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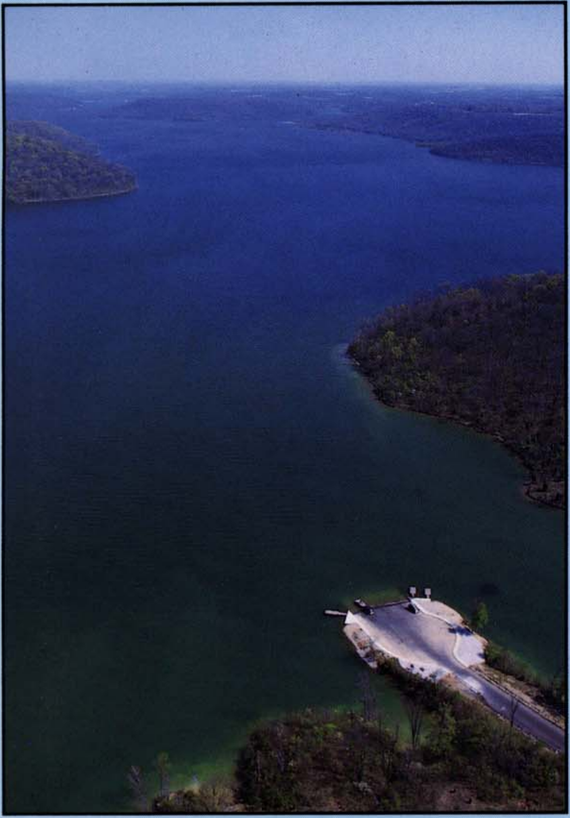
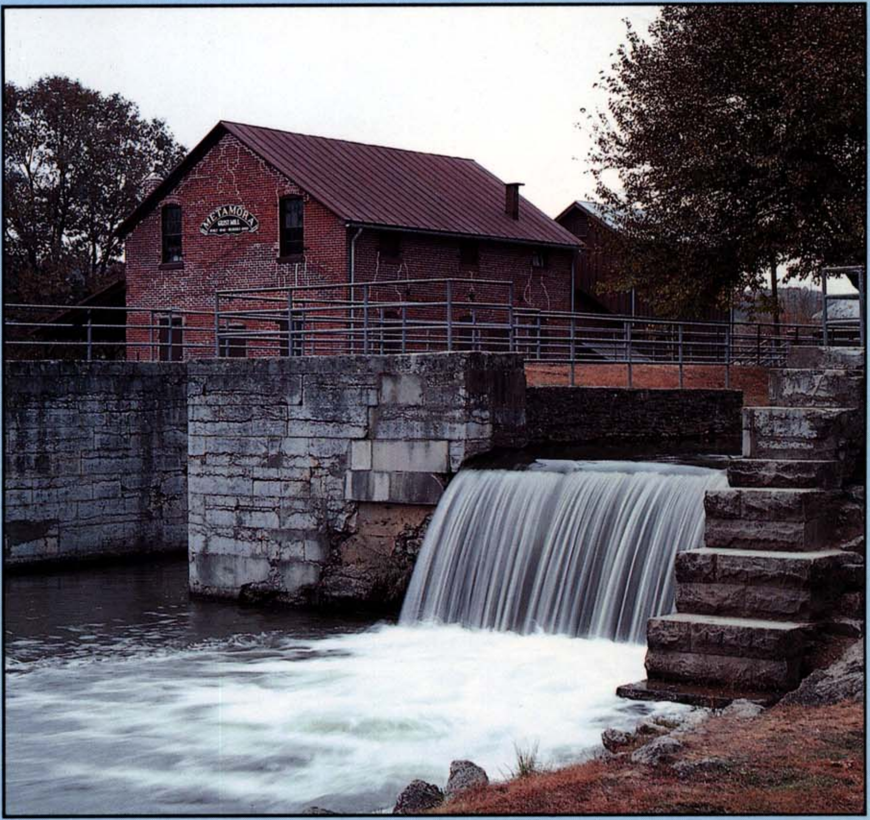
WATER RESOURCE AVAILABILITY IN THE WHITEWATER RIVER BASIN, INDIANA





STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

1988

WATER RESOURCE AVAILABILITY IN THE WHITEWATER RIVER BASIN, INDIANA

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

Water Resource Assessment 88-2

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CONTENTS

SUMMARY

ILLUSTRATIONS

TABLES

APPENDICES

ACRONYMS AND ABBREVIATIONS USED IN TEXT

IDNR	Indiana Department of Natural Resources
IDEM	Indiana Department of Environmental Management
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
NASQUAN	National Stream Quality Accounting Network
USEPA	U.S. Environmental Protection Agency
USCE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
app.	appendix
fig.	figure
pl.	plate
cfs	cubic feet per second
°F	degrees Fahrenheit
m.s.l.	mean sea level
gpd	gallons per day
gpm	gallons per minute
mg	million gallons
mgd	million gallons per day
mg/l	milligrams per liter
ml	milliliters
sq. mi.	square miles

SELECTED CONVERSION FACTORS

Mulitply	By	To obtain
	AREA	
Acres	43,560	Square feet
	0.001562	Square miles
	VOLUME	
Acre-feet	0.3259	Million gallons
	43,560	Cubic feet
	FLOW	
Cubic feet per second	0.646317	Million gallons per day
Gallons per minute	0.002228	Cubic feet per second
Gallons per minute	0.0014	Million gallons per day

WATER RESOURCE AVAILABILITY IN THE WHITEWATER RIVER BASIN, INDIANA

INTRODUCTION

The Water Resource Management Act (I.C. 13-2-6.1) was signed into law on April 7, 1983 by Governor Robert D. Orr. Under Section 3 of the act, the Natural Resources Commission must (1) conduct a continuing assessment of water resource availability, (2) conduct and maintain an inventory of significant withdrawals of ground and surface water, and (3) plan for the development and conservation of the water resource for beneficial uses. Section 5 further mandates the statewide investigation of (1) low stream-flow characteristics, (2) water use projections, (3) the capabilities of streams and aquifers to support various uses, and (4) the potential for alternative water supply development. These and other directives reflect a comprehensive approach to water resource management and establish a legislative foundation upon which management programs can be further developed.

To help meet mandated responsibilities, the Commission has divided Indiana into 12 water management basins (fig. 1). As the Commission's technical staff, the Indiana Department of Natural Resources, Division of Water will characterize the availability of water on and below the land surface through a series of basin-wide investigations.

