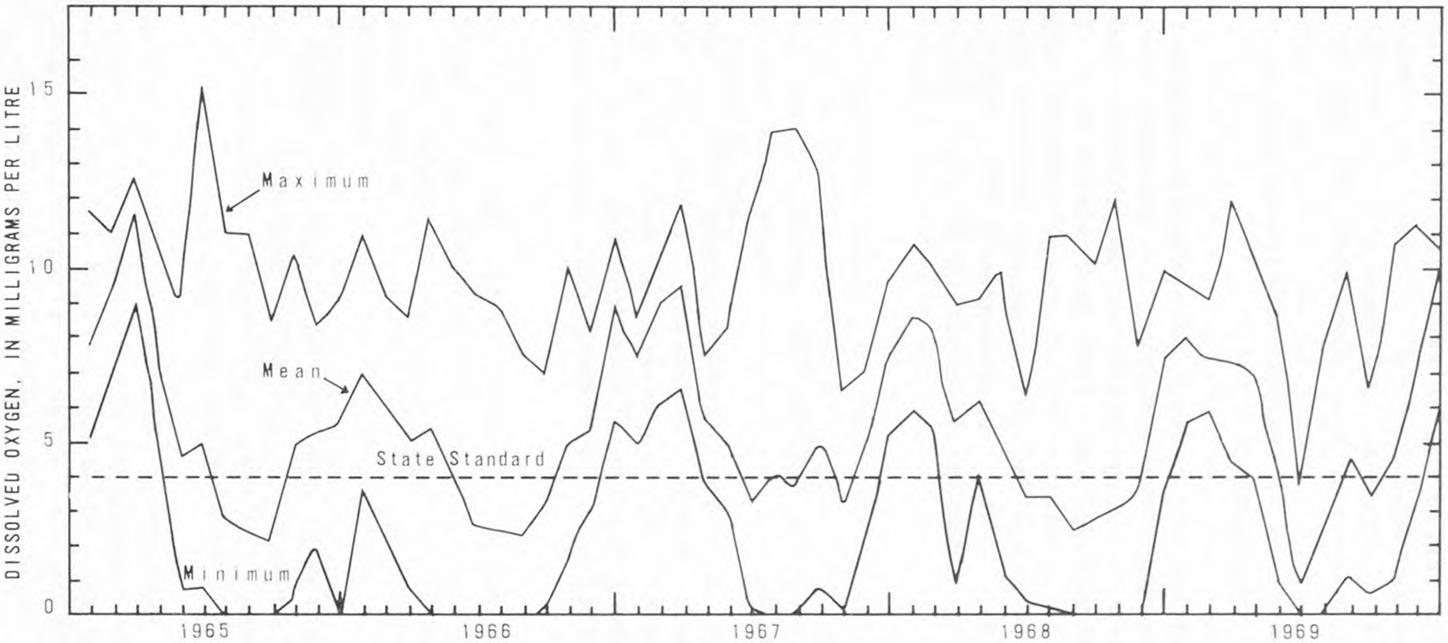


Figure 15.--Downstream variations in dissolved oxygen



Data from Indiana State Board of Health (1965-69)

Figure 16.-- Monthly range of dissolved oxygen in the White River at Centerton

Most of the wastes in sewage effluents are biodegradable and exert a biochemical oxygen demand (BOD). Other wastes exert a chemical oxygen demand (COD), such as the conversion of ammonia to nitrate. A certain amount of oxygen-consuming wastes can be put into a river with no harm to the water because the oxygen dissolved in a river is being replenished constantly through natural processes. Problems only occur when the wastes exceed the assimilative capacity of the river (defined here as the amount of wastes that can be added without depleting the dissolved oxygen), or when the wastes are slowly oxidized or are nonoxidizable, such as toxic metals, pesticides, and petroleum products.

The assimilative capacity of a river is strongly interrelated with many of the physical and chemical characteristics previously described. For example, thermal pollution raises the water temperature and lowers the oxygen solubility; sediment reduces light penetration into the water and lowers the photosynthetic activity of plants; reduced water velocities reduce turbulence and lower the reaeration ability of the water; and wastes toxic to plants terminate the photosynthetic activity. All these characteristics reduce the assimilative capacity of the river.

Biological

Living organisms in a river include, among others, bacteria, algae, invertebrates, and fish. These organisms constitute the biological characteristics of a river and represent a very complex and delicate balance. There is a strong interrelationship among the physical, chemical, and biological characteristics of a river, with each exerting some control on the others.

Bacteria

Microbial wastes of primary concern in stream sanitation are bacteria, viruses, and other forms pathogenic (disease causing) to man. The major sources are municipal sewage systems, storm-water drainage, urban wash, and agricultural sources, primarily from livestock.

Because tests for pathogenic organisms are difficult and dangerous, simpler tests have been developed for other bacteria commonly associated with the pathogens. One such indicator test is for the coliform group of bacteria. Coliform bacteria in water are derived from many sources, but their presence in high numbers is indicative of pollution. More specific tests, such as fecal coliform and fecal streptococci, indicate the presence of human wastes and animal wastes, respectively.

Samples for bacteria analysis were collected throughout the basin on October 25-26, 1972, when the streams were at a flow that is equaled or exceeded about 45 percent of the time (fig. 17). Under the conditions at that time, the rural areas were yielding coliform counts from about 1,000 to about 5,000 colonies per 100 ml of water. The fecal coliform concentration generally was 50 or less colonies per 100 ml and the fecal streptococcus concentration ranged from about 100 to 400 colonies per 100 ml.

The bacteria concentrations around urban areas increased sharply over those found in rural areas. Urban runoff around Muncie and Indianapolis yielded total coliform counts of 42,500 and 80,000 colonies per 100 ml and fecal coliform counts of 2,400 and 10,000 colonies per 100 ml. The highest concentration measured in the October sampling period was a count of 1.5 million colonies per 100 ml in the White River below the sewage-treatment plant at Muncie. For some reason the bacteria counts in the White River near the Indianapolis sewage outfall were extremely low. Either an analytical error was made or some material toxic to the bacteria was in the water at this time. The median coliform count in the White River at Antrim of 360,000 colonies per 100 ml of water is more representative of the degree of pollution usually found below Indianapolis.

State water-quality standards for public water supplies limit the coliform count to a monthly average of 5,000 colonies per 100 ml (Indiana Stream Pollution Control Board, 1970). The median values shown in figure 13 would indicate that this value probably is exceeded regularly below Muncie, Anderson, and Indianapolis.

Phytoplankton

Phytoplankton are the free-floating plants in water, and consist primarily of algae. The phytoplankton population in a river is a dynamic characteristic that varies in both quantity and kind in response to water discharge, channel characteristics, weather, and nutrient loading. Although there is a continuous "washout" of the phytoplankton from the basin, there also is a relatively continuous replacement by new growth and movement from upstream. In general, a reach of the river will come to equilibrium with its environment and will develop a characteristic biological community that is repetitive from year to year. The peak concentration of algae generally occurs in the summer months when the weather is warm and the flow is low.

The maximum concentrations vary from point to point in the river in response to factors such as the waste-nutrient loading, which acts as fertilizer to the algae. Data from the Indiana State Board of Health (1965-71) show that the average standing phytoplankton crop in the White River at Winchester is about 400 microorganisms per millilitre (fig. 18). At Nora and Antrim the standing crop has increased to about 5,000 and 2,000 microorganisms per millilitre, respectively. The White River at Nora supports a large algal growth because the river has received a considerable nutrient load upstream. The reduction in phytoplankton growth at Antrim may

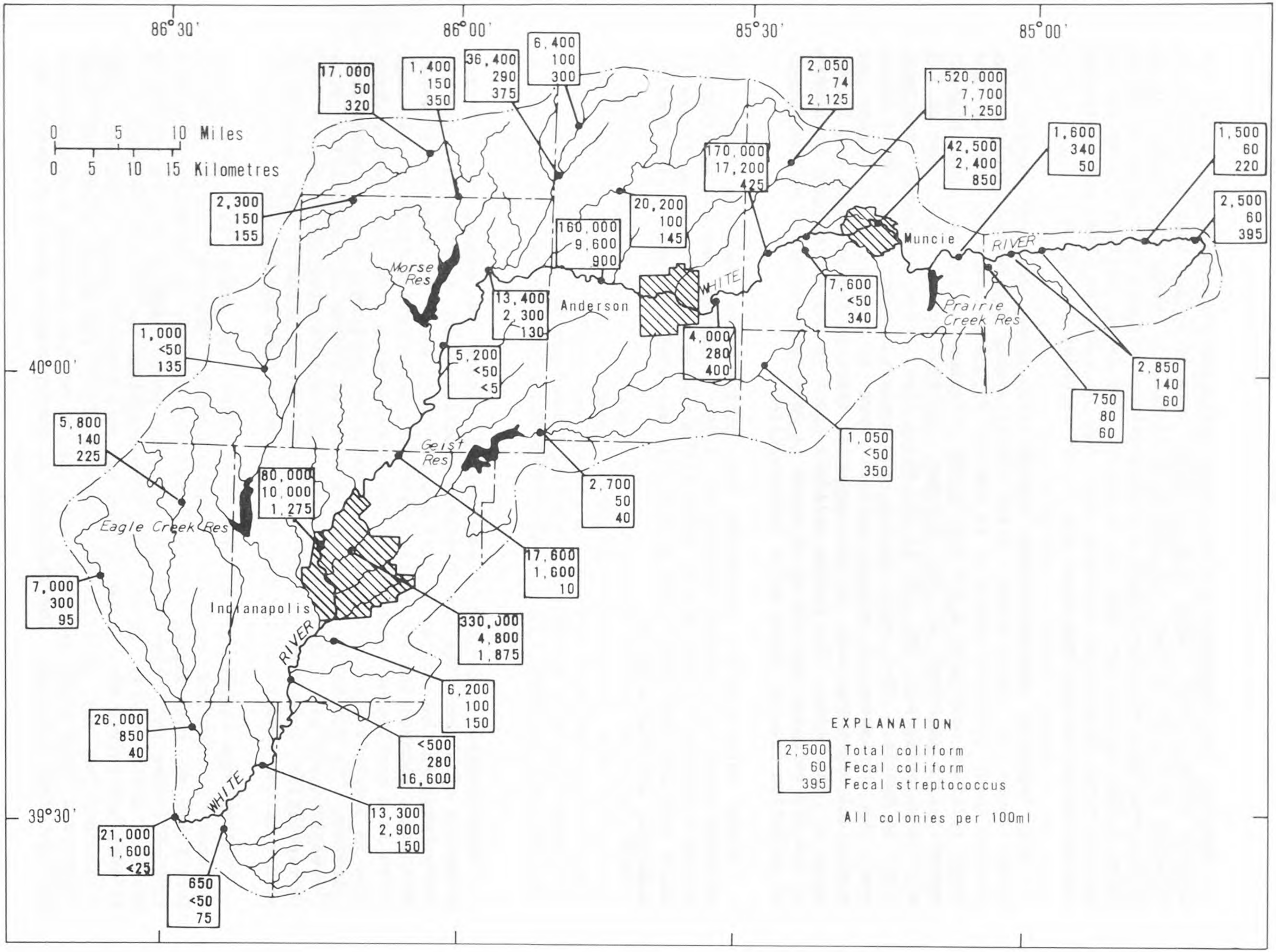


Figure 17.-- Areal variations of indicator bacteria in water samples

be the result of some toxic wastes from the Indianapolis area. The diatoms *Cyclotella* sp. are, by far, the dominant algae found in the White River at these three sites. Other common forms include *Synedra* sp., *Scenedesmus* sp., *Euglena* sp., and *Chlamydomonas* sp.