STUDY AREA

The Whitewater River Basin, which lies within the Miami River Basin of the Ohio River drainage system, drains 1329 sq. mi. (square miles) in southeast Indiana and 145 sq. mi. in southwest Ohio (fig. 2). Headwaters of the Whitewater River and its east fork are located in extreme southern Randolph County, Indiana and southwest Darke County, Ohio. The two rivers flow south and slightly west through Indiana's Wayne, Fayette, and Union Counties (fig. 2). In Franklin County, the Whitewater River bends southeast to join the east fork near Brookville, then exits Indiana in Dearborn County. About two miles into Ohio, the Whitewater River joins the southwest-flowing Great Miami River, which empties into the Ohio River at the intersection of the Indiana, Ohio, and Kentucky state lines.

The Whitewater River Basin drains an area characterized by rolling farmland and adequate to abundant water resources in the north, and hilly to rugged forested topography and less abundant water supplies in the south. The basin also contains Brookville Lake, Indiana's second deepest and third largest manmade reservoir.

Surface-water and ground-water supplies in the Whitewater River Basin serve a diversity of human needs, ranging from non-withdrawal uses such as in-stream recreation to large water withdrawals for public supply and industrial manufacturing. Demands on the water resource are expected to increase as both the economy and population continue to diversify.

PURPOSE AND SCOPE

This report describes the availability, distribution, quality, and use of surface and ground water in the Whitewater River Basin, Indiana (fig. 2). The second in a series of 12 regional investigations, the report is intended to provide background hydrologic information for water resources decision-making. Industrial, agricultural, commercial, recreational, governmental, and other public interests can utilize the summarized data in developing and managing the basin's water resource.

Because the report is written for a wide spectrum of readers, key technical words within the text are italicized the first time they appear, and where appropriate thereafter. Brief definitions are given in the glossary (app. 1).

Although some detailed data are included in technical appendices, this report is not intended for evaluating site-specific water resource development projects. Persons involved in such projects should contact the Division of Water for further information.

The Whitewater River Basin includes parts of two states (fig. 2), but all discussions in this report refer only to the Indiana portion. Unless otherwise indicated, discussions address only the areas of Indiana counties lying within the basin boundary (see table 1).

Much of the information presented has been summarized from data and maps obtained from state and federal agencies, from various technical reports, and from departmental communications. Some new ground-water quality data were collected during the

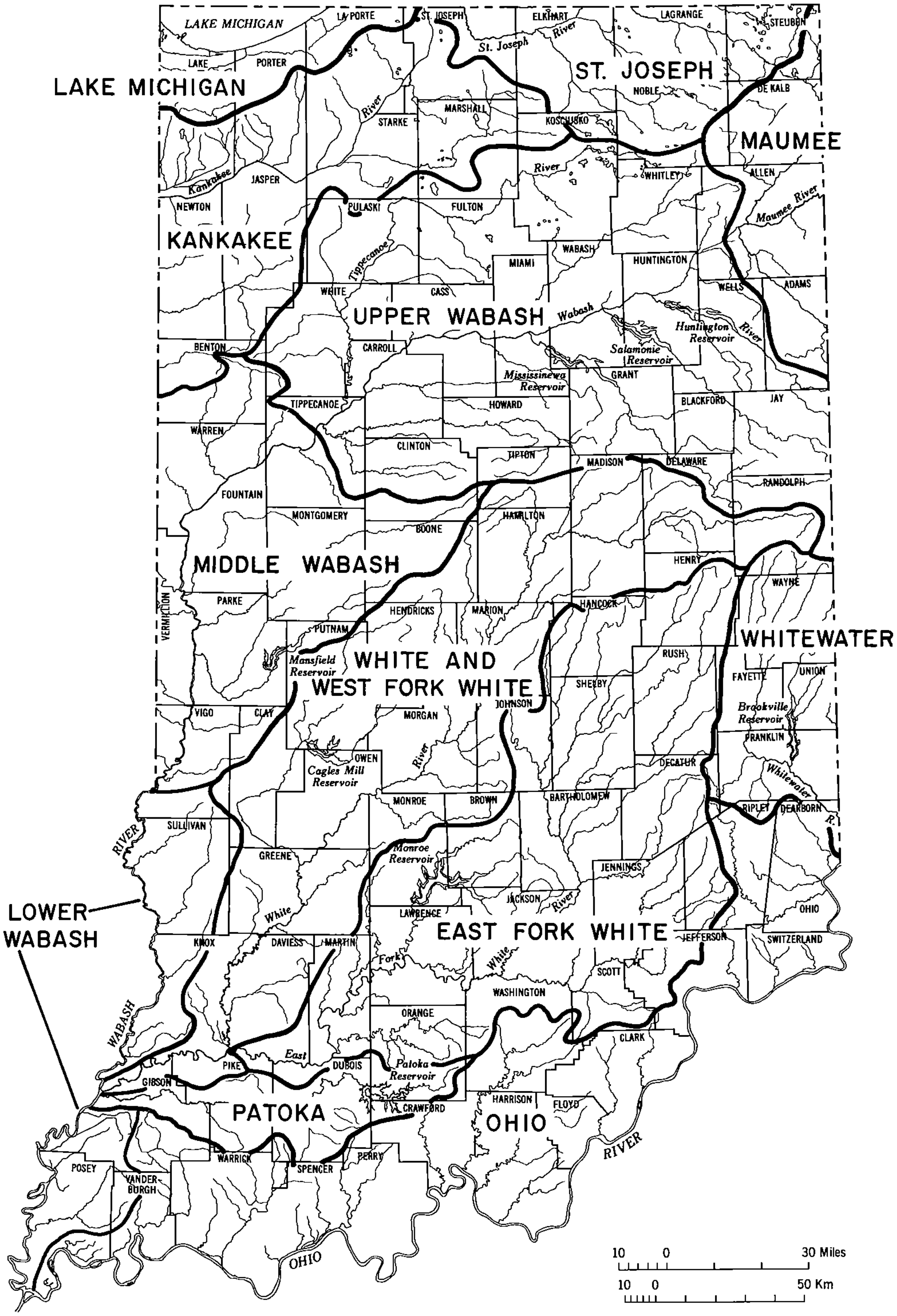

Figure 1. Indiana water management basins

investigation, and other hydrologic data have been compiled, analyzed, and interpreted.

PREVIOUS INVESTIGATIONS

To date, no comprehensive hydrologic studies of the Whitewater River Basin have been published. However, a work plan for structural engineering improvements in the East Fork Whitewater River Basin discusses proposed measures for watershed protection, flood prevention, recreation, and water management (State of Indiana and State of Ohio, 1971).

Four journal articles by Gooding (1963, 1966, 1973, and 1975) were particularly useful in describing the geology of the Whitewater Basin. A series of unpublished geologic quadrangle maps of southeast Indiana by Gooding, in addition to various reports by his co-workers and students at Earlham College, address both geologic and hydrogeologic characteristics of various areas within the basin. A report by Bruns (1976) summarizes the geology of Wayne County.

Maps by the Indiana Geological Survey (Burger and others, 1971; Gray, 1983; Gray and others, 1972, 1987) summarize surficial and bedrock geology. Malott (1922) provides a comprehensive treatment of regional *physiography*. Gruver (1984) characterizes *outwash* deposits along the Whitewater River.

Table 1. Indiana counties within the Whitewater River Basin

County	Total area (sq mi)	In-basin area (sq mi)	Percent of total basin area
Dearborn	307	42	3.16
Decatur	373	33	2.48
Fayette	215	197	14.82
Franklin	385	365	27.47
Henry	395	43	3.24
Randolph	454	84	6.32
Ripley	447	21	1.58
Rush	408	14	1.05
Union	163	128	9.63
Wayne	404	402	30.25
Total	3551	1329	100

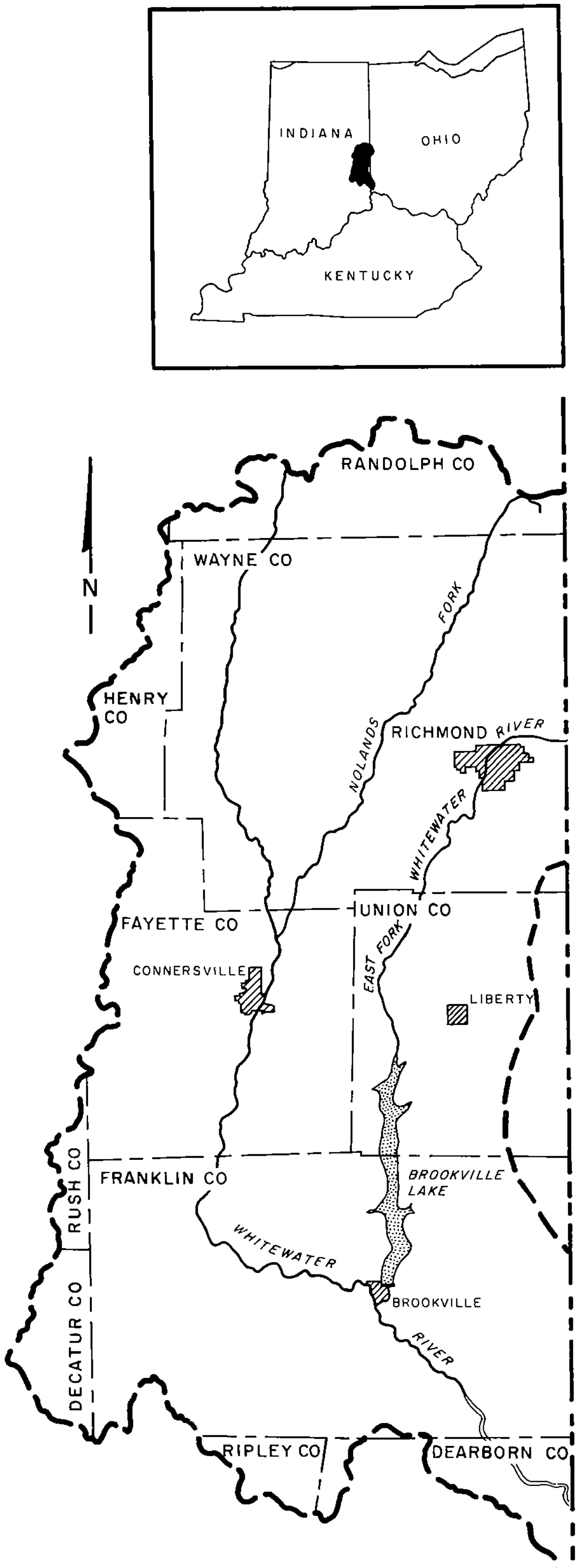

Figure 2. Whitewater River Basin in Indiana

A report by the Governor's Water Resource Study Commission (1980) assesses various aspects of water availability and use for 18 planning and development regions in Indiana. Most of the Whitewater Basin lies within two of these regions. A series of land use and planning maps for Fayette County (Smith, 1977) and Wayne County (Wayne County Resource Inventory Council, Inc., 1976) includes maps of bedrock and unconsolidated deposits, depth to bedrock, bedrock *topography*, and ground-water availability. Two atlases by Uhl (1969, 1973) outline the geography, population, climate, geology, ground-water and surface-water quality, ground-water availability, and water usage for Randolph and Henry Counties. Soil survey reports provide background information on the economy, land use, and water resources of Fayette and Union Counties (Alfred and others, 1960), Rush County (Brock, 1986), Decatur County (Shively, 1983), and Dearborn County (Nickell, 1981).

Sources utilized in the Whitewater study and those of potential use are listed in the ''Selected References.''

ACKNOWLEDGEMENTS

The following agencies provided valuable information and assistance during the preparation of this report: IDNR Divisions of Engineering, Fish and Wildlife, and the Indiana Geological Survey; Indiana State Board of Health; Indiana Department of Environmental Management; Indiana State Data Center; Indiana-American Water Company, Inc.; Earlham College; Purdue University; Indiana University; U.S. Geological Survey (Water Resources Division); U.S. Army Corps of Engineers (Louisville District); U.S. Environmental Protection Agency (Region 5); U.S. Department of Agriculture (Soil Conservation Service); and the National Oceanic and Atmospheric Administration (National Weather Service).

The authors also thank residents of the Whitewater River Basin for their cooperation during the 1985 ground-water sampling project. In addition, well-drilling contractors and county clerks contributed water-well and property records during the study.

The authors also extend their appreciation to support staff of the Division of Water, particularly word processing coordinator Amy S. James. The report was typeset by Margaret Petrey of the Division of Public Information and by temporary assistant Ruth Schuller. Temporary assistant Charmaine Balsley prepared the camera copy.

POPULATION AND ECONOMIC FRAMEWORK

POPULATION

In 1980, the estimated population of the Whitewater River Basin (145,542) comprised 2.7 percent of Indiana's total population (5,490,224). About 52 percent of the basin's population resided in Wayne County, and 31 percent resided in Fayette and Franklin Counties. Fig. 3 shows historic and projected changes in the basin population of these three counties, as well as of the less populous Union County. About 82 percent of the basin's land area in Indiana is occupied by these four counties (table 1).

Forty percent of the basin residents in 1980 lived within the corporate boundaries of Richmond (population: 41,349) in Wayne County and Connersville (population: 17,023) in Fayette County. The declines in city population since the 1960 census are evident in fig. 4.

App. 2 lists population estimates for county areas within the basin as well as census totals for entire counties. The appendix also lists in-basin population *projections* derived from county projections published by the Indiana State Board of Health (1983).