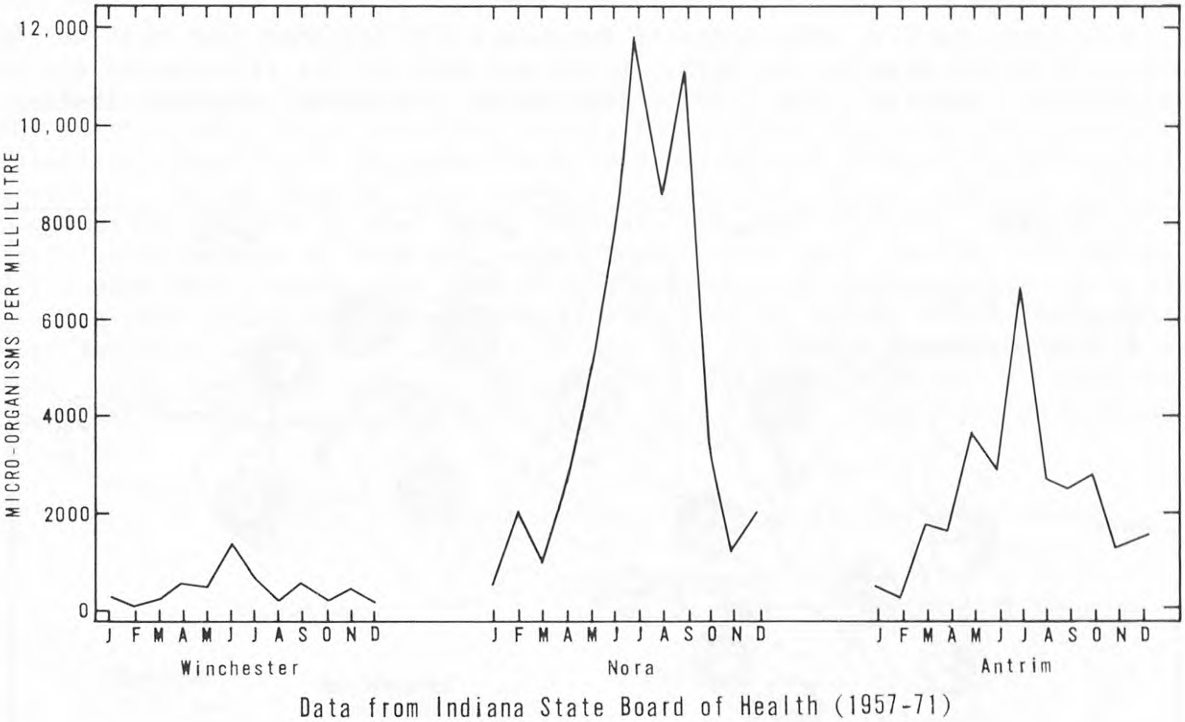


Figure 18.-- Average monthly phytoplankton concentration in the White River

The algae in the water can be both beneficial and detrimental. By photosynthesis the algae help provide the oxygen necessary to oxidize the organic waste load put into the river. However, some algae cause taste and odor problems, may clog water filters, or in large populations may be esthetically displeasing.

Benthic Invertebrates

The biological community living on the stream bottom is a good index of the amount of organic wastes in a stream. The community varies in quantity and kinds of species in response to changes in organic waste loading. The river bottom of an unpolluted stream generally will contain a wide variety of organisms, although a lack of food commonly limits the total number of organisms to a moderate amount. Heavily polluted water normally contains large numbers of organisms, but only a few species survive the harsh conditions. Organisms commonly found in heavily polluted water are called tolerant species, whereas organisms commonly found in unpolluted water are called clean-water species. Many organisms are likely to be found in either environment and are called intermediate or intermediately tolerant species.

Data from the U.S. Army Corps of Engineers (1971b) show that most of the benthic invertebrates in the White River and many of its tributaries are of the tolerant species (fig. 19), indicating extensive organic loading.

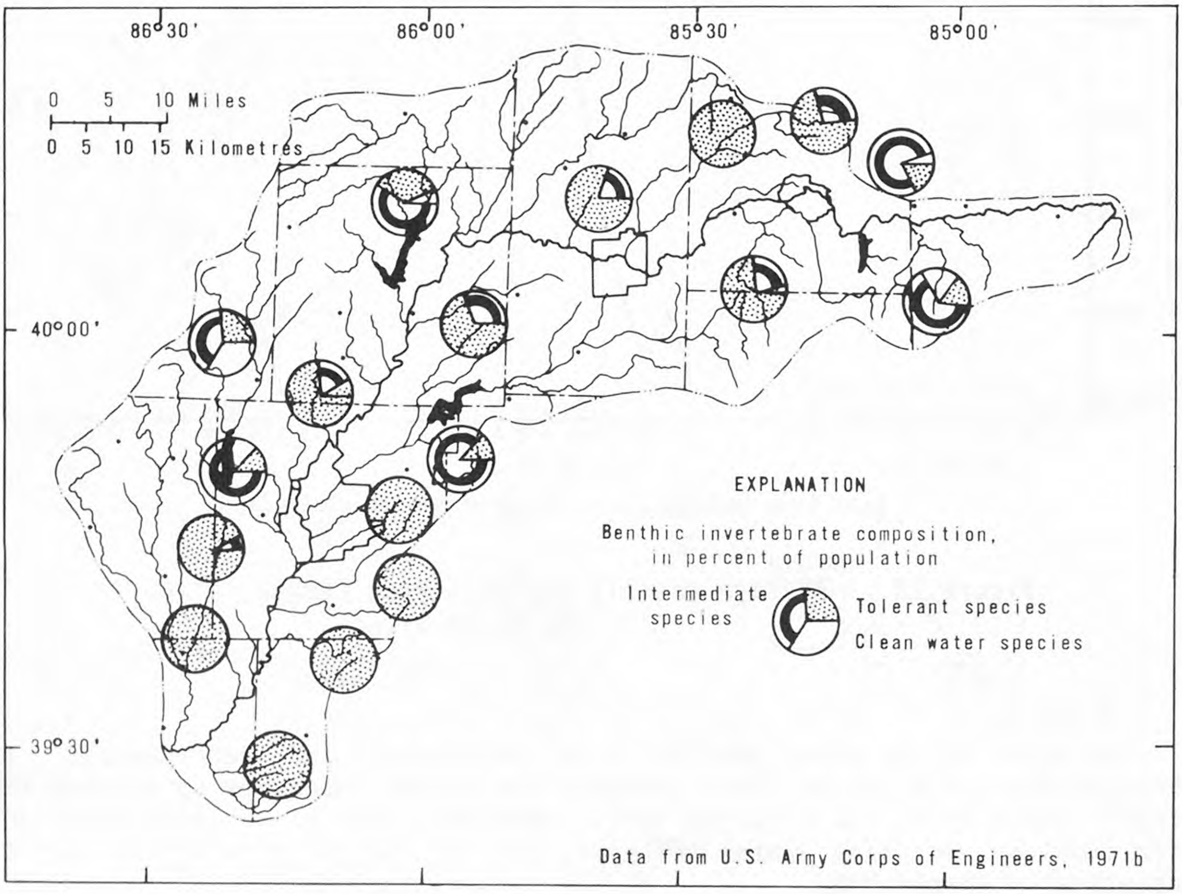


Figure 19.-- Benthic invertebrate distribution

Clean-water and intermediate species dominate only in headwater areas and in an area of the White River below Anderson. In general, the benthic invertebrate composition gradually changes from predominantly tolerant species around Anderson to predominantly intermediate and clean-water species at Indianapolis, indicating improving water- quality conditions. However, organic loading at Indianapolis causes the benthic invertebrate community to revert back to tolerant species below the city.

Fish

The effects of various polluting agents on fish life are complex. Each species of fish has its own tolerance to various types of pollutants. In general, carp and suckers are more tolerant of pollution than game fish such as bass and crappie. As with the other groups of organisms, pollution is indicated by the presence of fewer fish species and usually greater numbers of the tolerant species.

Pollution in the White River is indicated by the distribution of fish in the river (table 10). The water in the White River above Muncie seems to be relatively unpolluted because there is a variety of fish, with game species present. Below Muncie the number of species drops sharply and the composition changes to the more tolerant carp and suckers. Because of the addition of wastes at Anderson, the river does not recover biologically until near Nora, where game species are present. At Indianapolis, more fish species were found than at any other site on the river; below Indianapolis very few fish were found. Carp were the only species found at Waverly and they were small. At Centerton the river had recovered to a sufficient degree to support a moderate population of carp; few other fish were found.

Table 10.--Distribution of fishes in the White River

Location	Total Number of fish 1/	Number of species
Muncie	154	12
Yorktown, 6 miles below	99	4
Anderson, 15 miles below	172	6
Near Nora	196	12
Indianapolis	435	18
Waverly	59	1
Near Centerton	28	4

Data from Christensen (no date)

1/ Collected by electro-fishing for a unit of time

Oxygen depletion is one of many forms of pollution that affect fish life. There is a very good correlation between the number of fish species and the annual minimum dissolved oxygen in the White River (fig. 20). Although the Indiana Stream Pollution Control Board has established a minimum level of dissolved oxygen in warm-water streams of 4.0 mg/1, a concentration considered suitable for supporting life, concentrations below that level occur regularly in the White River.

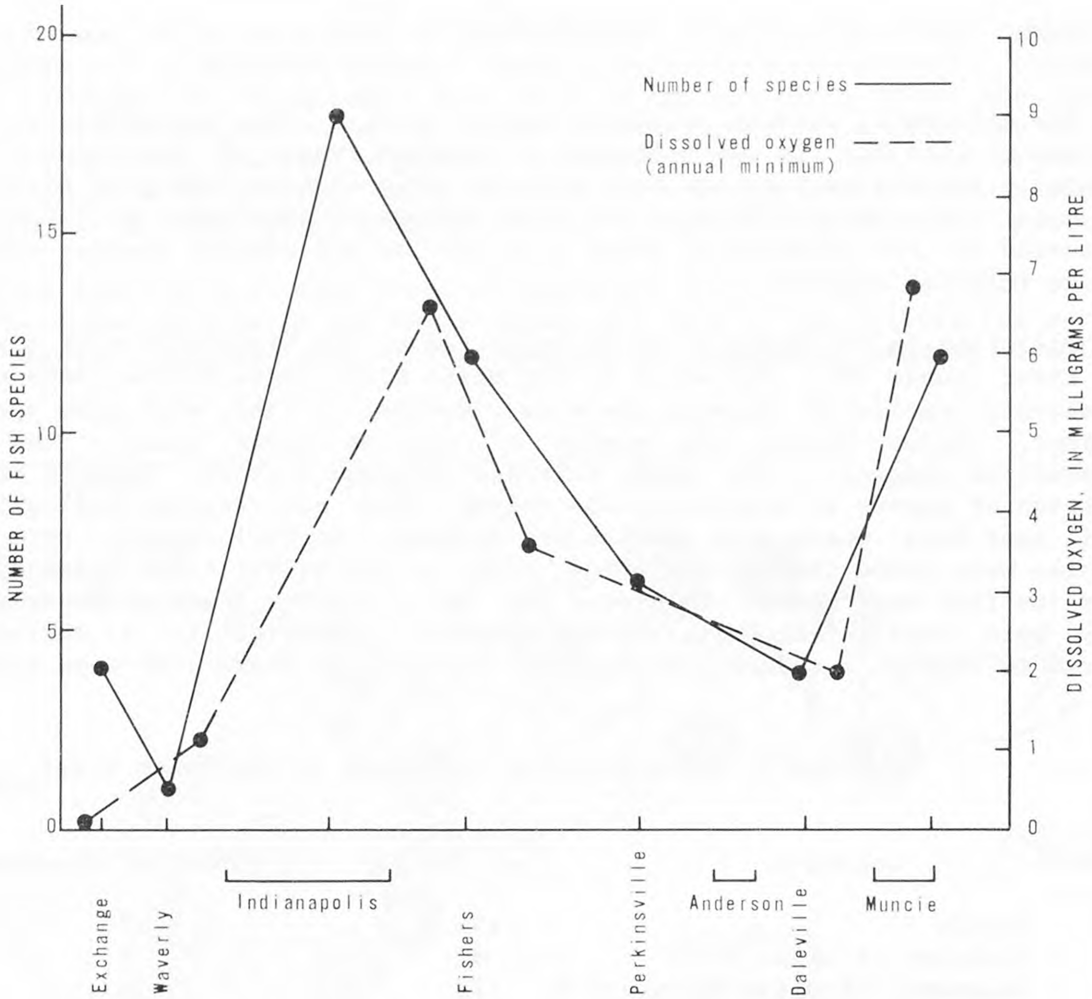


Figure 20.-- The number of fish species as related to annual minimum dissolved oxygen

From : Christensen (no date)

From 1960 to 1970, 41 fish kills in the major streams of this basin were reported to the Indiana Stream Pollution Control Board. They were distributed as follows:

11 on the White River in the Indianapolis area
10 on Eagle Creek
8 on the White River near Muncie
4 on White Lick Creek and tributaries
3 on Cicero Creek
3 on Fall Creek
2 on the White River near Anderson

Municipal wastes, industrial wastes, or a combination of the two were reported as the primary causes of the fish kills (U.S. Army Corps of Engineers, 1971b).

Reservoirs

Four reservoirs have been built in the basin--Geist in 1943, Morse in 1955, Prairie Creek in 1963, and Eagle Creek in 1970. They all are similar in shape and size, being long, narrow, and relatively shallow (fig. 21 and table 11).

The quality characteristics of a reservoir react to a set of controls different from that of a river because of the different hydrologic environment. The primary differences are the relative quiescence of the water and the time available for the various interreactions to occur. Both beneficial and detrimental effects may result from impounding water.

Possible beneficial effects include reduced turbidity, hardness, BOD, and coliform density, and an equalizing action of most quality parameters over a period of time. These effects would result from long detention times of the water in the reservoir, permitting settling of materials, biodegradation of organic substances, and dieoff of bacteria.

Table 11.--Selected physical data for the reservoirs in the basin

	Eagle Creek Reservoir	Prairie Creek Reservoir	Morse Reservoir	Geist Reservoir
Spillway (feet above mean sea level)	790	990	810	785
Surface area (acres)	1,350	1,252	1,430	1,800
Volume (acre-feet)	24,000	22,100	21,180	21,180
Maximum depth (feet)	45	30	50	30
Drainage area (square miles)	162	16.8	217	218
Length (miles)	5.25	3.5	6.25	6.5
Year built	1970	1963	1955	1943
Owner	City of Indianapolis	Muncie Water Works	Indianapolis Water Co.	Indianapolis Water Co.

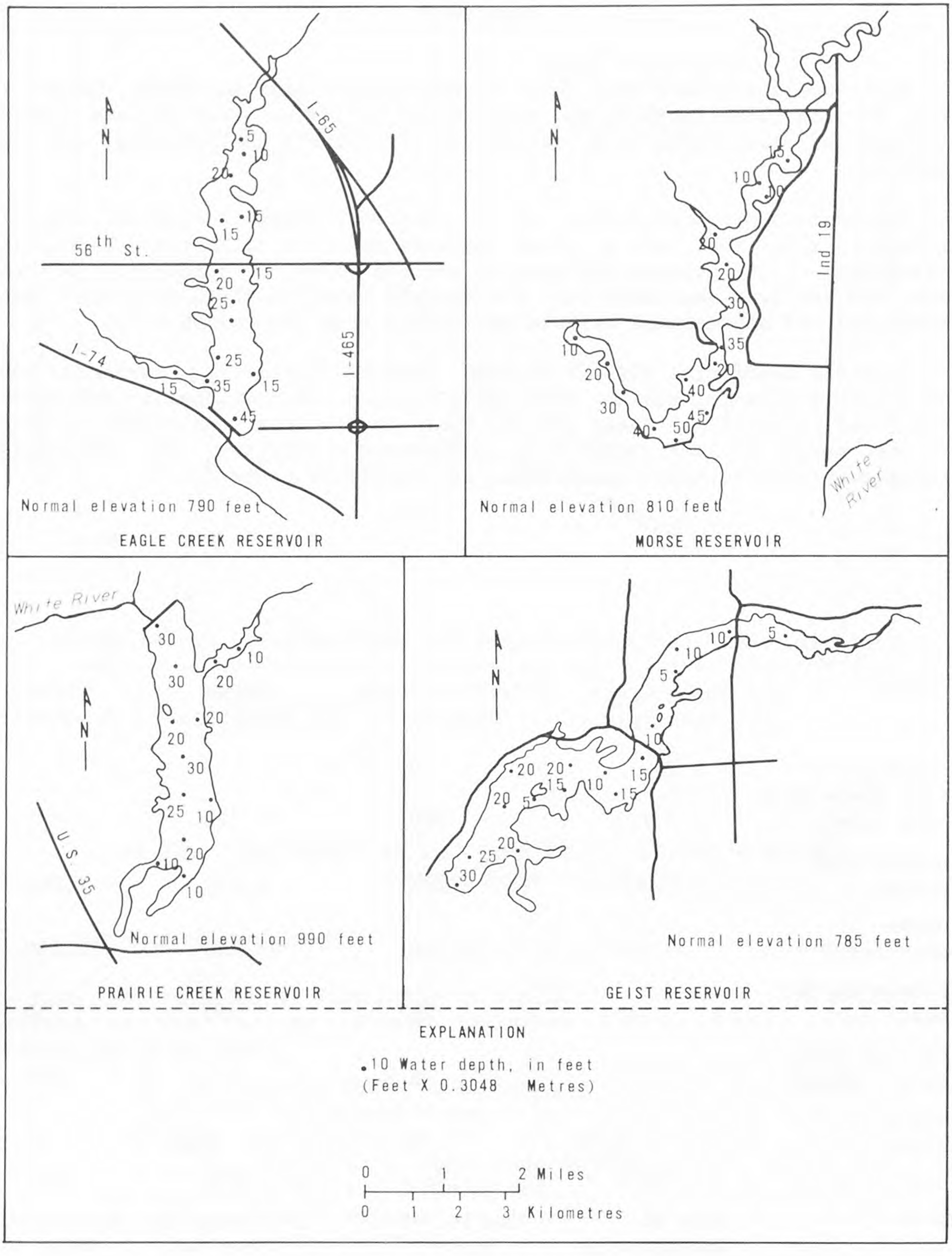


Figure 21.-- Reservoirs

The most important detrimental effects result from thermal stratification and consequent degradation of water quality in the lower layer of the reservoir. When thermal stratification occurs, usually beginning in the spring, the epilimnion (upper layer) remains oxygenated due to wind action, contact with the atmosphere, and inflows from tributary streams. The lowest layer in the reservoir, the hypolimnion, is markedly cooler and denser than the upper layer. Figure 22 illustrates thermal stratification in Eagle Creek Reservoir during June 1965; the epilimnion extended from the surface to about 10 feet (3 metres) and the hypolimnion extended from a depth of 24 feet (7.3 metres) to the bottom. The zone separating these two layers is called the metalimnion. The hypolimnion is prevented from mixing with aerated water by the metalimnion. The natural oxygen demand of biota and decomposing matter in the hypolimnion usually removes all the dissolved oxygen. In the absence of oxygen, iron and manganese are reduced and go into solution, sulfates are reduced to hydrogen sulfide, the pH is lowered, and some minor elements may go into solution.