According to data of the Indiana State Board of Health, the population of Wayne County is expected to continue its decline for the next several decades as Richmond's population continues to decrease. In Franklin and Union Counties, population totals are expected to increase through at least the year 2000, but at different rates. The population of Fayette County

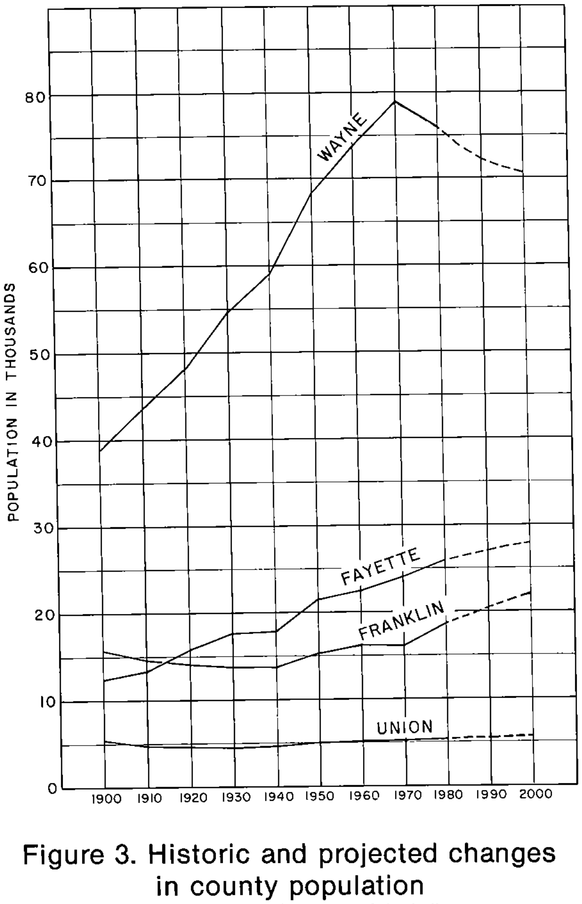

Figure 3. Historic and projected changes in county population

(Projections derived from data of the Indiana State Board of Health, 1983)

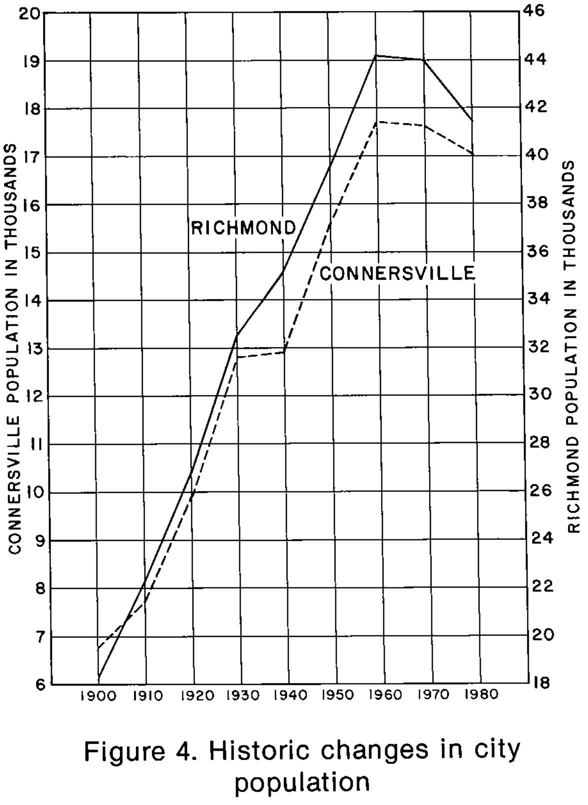

Figure 4. Historic changes in city population

is also expected to increase; however, provisional population *estimates* by the U.S. Census Bureau show a 2.8 percent decrease from 1980-86. In the other six counties listed in table 1, significant differences in projected and estimated countywide population appear to reflect changes in the population of cities lying outside the basin boundary.

ECONOMY[1]

Manufacturing, wholesale-retail trade, services, and government constitute the four largest non-farm employment classes in the Whitewater River Basin. In 1983, these four classes accounted for three-fourths of the total basin earnings.

Manufacturing employed 52 percent of Fayette County's non-farm working force in 1982 and accounted for 69 percent of the county's total earnings in 1983. In Wayne County, manufacturing employed 33 percent of the non-farm working force and accounted for 44 percent of the total earnings. Machinery, fabricated metal, and printing-publishing comprised the largest numbers of industries in these two counties. Farm employment exceeded non-farm employment in Franklin and Union Counties.

Manufacturing, government, and wholesale-retail trade acounted for 72 percent of Franklin County's total earnings; farming accounted for 4 percent. Farm earnings in Union County accounted for 20 percent of the total earnings, compared with 23 percent from government and 21 percent from wholesale-retail trade. Farm earnings in Fayette and Wayne Counties constituted less than one percent of the total county earnings, primarily due to the large amount of income from manufacturing.

Between 1972 and 1982, manufacturing decreased in all four counties, and particularly in Union County. However, at least 40 percent increases in non-farm wage and salary employment during this period have been observed within the following categories: mineral production and agricultural services-fisheries-forestry in Wayne County; finance-related, wholesale trade, and transportation-communication-public utilities in Franklin County; wholesale-retail trade in Union County; and finance-insurance-real estate in Fayette County.

Estimated *per capita income* in 1981 was highest for Wayne County ($7686) and Fayette County ($7162), and lowest for Franklin County ($6934) and Union County ($6866). Per capita income for these four counties averaged 85 percent of the statewide average. Unemployment in the four-county area averaged nearly 12 percent in 1984.

Table 2. Selected data from 1982 Census of Agriculture

Total area: refers to entire county, hence includes areas lying outside of the Whitewater Basin boundary; acreages from 1982 Census of Agriculture.

Land in farms, total cropland, total pastureland and total woodland: upper figures - 1982 data; lower figures - 1978 data.

County	Total area		Land in farms		Total cropland		Total pastureland[1]		Total woodland	
	Sq mi	Acres	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
Fayette	215	137,875	110,426	80.1	80,950	58.7	21,666	15.7	16,164	11.7
			109,378	79.3	81,409	59.0	22,074	16.0	16,340	11.9
Franklin	385	246,528	169,981	68.9	106,388	43.2	47,914	19.4	38,200	15.5
			158,030	68.2	104,255	42.3	52,442	21.3	35,570	14.4
Union	163	103,993	87,721	84.4	70,356	67.7	11,609	11.2	10,714	10.3
			86,718	83.4	69,063	66.4	13,791	13.3	10,570	10.2
Wayne	404	258,508	200,759	77.7	161,489	62.5	29,039	11.2	19,762	7.6
			204,527	79.1	162,817	63.0	35,837	13.9	22,676	8.8

[1] Includes cropland and woodland pastured.