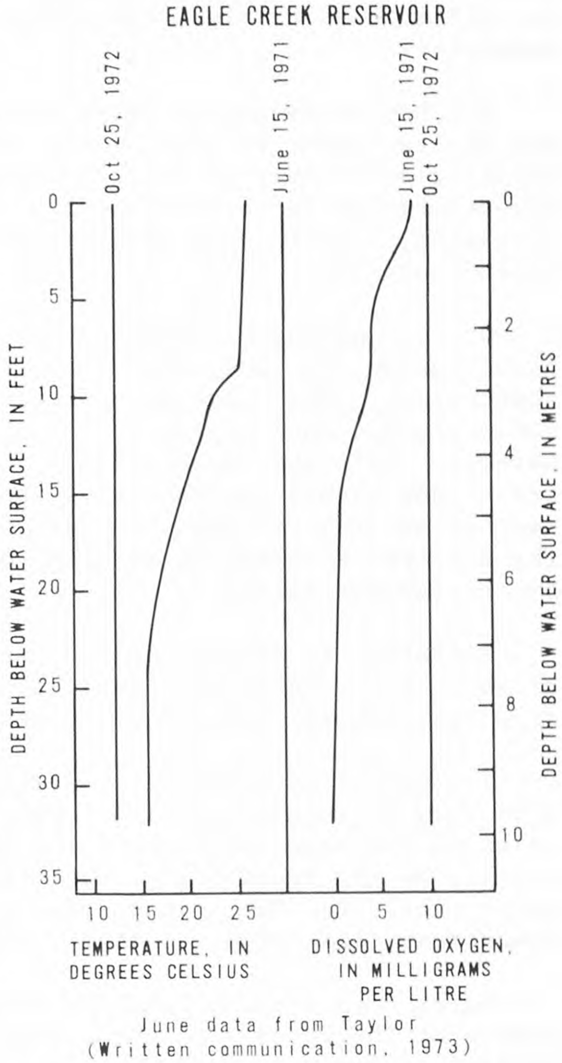


Figure 22.-- Reservoir stratification

Figure 22 also illustrates the condition of no stratification that usually occurs during the cooler months. Under these conditions there are few chemical or physical variations in the water column.

The inorganic chemical quality of the reservoirs in the basin is generally good (tables 6 and 7). The dissolved solids range from about 200 mg/l in Prairie Creek Reservoir to about 350 mg/l at Geist and Morse Reservoirs. None of the common inorganic constituents occur in solution in concentrations exceeding State water-quality standards. However, in October 1972, the water in Morse Reservoir contained 4.9 mg/l nitrate (as nitrogen), and the water in Eagle Creek Reservoir contained 1.4 mg/l nitrate (as nitrogen) (table 7). The other two reservoirs contained less than 0.2 mg/l nitrate (as nitrogen). Nitrate values as high as those found in Eagle Creek and Morse Reservoirs are usually indicative of pollution and can contribute to objectionable algal growths, such as is commonly found in Geist Reservoir.

The bottom sediments serve as a storehouse of chemical substances that may be released to the water under the reducing conditions found in the hypolimnion. Table 12 lists the analytical results of samples collected in the reservoirs in October 1972. These data show substantial amounts of nutrients, pesticides, and some minor elements in association with the bottom sediments.

Organic nitrogen in the bottom material is accumulated from the decay of algae grown in the reservoir and from sediment from tributaries to the reservoirs. The high concentrations found associated with the bottom sediments in the reservoirs listed in table 12 is indicative of enriched waters. All the reservoirs probably experience heavy summertime algal growth and dieoff and the associated water-quality problems of odors, oxygen demand, and the release of nutrients. The data also indicate that much of the nutrient material is retained by the reservoir rather than being removed by the release water.

Pollution is also evident. Concentrations of pesticides and PCB's (none of which occur naturally) indicate that the reservoirs are receiving wastes from agricultural and urban sources.

The effect of reservoir releases on the quality of the receiving stream will vary in relation to the vertical location of the outlet gate. Water released from the epilimnion will have relatively little effect on the water quality of the receiving stream. Water from the hypolimnion may cause foul odors near the dam, iron precipitate staining the rocks and washing downstream, low oxygen concentrations, and high nutrient concentrations.

Water from Prairie Creek Reservoir usually is released from the middle depths of the reservoir, and would probably contain water from both of the stratified layers. Occasionally water is released from the hypolimnion to "clean out the old water". Water from Morse and Geist Reservoirs is always taken from near the top of the reservoir.

The city of Indianapolis is required to maintain a flow of 4 ft^3/s (0.1 m^3/s) in Eagle Creek below the reservoir. This is accomplished by a bypass gate releasing water from about the mid-depth of the reservoir, which probably includes water from both zones.

Esthetic and Cultural

Esthetic is defined as pertaining to the beautiful, as distinguished from the useful or moral. The esthetic value of a scene is difficult to measure quantitatively because each person places a different value on it.

Table 12.--Selected constituents extracted from the bottom sediments of the reservoirs

		Nutrients (mg/kg)					Pesticides[1/] (ug/kg)					Minor Elements (mg/kg)				
Location	Date	Total Nitrogen as N	Organic Nitrogen as N	Exch. Ammonia as N	Nitrate as N	Total Phosphorus as P	Aldrin	DDD	Dieldrin	Chlordane	PCB	Iron	Manganese	Aluminum	Lead	Zinc
Prairie Creek Reservoir	Oct. 27, 1972	4,140	3,070	1,060	5	850	0	6.0	0.5	7	0	19,000	1,250	7,920	53	65
Morse Reservoir	Oct. 26, 1972	6,070	4,130	1,940	4	1,230	0	2.0	4.6	15	20	13,500	728	6,920	67	86
Geist Reservoir	Oct. 26, 1972	4,430	2,990	1,440	8	900	0	2.3	1.5	8	10	12,000	655	5,110	50	79
Eagle Creek Reservoir	Oct. 25, 1972	3,830	2,860	970	2	840	2.1	.7	2.6	10	10	10,300	1,100	5,080	35	48

1/ Sought but not found: DDE, DDT, Endrin, Heptachlor, Lindane

Esthetic problems may take several forms and result from different controls. Junkyards, landfills, abandoned strip mines, power lines, smoke stacks, billboards, unmowed highway rights-of-way, and garbage tossed in a stream at bridge crossings esthetically degrade the landscape and may directly affect the chemical or biological characteristics of the water resources. In general, the solution to these problems is a compromise between natural beauty and economics, politics, convenience, or apparent hard necessity.

Water pollution causes esthetic problems. The water may look bad because of solids or colors added by wastes. The waste also may detrimentally affect the biological characteristics. An enriched water may develop growths of algae that make the water look bad and even smell bad as the algae begin to die. Geist Reservoir is so enriched with nutrients that biological problems, thus esthetic problems, are an annual occurrence.

The cultural characteristics of a river may include the historic, natural, and archeological areas in the vicinity (fig. 23), as well as the direct recreation and leisure-time use of the river.

The present extent of urbanization as well as the continual expansion of urban areas and highways is endangering many of the historic, natural, and archeological sites. Pollution in the White River has probably curtailed its use as a canoe trail. Swimming in the White River would be hazardous below sewage outfalls, and fishing would be unproductive in many parts of the river.

TRENDS

River quality problems were found in the upper White River basin in 1973. These problems probably will intensify. The U.S. Army Corps of Engineers (1971 b) predicts that by 1980 water use and wastewater outflow in the basin will increase about 75 percent over the 1970 levels to 260 and 183 Mgal/d (11.4 and 8.02 m^3/s, respectively). Similarly, the Corps predicts that by 2020 water use in the basin will be about 460 Mgal/d (20.2 m^3/s), and wastewater outflow will be 391 Mgal/d (17.1 m^3/s).

In an effort to estimate the potential of future river-quality problems, historical data have been gathered and long-term trends of some characteristics have been prepared.

Physical

The land in the upper White River basin has undergone a radical change in appearance since the U.S. Government signed a treaty with the Delaware Indian Nation in 1818 and acquired the large tract of land in central

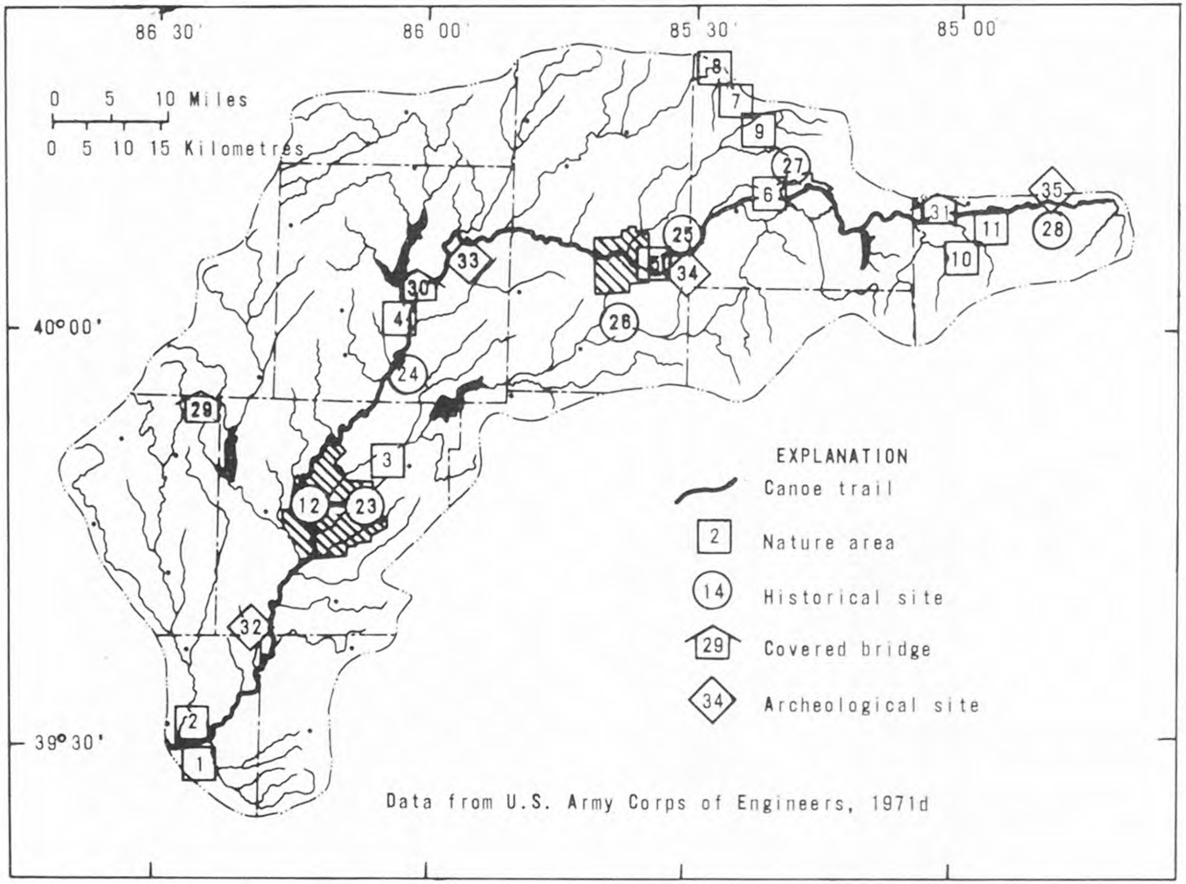


Figure 23.-- Nature areas and areas of historical and archeological interest

NATURE AREAS

1. Blue Bluff Preserve
2. Bradford Nature Preserve
3. Woolens Garden
4. W.S. Blatchley Sanctuary
5. Mounds State Park
6. Ball State Wildlife Preserve
7. McColm Bog
8. Old Prairie Swamp
9. Ginn's Woods
10. Cabin Creek Raised Bog
11. Davis Forestry Farm