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[1] Economic data, taken from Marcus (1985), are for entire counties, rather than just the portions lying within the Whitewater Basin. Only data for Wayne, Fayette, Union, and Franklin Counties are considered in the discussions of economy and land use.

LAND USE

The Whitewater River Basin constitutes 3.7 percent of Indiana's total land area. Cropland, pasture, and forest land are the major land uses in the basin (fig. 5). Table 2 shows selected data for these land use categories as reported in the 1982 Census of Agriculture (U.S. Bureau of Census, 1984a).

About three-fourths of the basin's land area is in farms (table 2). The average size of farms in the basin ranged from 163 acres in Franklin County to 259 acres in Union County (U.S. Bureau of Census, 1984a). Corn for grain, soybeans, and winter wheat were the major crops grown in the four-county area in 1983. Hogs, poultry, and beef cattle were the main livestock raised.

Cropland covers about two-thirds of the land area of Union and Wayne Counties (table 2). In these counties, forest land generally occurs as small parcels scattered among cropland (fig. 5). However, forested areas are more extensive in southern Fayette and western Franklin Counties, where silty, erosive soils and more rugged topography decrease the availability of prime cropland.

Residential and commercial development is most extensive in and near the cities of Richmond and Connersville (fig. 5). Brookville Lake, which covers 5,260 acres at summer pool elevation, is the largest body of water in the basin. The lake extends from west-central Union County to central Franklin County (fig. 5).

EXPLANATION

URBAN OR BUILT-UP LAND

11	Residential
12	Commercial and Services
13	Industrial
14	Transportaton, Communications, and Utilities
15	Industrial and Commercial Complexes
16	Mixed Urban or Built-up Land
17	Other Urban or Built-up Land

AGRICULTURAL LAND

21	Cropland and Pasture
22	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
23	Confined Feeding Operations
24	Other Agricultural Land

FOREST LAND

41	Deciduous Forest Land
42	Evergreen Forest Land
43	Mixed Forest Land

WATER

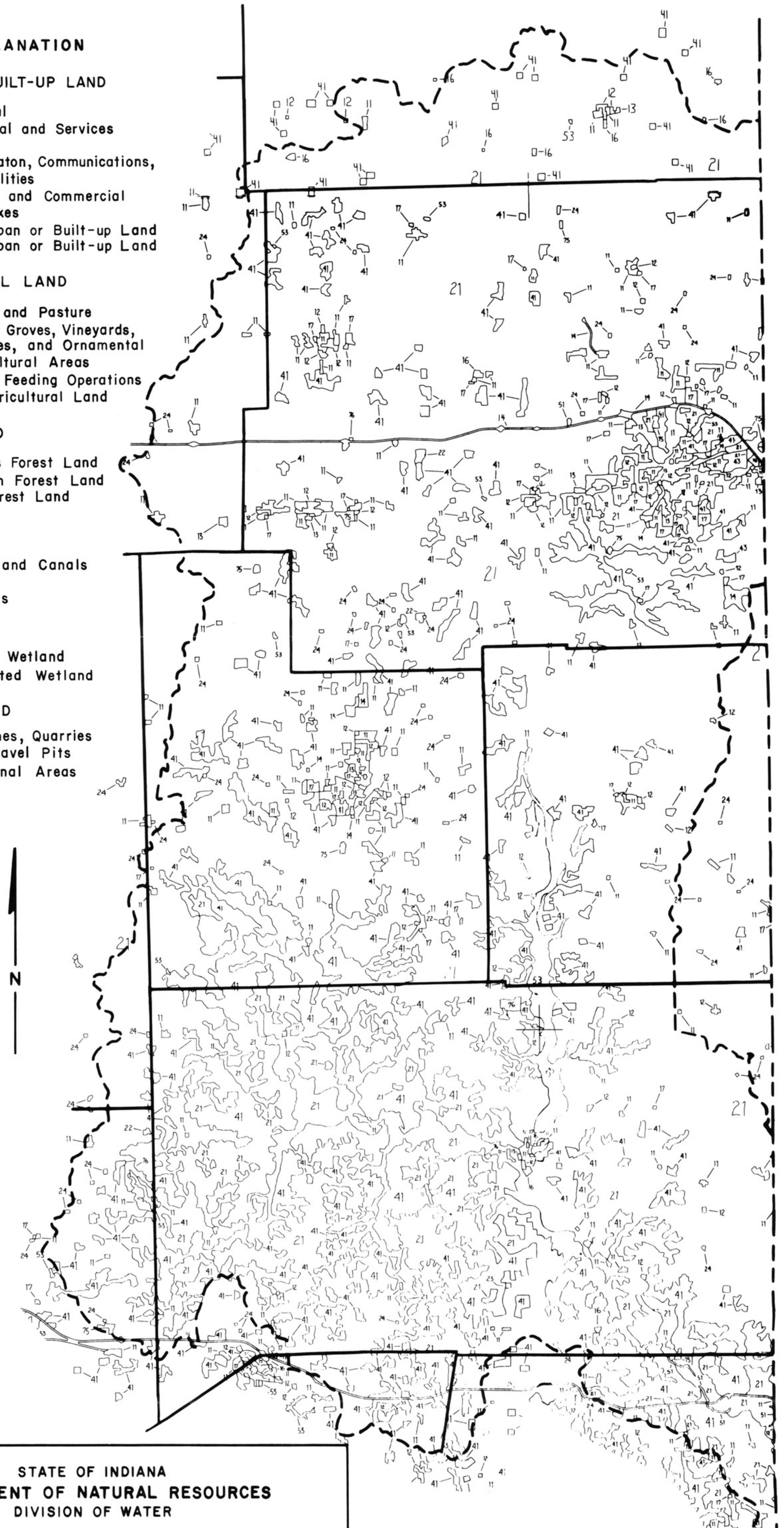
51	Streams and Canals
52	Lakes
53	Reservoirs

WETLAND

61	Forested Wetland
62	Nonforested Wetland

BARREN LAND

75	Strip Mines, Quarries and Gravel Pits
76	Transitional Areas



STATE OF INDIANA
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WHITEWATER RIVER BASIN

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
OPEN FILE 81-614-1
LAND USE SURVEY

Drafted by: Burton C. Daniels, Supv.
Connie K. Williams

SCALE AS SHOWN

5 0 5 10 MILES

5 0 5 10 KILOMETERS

DRAFTED 1987

Figure 5. Land use

GEOLOGIC FRAMEWORK

Geology, *topography*, and soils are major factors in determining the portion of precipitation which runs off the land to become surface water, as opposed to the portion which infiltrates into the soil and percolates through underlying materials to become ground water.