HISTORICAL SITES

12. Benjamin Harrison Home
13. Lockerbie Street Home
14. House of Twin Chimnies
15. Prosser House
16. Albert Fletcher Museum
17. Christ Church
18. Kemps House
19. Meredith Nicholson House
20. Fairbanks House
21. Camp Robinson
22. Booth Tarkington Home
23. Camp Morton
24. Conner Prairie Farm
25. Moravian Mission
26. Glacial Esker
27. Munsee Town Indian Village
28. General Ashel Stone Home

COVERED BRIDGES

29. Fishback Creek
30. West Fork White River
31. West Fork White River

ARCHEOLOGICAL SITES

32. Oliver Farm
33. Strawtown Site
34. Mounds
35. Thornburg Site

Indiana that includes the basin. Reports by Brown (1882), Goodrich and Tuttle (1876), Forkner (1914), Tucker (1882), and Banta (1881) describe the basin as a wild, heavily forested land inhabited by turkeys, wolves, wildcats, minks, snakes, and a few bear. There were many prairies, marsh areas, and springs.

Today the thick forests of the early 1800's are gone. The land was very rich and, after clearing and draining, made excellent farmland. Thus, the farms replaced woodlands, which now mostly remain as narrow strips along the streams and drainageways or in small holdings too wet to cultivate.

Steadily increasing population presently is causing land use to shift from agricultural to urban. The U.S. Army Corps of Engineers (1971 c) projects that by 2020 about 9 percent of the 1967 agricultural land will have been converted to urban use.

Flow

Historically, the basin has been relatively wet. Springs, ponds, and marshes were common in the early 1800's. In 1819 the White River was declared navigable to a point near Noblesville, although it was about 1830 before a steamship was able to overcome the log jams and shifting sands and reach Indianapolis.

Brown (1882) reports that in the early 1800's it was unusual to be able to ford the White River; however, by 1882, the river was a mere rivulet much of the time. Fall and Eagle Creeks were no longer able to furnish year-around power to the mills on their banks. Brown suggests that draining the ponds and marshes for agriculture was one of the reasons for the shrinking water supply.

Although historical quantitative data are lacking, the flow in the White River today seems to be similar to the flow in the 1880's, as described by Brown in that the river is commonly fordable. On the other hand, the reservoirs built on Fall and Eagle Creeks have caused significant changes in the flow patterns of these streams since 1882.

Statistical analysis of historical data enables predictions of future discharge in a river. Some of the commonly used statistical flow values for this basin are shown on figure 24. For example, a flood with a discharge exceeding about 55,000 ft^3/s (1,600 m^3/s) has a 2-percent chance of occurring in the White River at Centerton during any year (that is, it will probably be exceeded once every 50 years). On the other hand, a flow of 340 ft^3/s (9.6 m^3/s) is equaled or exceeded 90 percent of the time. Note that the values shown on figure 24 represent three distinct types of statistical analyses and are not directly relatable one to another.

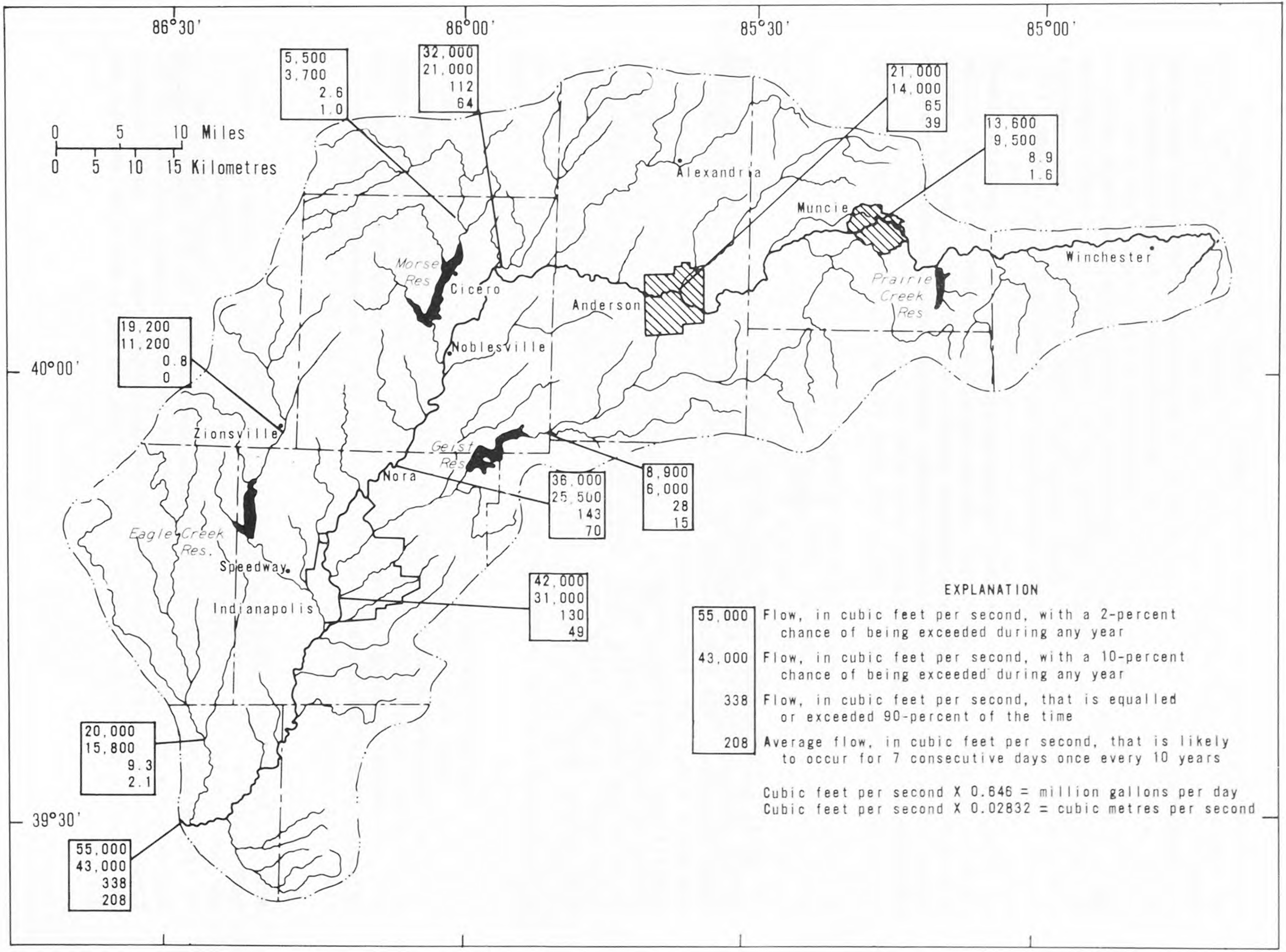


Figure 24.-- Predicted discharges at selected sites

Turbidity

Turbidity data on the White River at Indianapolis have been collected daily since 1904 by the Indianapolis Water Company. During the period of record, the instantaneous turbidity concentration has ranged from 0 to 1,400 mg/l. The annual concentration has averaged 44 mg/l, with a range of 11 to 84 mg/l. There is considerable scatter from year to year with no discernable trend in turbidity concentrations since 1904. The average annual concentration in 1972 is essentially the same as it was in 1904.

Although the average annual values exhibit no long-term pattern, there is a definite seasonal pattern. Being strongly related to discharge, the seasonal turbidity pattern generally parallels the flow pattern. Peak monthly averages occur in the wet spring and the minimums occur during the low-flow periods in late fall.

Color

Water color usually is attributed to dissolved organic compounds. Color is not physiologically harmful but is esthetically unappealing at high concentrations. The Indianapolis Water Company has collected color data on the White River at Indianapolis daily since 1911. These data show no significant long-term changes. The average color concentration for the period of record is 32 mg/l, a concentration that imparts only a slight color to the water. The only other definitive conclusion to be drawn from these data is that since about 1940 there has been a smaller range of color than before 1940--3 to 180 mg/l and 4 to 600 mg/l, respectively.

Chemical

The Indianapolis Water Company has collected selected water-quality data on the White River at Indianapolis daily since 1904. Some long-term trends are discernable using these data, data from the annual reports of the Indiana State Board of Health (1957-71), and other selected references.

Common Inorganic Constituents

Dr. Moses T. Runnels collected some chemical data on the White River at Indianapolis in 1880 (U.S. Circuit Court of Appeals, Seventh Circuit, 1893). These data indicated the total solids concentration was 360 mg/l, organic and volatile matter was 32 mg/l, chlorine was 105 mg/l, and free ammonia was 0.72 mg/l.

Testimony by John N. Hurty (U.S. Circuit Court of Appeals, Seventh Circuit, 1893) present the following data collected on the White River at Indianapolis in 1889: total solids ranged from 270 to 470 mg/l, total hardness ranged from 170 to 190 mg/l, chloride ranged from 16 to 20 mg/l, and free ammonia ranged from 0.01 to 0.03 mg/l.