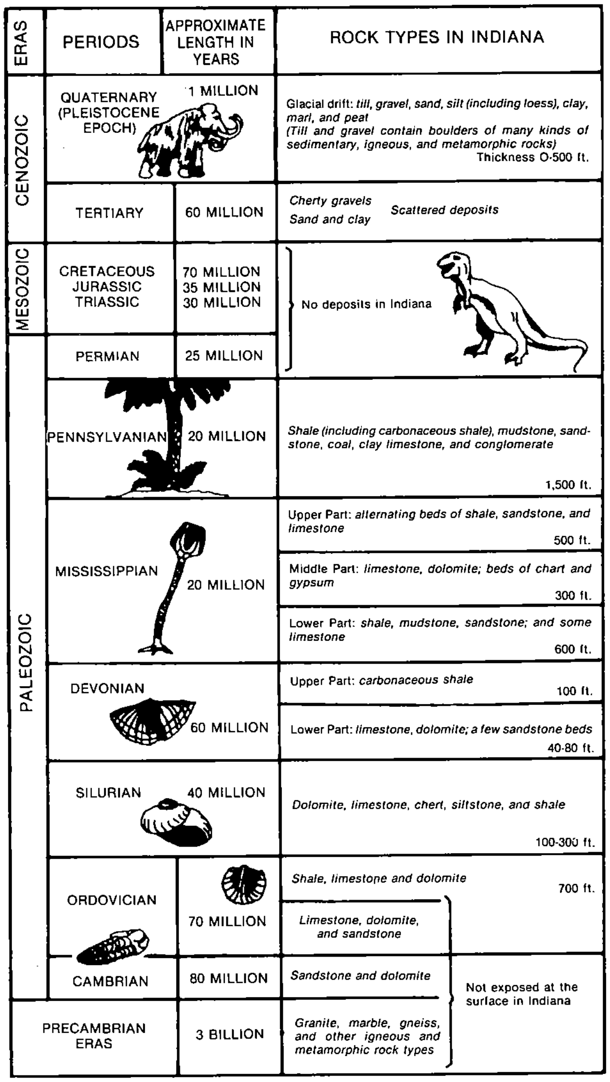
A generalized geologic timescale (fig. 6) illustrates the relationships of geologic periods and the rock types in Indiana associated with each period. During the Pleistocene Epoch (Ice Age), glacial lobes repeatedly entered Indiana. The glaciers entered the state from at least two directions: from the northeast out of the Lake Erie and Saginaw Bay Basins, and from the northwest out of the Lake Michigan Basin (fig. 7). In general, advancing glaciers scoured the land surface, while retreating glaciers left behind large deposits of *drift*. Erosion has subsequently modified the glacial deposits to produce existing landforms.

Glacial drift covers most of the Whitewater River Basin except for the southeastern portion. A complex series of glacial sediments has been deposited during repeated ice advances during both the older glacial periods and the most recent period, the Wisconsinan. (See fig. 7 for the approximate southernmost boundaries of the Wisconsinan and pre-Wisconsinan glaciations.)

The Wisconsinan glacial boundary, trending roughly northwest-southeast through Franklin and southwest Fayette Counties, divides the basin into two distinct portions (fig. 8). North of this glacial boundary, the bedrock is covered with variable but often thick layers of *lacustrine* clays, sands and gravels, and *tills*. The thickness of unconsolidated material is commonly 100 feet or more along the northern basin boundary.

Bedrock exposures north of the Wisconsinan boundary are rare, but in some areas of high bedrock, glacial meltwater and the larger post-glacial streams have cut their channels through the unconsolidated glacial materials and into bedrock. This is the case with the East Fork Whitewater River and its major tributaries. Bedrock exposures can be found as far north as the Richmond vicinity.

South of the Wisconsinan glacial boundary, thin layers of *residuum* and pre-Wisconsinan till overlie the bedrock surface. Bedrock exposures are common along valley walls. Depth to bedrock south of the Wisconsinan glacial boundary ranges from 5 to about 120 feet, as based on well drilling records. The thickest unconsolidated deposits are *alluvial* materials present in and along the Whitewater River valley.



ERAS	PERIODS	APPROXIMATE LENGTH IN YEARS	ROCK TYPES IN INDIANA	
CENOZOIC	QUATERNARY (PLEISTOCENE EPOCH)	1 MILLION	Glacial drift: *till, gravel, sand, silt (including loess), clay, marl, and peat* *(Till and gravel contain boulders of many kinds of sedimentary, igneous, and metamorphic rocks)* Thickness 0-500 ft.	
	TERTIARY	60 MILLION	*Cherty gravels* *Sand and clay*	*Scattered deposits*
MESOZOIC	CRETACEOUS JURASSIC TRIASSIC	70 MILLION 35 MILLION 30 MILLION	No deposits in Indiana	
PALEOZOIC	PERMIAN	25 MILLION		
	PENNSYLVANIAN	20 MILLION	*Shale (including carbonaceous shale), mudstone, sandstone, coal, clay limestone, and conglomerate* 1,500 ft.	
	MISSISSIPPIAN	20 MILLION	Upper Part: *alternating beds of shale, sandstone, and limestone* 500 ft.	
			Middle Part: *limestone, dolomite; beds of chart and gypsum* 300 ft.	
			Lower Part: *shale, mudstone, sandstone; and some limestone* 600 ft.	
	DEVONIAN	60 MILLION	Upper Part: *carbonaceous shale* 100 ft.	
			Lower Part: *limestone, dolomite; a few sandstone beds* 40-80 ft.	
	SILURIAN	40 MILLION	*Dolomite, limestone, chert, siltstone, and shale* 100-300 ft.	
	ORDOVICIAN	70 MILLION	*Shale, limestone and dolomite*	700 ft.
			Limestone, dolomite, and sandstone	Not exposed at the surface in Indiana
	CAMBRIAN	80 MILLION	*Sandstone and dolomite*	
PRECAMBRIAN ERAS		3 BILLION	*Granite, marble, gneiss, and other igneous and metamorphic rock types*	

Figure 6. Generalized geologic timescale
(*From Wayne, 1958b*)

TOPOGRAPHY AND SOILS

The Whitewater River Basin includes two contrasting physiographic regions. The northern third lies within the Tipton Till Plain, and the southern two-thirds is in the Dearborn Upland (fig. 9). The Tipton Till Plain has nearly flat to gently rolling topography characterized by slightly modified *ground moraine* and

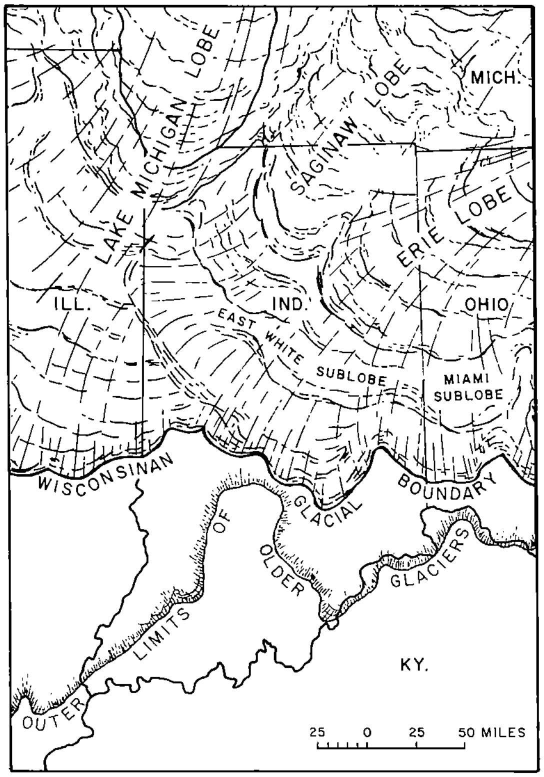


Figure 7. Extent of major ice lobes during Wisconsinan time in Indiana
(Modified from Wayne, 1965)

poorly developed *end moraines* formed by glaciation during Wisconsinan time. Wide stream valleys containing *valley-train* deposits of *outwash* are common.

The boundary between the Tipton Till Plain and the Dearborn Upland is gradational. As the drift thins near the Tipton Till Plain's southern margin, bedrock features become more apparent. The boundary placement shown on fig. 9 is within the transitional zone.

The rugged Dearborn Upland is dominated by slopes. Relatively little bottom land is present along the streams, and much of the upland surface has been *dissected*. The higher elevations are covered by glacial drift, which is much thinner south of the margin of Wisconsinan deposition (fig. 8), where only pre-Wisconsinan glacial deposits are present. Even these pre-Wisconsinan deposits are absent from the extreme southeastern part of the Whitewater Basin where bedrock is covered with thin residuum.

Evolution of Whitewater drainage patterns on the Tipton Till Plain is almost exclusively a post-glacial event, and bedrock topography has had little effect on drainage development. In contrast, drainage patterns in the southern part of the basin were less obviously rearranged by glaciation, and most of the dissection of bedrock predates the latest (Wisconsinan) glaciation in the basin.

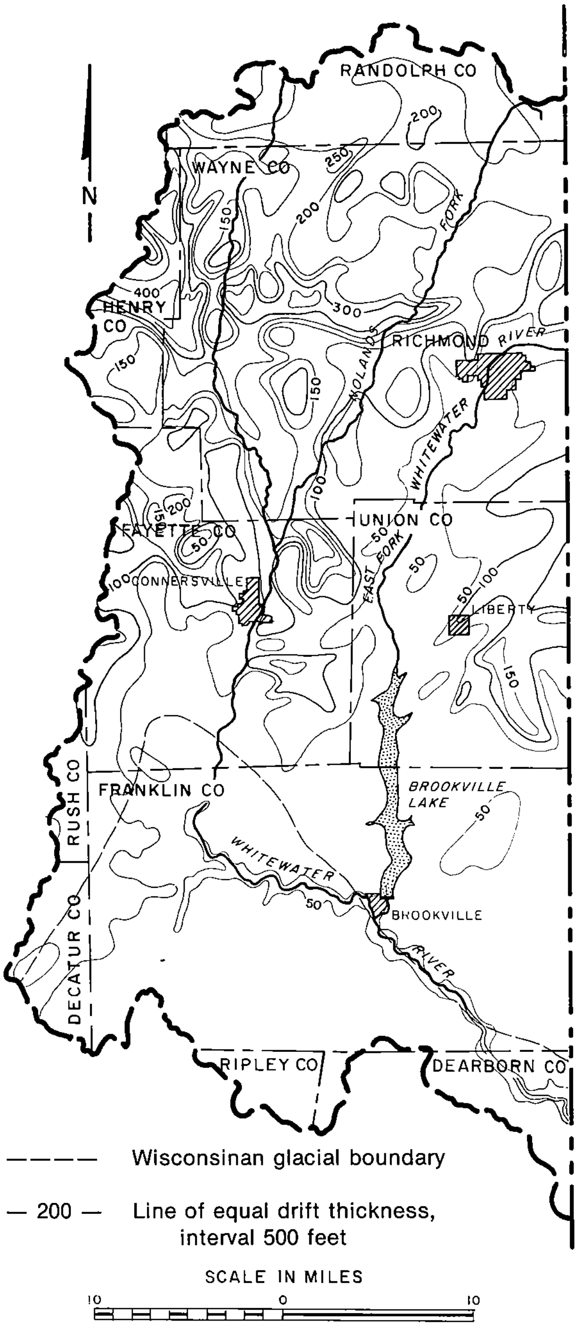
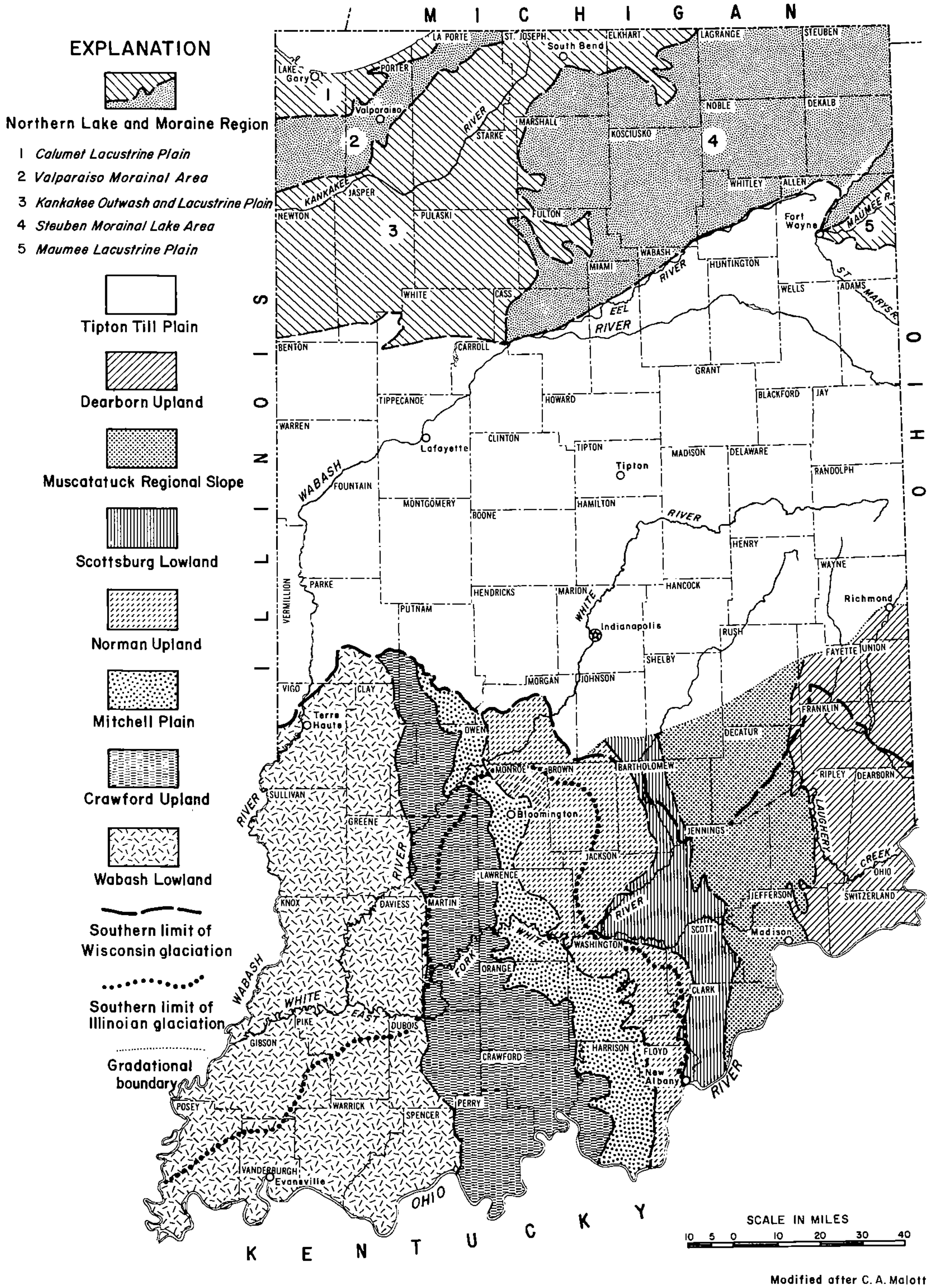