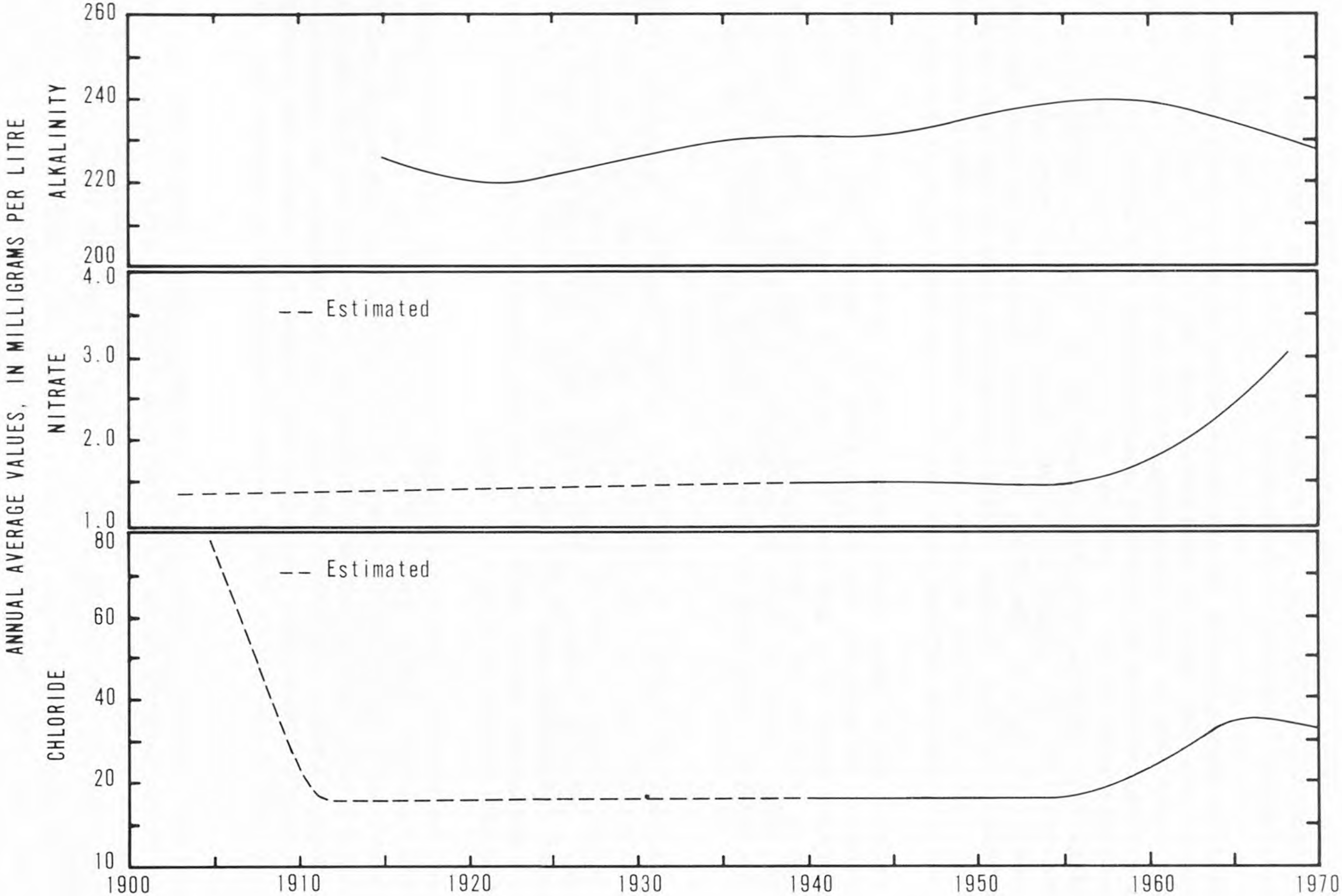
The chloride concentration in the White River at Indianapolis apparently ranged from 8 to 32 mg/l in the 1880's and 1890's. Indianapolis Water Company data from 1905 to 1912 (Indianapolis Water Company, written commun., 1973) show a sharp decline in chloride concentration from about 100 to about 15 mg/l, possibly indicating a period of pollution and its subsequent reduction (fig. 25). Independent data reported by Clarke (1924) tend to verify this period of pollution. His data show an average chloride concentration of 78 mg/l in the White River near Indianapolis from September 1906 to September 1907. Denham (1938) recognized this period and reported that the high chloride values at this time undoubtedly were due to pollution by sewage and oil wastes emptied into the river in the region of Muncie.

More recent data show relatively stable average annual chloride concentrations of 16 mg/l for the period 1940 to about 1957. This value began to increase about 1957 and rose to a peak of 36 mg/l in 1966. Part of this rise can be attributed to decreasing flow during the same period, but some of it also results from an increasing pollution load. The slight concentration decline from 1966 to 1970 is probably the result of increasing flow.

Concentrations of nitrate in the White River exhibit long-term trends closely paralleling the chloride trends (fig. 25). Clarke (1924) shows high nitrate concentrations in 1906-07 (6.1 mg/l) and data from the Indianapolis Water Company (written commun., 1973) shows lower and relatively consistent average annual concentrations (1.5 mg/l) from 1910 to 1915 and from 1940 to about 1957. Beginning about 1957 the average annual nitrate concentration began to rise and peaked at 3 mg/l in 1968.

Nitrogen, as ammonia, and nitrite show no significant long-term changes. Concentration averages before about 1915 are generally less than 0.05 mg/l for ammonia and 0.015 mg/l for nitrite. Since 1940, the concentrations for these parameters have been relatively uniform and commonly are 0.20 mg/l and 0.03 mg/l, respectively. Although these values indicate a substantial increase in concentration, the imprecise analytical procedures for nitrogen in the late 1800's and early 1900's makes it difficult to assess the data properly.

The average annual alkalinity concentrations determined by the Indianapolis Water Company since 1915 (written commun., 1973) exhibit some long-term changes (fig. 25). However, the change is oscillatory, and the concentration range is so narrow (about 20 mg/l) that the trend probably is insignificant.

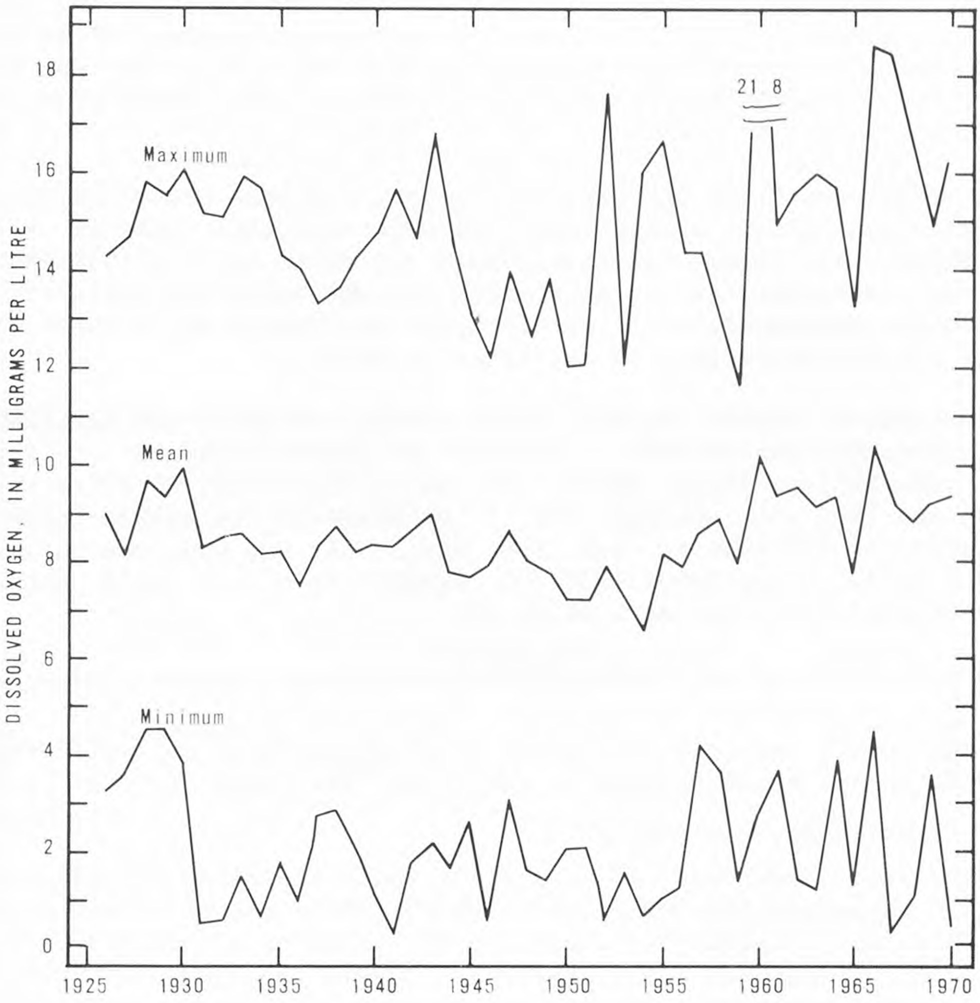


Data from Indianapolis Water Company files

Figure 25.-- Long-term trends in selected water-quality parameters of the White River at Indianapolis

Dissolved Oxygen

Daily dissolved-oxygen concentrations of water in the White River at Indianapolis have been measured by the Indianapolis Water Company since 1925. The annual maximum, minimum, and mean concentrations are plotted on figure 26. Disregarding annual variations, the annual mean dissolved-oxygen concentration has declined steadily from 1925 to the early 1950's followed by a general increase to 1970.



Data from Indianapolis Water Company files

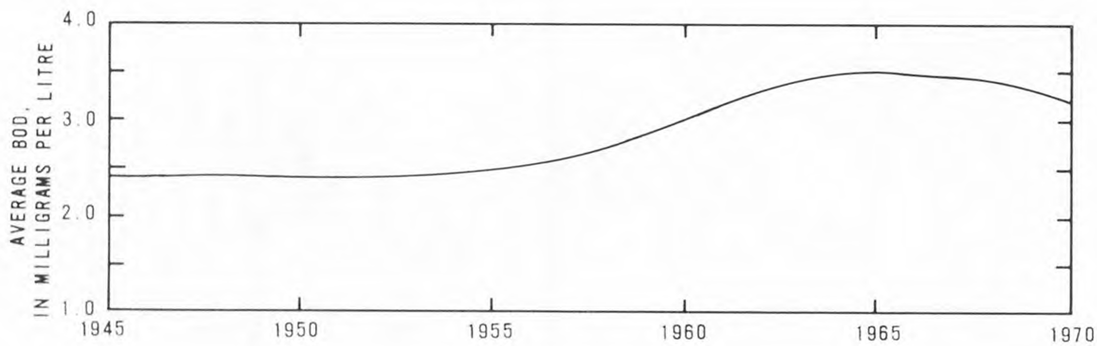
Figure 26.-- Long-term variations in dissolved oxygen in the White River at Indianapolis

The minimum dissolved-oxygen concentrations probably are more important than the mean values. The water-quality standards of Indiana (Indiana Stream Pollution Control Board, 1970) for aquatic life require that the dissolved- oxygen concentration shall average at least 5.0 mg/l per calendar day and shall not be less than 4.0 mg/l at any time or any place outside the mixing zone. The data on figure 26 show that the oxygen concentration in the White River at Indianapolis has not met these standards at least once a year since 1925. It is significant to note that earlier sections of this report have shown this section of the river to be a zone of recovery with a minimum of dissolved oxygen problems. The oxygen concentrations both upstream and downstream are significantly lower.

The Indiana State Board of Health (no date) reported on data they collected in 1925, 1926, and 1930 between Muncie and Anderson. The data show the average dissolved-oxygen concentration of the water at the Muncie intake was 7.4 mg/l, corresponding to 71 percent of saturation. The average value at Yorktown was 5.4 mg/l, or 49 percent of saturation, while at the Anderson intake the average concentration was 6.9 mg/l, or 66 percent of saturation. These values approximate the concentrations in this area during the current study.

Denham (1938) described the dissolved-oxygen patterns below Indianapolis in 1934. The data include a series of diel determinations taken at varying distances below the sewage outfall. Data collected in July 1934 show the river to be anaerobic as far as 8 miles (13 km) below the outfall, with dissolved oxygen ranging from 1 to 7 mg/l at Centerton. These values approximate the concentrations in the river in 1972.

The biochemical oxygen demand (BOD) exerts a significant influence on the dissolved-oxygen concentration and is a common measure of organic pollution. The Indiana State Board of Health (no date) reported that in 1925, 1926, and 1930 the average BOD of the water at the Muncie intake was 4.4 mg/l, while at Yorktown it was 5.6 mg/l. At the Anderson intake BOD averaged 3.4 mg/l. In September 1930 BOD ranged from 1.6 mg/l above the Muncie sewage outfall to 121 mg/l below it.



Data from Indianapolis Water Company files

Figure 27.-- Long-term trends of BOD in the White River at Indianapolis

BOD data on the White River at Indianapolis date back to 1892, when the concentration was about 5 mg/l (U.S. Circuit Court of Appeals, Seventh Circuit, 1893). The Indianapolis Water Company has been collecting BOD data daily since 1945 (fig. 27). These data show similarity to the chloride and nitrate data, beginning to rise about 1957 and peaking about 1966. The concentration ranges from 2.4 mg/l to 3.5 mg/l.

Biological

Bacteria

Bacteria data have been collected in the White River since the early 1900's. These early data do not lend themselves to correlation with recent data, however, because of changes in methodology over the years.

In general, however, the areas with historic problems of bacterial pollution are still problem areas. For example, the Indiana State Board of Health (no date) reported that in 1925-26 "...the White River below Muncie is so polluted as to be dangerous from the standpoint of health....White River is being unduly polluted by the discharge into it of domestic sewage and industrial wastes from and in the city of Muncie, Indiana." In 1925 and 1926 the average bacterial count (incubated at 37°C) was 3,500 colonies/ml at the Muncie intake, 600,000 colonies/ml at Yorktown, and 16,500 colonies/ml at the Anderson intake. These numbers are not directly relatable to counts derived from the total coliform test in common use today, but they do indicate that bacterial pollution was extensive in the past.

Data collected by the Indiana State Board of Health on the coliform concentration in the White River since 1957 indicate that the annual median coliform concentration may be declining slightly, although there is considerable scatter in the data.

Phytoplankton

Phytoplankton data in the basin dates to Curtiss (1882) who lists and illustrates more than 100 varieties of diatoms found in the waters around Indianapolis.

The first significant study of algae in the White River was done by Palmer (1932). In his study, Palmer identified 182 varieties of algae, 120 of which were new to Indiana. He collected 196 samples from three locations near the Indianapolis sewage disposal plant and one at Waverly. The dominant forms, based on the number of samples containing those forms, were *Synedra* sp, *Navicula* sp., *Scenedesmus* sp., *Euglena* sp., *Chlamydomonas* sp., *Cyclotella* sp., *Oscillatoria* sp., and *Pediastrum* sp.

During August and September 1940, Brinley (1942) studied the phytoplankton population of the entire White River from the headwaters to the mouth. He found a heavy phytoplankton population above Muncie consisting largely of *Euglena* sp., *Trachelomonas* sp., and *Cryptomonas* sp. Below Muncie, the phytoplankton population was almost nonexistent and consisted primarily of *Chlamydomonas* sp. The population continued to rise and fall downstream in response to zones of pollution and recovery.

Stephanodiscus sp. and Melosira sp. were dominant at Anderson and Nora, respectively. As in the study by Palmer (1932), diatoms were the dominant form found below Indianapolis.

Data collected by the Indiana State Board of Health (1957-71) show that about three-fourths of all the algae found in the White River at Antrim are diatoms. The dominant forms are Cyclotella sp., Navicula sp., Synedra sp., Scenedesmus sp., Euglena sp., and Chlamydomonas sp.

Samples collected in October 1972 yielded results similar to these earlier studies. Dominant forms found in the White River near Waverly were Scenedesmus sp., Cyclotella sp., and Ankistrodesmus sp. All of these studies indicate that there have been no significant changes in the phytoplankton population from 1931 to 1972.

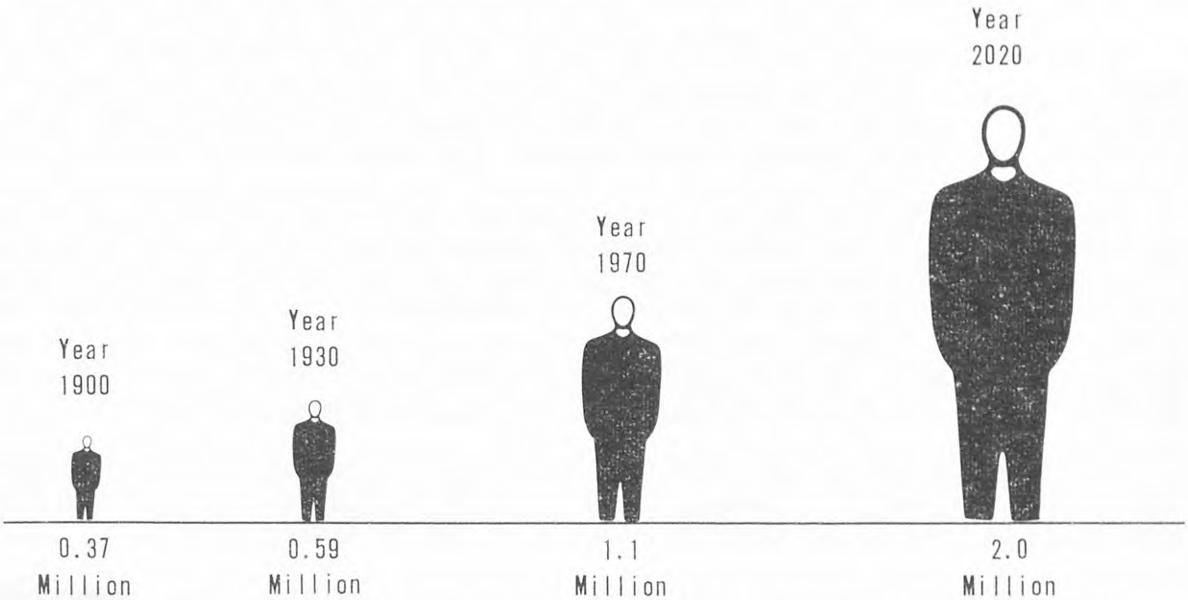
Bottom Organisms

The only significant study of the bottom organisms of the White River known to the author was conducted by Denham (1938). At Waverly, Denham found an average of 11,800 organisms per square metre of river bottom, of which 99 percent were Oligochaeta and Chironomidea. Some leeches also were found. These are all pollution tolerant organisms. Scant data collected during this study indicate that the community of organisms found in the White River at Waverly in 1972 was similar to that found by Denham in 1932.

Esthetic and Cultural

Population

The population of the upper White River basin is growing steadily. It has increased from 0.37 million in 1900 to 1.1 million in 1970 (fig. 28). The Indiana Department of Natural Resources (1968) predicts that the basin population will reach about 2 million by 2020. The growth will be principally in the suburban areas of Indianapolis, Muncie, and Anderson. The U.S. Army Corps of Engineers (1971 a) predicts that the rural population will continue to decline steadily until by 2020 it will be about 12,000, less than half the 1972 rural population.



Data modified from State of Indiana Department of Natural Resources, 1968.

Figure 28.-- Basin population growth

Recreation and Leisure

If the predictions regarding population increase are correct, recreational demands such as swimming, boating, picnicking, camping, hunting, fishing, and sightseeing probably will increase also.

In the upper White River basin recreation demand already exceeds the capacity of available facilities. The U.S. Army Corps of Engineers (1971 d) predicts that only 30 percent of the estimated 1980 demand for 19 million recreation days will be met, and only 22 percent of the estimated 2020 demand for 49 million recreation days will be met.

ENVIRONMENTAL ASSESSMENT

Areal Summary

A 170-mile (274-km) reach of the White River is the major water feature draining a basin of about 2,444 mi^2 (6,330 km^2) in central Indiana. The climate is characterized by a normal annual precipitation of 40 inches (1,020 mm), mainly as summer thundershowers and broad, general winter rains.

About 90 percent of the 1.1 million people living in the basin are concentrated in the three urban areas of Indianapolis, Muncie, and Anderson. In spite of the urbanization, 68 percent of the land was agriculturally oriented in 1967 and only 19 percent was urbanized. The remaining land includes forest (7 percent) and water surface, roads, investment tracts, and mines (6 percent). In 1970, people in the basin were using about 149 x 10^6 gallons (5.64 x 10^5 m^3) of water daily, mostly for domestic purposes.

Of the 9,000 industries seven electric-power generation plants produce most of the wastewater. These plants produce heated water, which may have beneficial as well as detrimental effects on the receiving waters.

Urban sewage disposal can cause problems even when the sewage is treated. Sewage-treatment plants are adding significant BOD loads to the White River at Muncie, Anderson, and Indianapolis. Disposal and treatment problems are compounded by the combined sanitary-storm sewer systems in 16 of the 35 municipalities.

About 25 mi^2 (65 km^2) of drainage area in the basin discharges enough ground water to maintain water in the stream all year.

The six electric generating plants at Noblesville and Indianapolis cause the mean monthly temperature of the White River at Centerton to be 6°F (3°C) higher than it is above Noblesville.

Mineralization of the White River varies widely downstream in response to waste discharges from the urban areas, tributary flow, increased ground-water discharge, and water use. Generally speaking, the White River can be subdivided into five distinct river-quality sections. Section 1, above Winchester, is primarily rural. The river quality is good, although it is affected by agricultural land use. Section 2, between Winchester and Muncie, is affected by urbanization at Winchester and Muncie. The river quality generally is good, except occasionally near the cities. Section 3, Muncie to Anderson, is polluted as a result of urbanization. Section 4, Anderson to Indianapolis, is further polluted (particularly at Anderson), but the water tends to recover considerably by the time it reaches Indianapolis. Section 5, below Indianapolis, is polluted to Centerton, beyond the project area.

The "natural" chemical quality of the basin's streams is assumed to be approximated by the quality of the shallow ground water. It can be described as a very hard, calcium bicarbonate type water, with an average dissolved solids concentration of about 440 mg/l and a specific conductance of a little over 700 micromhos. At times and at places mineralization of the water exceeds the State's water-quality standards.

The water-quality standards for public water supply set by the Indiana Stream Pollution Control Board (1970) are not exceeded for common constituents such as calcium, bicarbonate, and chloride; however, the dissolved-solids standard is exceeded occasionally at Yorktown, Anderson, and Indianapolis. The common constituents vary seasonally in response to discharge variations, peaking during the low-flow periods in late summer and early fall, and reaching a minimum during the high-flow period in spring.

The rural drainage area above Harrisville is yielding water containing nitrate nitrogen and relatively little phosphorus. The increase in phosphorus and nitrogen as ammonia near Smithfield, below Muncie, and at Waverly indicated urban wastes. The load of nutrients in the upper White River increases downstream from the headwaters to below Indianapolis, where the river apparently begins to recover. Phosphorus concentrations, like the common constituents, are highest during low-flow periods, whereas nitrate concentrations are highest during the winter and spring and are at a minimum during the low flow, heavy plant-growth periods of summer and early fall.

Relatively high concentrations of metals such as cadmium, copper, lead, and zinc are found in the water of the White River and its tributaries in the vicinity of Indianapolis. In some places the concentrations measured exceeded the State water-quality standards.

The stream bottom materials have a high affinity for nutrients, minor elements, and pesticides, and significant increases in concentrations over the dissolved phase were measured. At Harrisville, the concentration of lead extracted from the sediment was 675 times higher than the lead in solution. Although no pesticides were found dissolved in the water, significant concentrations of DDD, Dieldrin, Chlordane, and PCB's were extracted from the sediment at several sites. Dieldrin seems to be the dominant insecticide found in streams draining predominantly rural areas, whereas DDD, Chlordane, and PCB's dominate in streams containing recent urban drainage.

Biodegradable wastes from sewage-treatment plants cause the dissolved oxygen concentration in the White River to be depressed below Muncie, Anderson, and Indianapolis. In the White River at Centerton the dissolved oxygen concentration was 1 mg/l or less for at least 1 day per month, for 6 months out of each year. This oxygen concentration is well below the State standard and will not support many life forms.

In October 1972, rural areas yielded coliform bacteria counts of 1,000 to about 5,000 colonies per 100 ml of water and generally less than 50 colonies per 100 ml of fecal coliform. Water from urban runoff increased these concentrations to a maximum of about 80,000 colonies per 100 ml for coliform at Indianapolis (above the sewage-treatment plant) and about 10,000 colonies per 100 ml for fecal coliform, also at Indianapolis. Below sewage-treatment-plant outfalls a maximum concentration of 1.5 million colonies per 100 ml was found in the White River below Muncie. The coliform concentration below Muncie, Anderson, and Indianapolis regularly exceeds the State water-quality standards for public water supplies.

The White River has been enriched by nitrogen and phosphorus wastes to the extent that the average standing crop of phytoplankton increases from about 400 microorganisms per millilitre at Winchester to 5,000 microorganisms per millilitre at Nora. The dominant algae at these sites are the diatoms *Cyclotella* sp. and *Navicula* sp.

The variety and type of fish in the White River further support the description of relatively unpolluted water above Muncie and immediately above Indianapolis and polluted water below Muncie and Indianapolis. Since 1960, 41 fish kills in the major streams of the basin have been reported to the Indiana Stream Pollution Control Board. Municipal wastes, industrial wastes, or a combination of the two were reported as the primary cause of the fish kills.

Four reservoirs have been built in the basin--Geist in 1943, Morse in 1955, Prairie Creek in 1963, and Eagle Creek in 1970. The first three were built primarily for water supply, and water is released daily to augment the flow of the receiving stream. Eagle Creek was built primarily for flood control.

The reservoirs stratify during the summer, and water in the hypolimnion becomes anaerobic. High concentrations of nutrients, pesticides, and minor elements have accumulated in the bottom sediments from decaying algae and fluvial sediments and may be released to the water under the reducing conditions of the anaerobic hypolimnion. Concentrations of pesticides and PCB's in the bottom sediments indicate that the reservoirs are receiving wastes from agricultural and urban sources. Generally speaking, the inorganic quality of the reservoirs is good, although the nitrogen concentration measured in Morse and Eagle Creek Reservoirs in October 1972 is indicative of pollution and can cause objectionable algal growth, such as is commonly found in Geist Reservoir.

Problem Areas

The most severe river-quality problems in the basin are found in the Indianapolis area. Industrial and municipal waste discharges detrimentally affect the White River and all its tributaries in the immediate vicinity of Indianapolis. For example, Eagle Creek contains a large concentration of minor elements and organic loading. The White River receives such an extensive organic loading from the Indianapolis sewage-treatment plant that the river does not recover fully as far downstream as Centerton. Heated water discharge from the electric powerplants in Indianapolis increases the waste-loading problems caused by Indianapolis sewage. The additional heat reduces the assimilative capacity of the river and increases the activity of the biota in the water. The coliform concentration in the White River below Indianapolis is a potential health hazard and restricts the water's use. The insecticides and PCB's on the sediments indicate periodic pollution.

The Muncie area is the second most severe problem area in the basin. Waste loading in this area has an immediate and dramatic effect on the chemical and biological characteristics of the river. Effluent from Yorktown and wastes carried by Buck Creek compound the effect on the White River, so that the river still has enrichment and dissolved oxygen problems by the time the city of Anderson adds its wastes. Similar to the reach below Indianapolis, the coliform concentration in this reach is generally high and is a potential health hazard.

The large volume of municipal and industrial wastes from Anderson affects the White River in much the same way as that from Muncie. An electric powerplant in Anderson adds heat to the White River, especially during low flow.

Other municipalities in the basin also discharge wastes into streams. Much of the time the receiving stream contains enough water to assimilate the wastes. Occasionally, however, the flow is low enough that localized pollution exists. Some of the more significant problem areas are near Lawrence, Mooresville, Elwood, and Winchester.

Analysis of bottom materials indicates that agricultural runoff contributes insecticides and nutrients to the streams. Some of these sediments are carried by the streams and are deposited in reservoirs.

Potential Changes

The development of additional water to meet projected demands for the metropolitan areas of Indianapolis, Muncie, and Anderson is a major need within the basin. With a substantial increase in water use, wastewater outflow and the potential for river-quality deterioration will increase accordingly. Rigorous control over wastewater treatment and disposal may become necessary.

If land-use patterns continue to change in the same way, river quality will be more affected by increased urban areas than by decreased agricultural areas. The point-source effect of wastes from an urban area can overload a stream reach more readily than wastes from diffused agricultural sources. Decreased agricultural activity may slightly decrease the turbidity, spring nutrient load, and pesticides in localized reaches, but the overall effect of a 9-percent decrease in agricultural land by 2020 probably will be negligible. More importantly, increased impervious urban areas will cause runoff to increase in magnitude and speed; thus, the potential for local flooding, especially along the waterway, also will increase.

Most of the chemical parameters for which trends could be developed exhibit similar variations with time. The concentrations seem to be stabilizing after steadily increasing since about 1957. The reason apparently is increasing flow in the river caused by a period of increasingly wet years. Discounting annual variations and additional water treatment, the long-term trend for the common inorganic constitutents indicates increasing concentrations. Although the trend is upward, the concentrations of chloride, calcium, sodium, magnesium, bicarbonate, and sulfate probably will never reach problem-causing levels, and concentrations of nitrogen and phosphorus already exceed these levels.

In spite of the general upward trend of average dissolved oxygen concentrations, oxygen problems within the basin are widespread because the minimum concentration is the controlling factor. If, as predicted, wasteloads increase, the periods of very low oxygen concentration also will increase.

The biological community in the White River is relatively stable and, without a significant reduction in the wasteload input, should remain about the same. The indicator bacteria concentration, however, is likely to increase. In the absence of more or better treatment of sewage, the bacterial population can only increase if the population increases. Microbial pollution probably will continue, at least as long as storm and sanitary sewers are combined.

The available recreation-leisure time facilities in the basin are scant, relative to the population. The heavy increased use projected for these facilities, reservoirs in particular, will stress them additionally.

Generally speaking, the outlook for the future quality of the White River and its tributaries is optimistic. Although increasing population and urbanization will stress the river, a burgeoning awareness of environmental problems by the populace and improvements in technology should, at least, help prevent wanton pollution. More stringent controls on the quality of wastewater discharges is a trend. It probably will never be possible (nor desirable economically) to achieve drinking-water quality for all wastewaters, but their quality can be improved to the extent that the waters of receiving waterways can be used more than once and for more than one purpose.

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