Figure 8. Drift thickness
(Modified from Gray, 1983)

Surface elevations often exceed 1,200 feet m.s.l. (mean sea level) in southeast Randolph and northeast



Modified after C. A. Malott
Compiled by W. J. Wayne

Figure 9. Physiographic regions in Indiana

Wayne Counties along the crest of the Knightstown Moraine (see fig. 11). The highest elevation in Indiana (approximately 1260 feet m.s.l.) is found within the Whitewater Basin in extreme northeastern Wayne County. The lowest elevation in the basin, which occurs where the Whitewater River leaves Indiana, is approximately 500 feet m.s.l. Maximum local relief occurs in southeast Franklin County, where bedrock ridges can rise more than 400 feet above the Whitewater River.

Soils in the Whitewater River Basin are closely related to geologic parent materials and topographic characteristics. *Loamy*, silty, and clayey soils are common in the northern two-thirds of the basin, according to maps by the Soil Conservation Service (1971, 1982). In these northern areas, soil parent materials consist of thin to moderately thick *loess* over loamy Wisconsinan glacial till. Representative soil associations include the Miami, Crosby, and Brookston in northern areas of the basin, and the Miami, Russell, Ragsdale, and Fincastle in central regions (app. 3).

Wisconsinan outwash and alluvial deposits constituting stream *terraces* and floodplains typically undergo *weathering* to form loamy, well-drained soils. Representative soil associations nearest the basin's major streams include the Fox, Ockley, Genesee, and Eel (app. 3).

Silty soils with *fragipans* occupy the rolling upland areas in the southwest part of the basin, primarily in western Franklin County. Soil parent materials consist of loess of variable thickness over weathered pre-Wisconsinan glacial till. Representative soil associations include the Cincinnati and Rossmoyne (app. 3).

Along valley sides of the Whitewater River and its major tributaries in Franklin County, shallow, stony, or clayey soils predominate. Parent materials are discontinuous loess over weathered Ordovician limestone and shale. Representative soil associations include the Fairmount, Eden, and Switzerland (app. 3).

SURFICIAL GEOLOGY

Four terrains, characterized by variations in surficial materials and the nature of potential aquifers, can be recognized in the Whitewater Basin (fig. 10; table 3). These include: (1) bedrock covered by a generally thin veneer of residuum and/or *colluvium*; (2) dissected pre-Wisconsinan tills; (3) Wisconsinan tills; and (4) valley-train deposits.

The far southeastern part of the basin consists of Ordovician bedrock covered by residual soils, colluvial debris, and loess (terrain 1; fig. 10). Thickness of this cover is variable, but in only a few places does it exceed 10 feet. The cover consists mainly of oxidized clay-rich soils that locally contain weathered fragments of the underlying parent rock. Sand and gravel deposits that have significant potential as *aquifers* are not present within this material. Areas of residual soils occur mainly in Dearborn County near the mouth of the Whitewater River, but small areas also occur along the margins of the valleys of the Whitewater River and its tributaries in Franklin, Union, and Wayne Counties.

The southwestern part of Franklin County is underlain by loess-covered tills of pre-Wisconsinan age (terrain 2; fig. 10). At least four till units, separated by stratified sediments, organic silts, or *paleosols* have been identified in northern Franklin County (Gooding, 1963, 1966). These deposits have traditionally been considered to be Illinoian in age, but recent work in Decatur County (N. K. Bleuer, unpubl.) suggests that the drifts are significantly older. The loess, of Wisconsinan age and older, overlies a paleosol developed on loamy to pebbly silts.

The unconsolidated deposits in terrain 2 normally do not exceed 50 feet in thickness, and form a gently rolling land surface except where dissected by stream valleys of the Whitewater system. Beds of sand and gravel, normally less than 5 feet thick, occur within the glacial material. The lateral extent and degree of interconnection of these beds are unknown at this time. Because the sands and gravels are thin, their potential as aquifers is limited.

Most of the northern two-thirds of the basin is covered by tills of Wisconsinan age (terrain 3; fig. 10) that overlie older till units. The southern boundary of Wisconsinan deposits extends through Decatur, Fayette, and Franklin Counties (fig. 10). The boundary has a V-shaped configuration, opening to the south, that may reflect the juncture of the *terminal moraines* of the East White Sublobe moving from the west and the Miami Sublobe moving from the east (fig. 7).

The Wisconsinan margin on the west side of the basin is marked by the massive Shelbyville *Moraine* (fig. 11) rising as much as 70 feet above the older, more level plain to the south. The Wisconsinan margin is discontinuous and less conspicuous on the east side of the basin where it is cut by tributaries of the Whitewater River. The surface of the Shelbyville Moraine is mildly *hummocky* and marked by numerous closed depressions.

The Knightstown Moraine (fig. 11) forms the drainage divide between the Whitewater River Basin

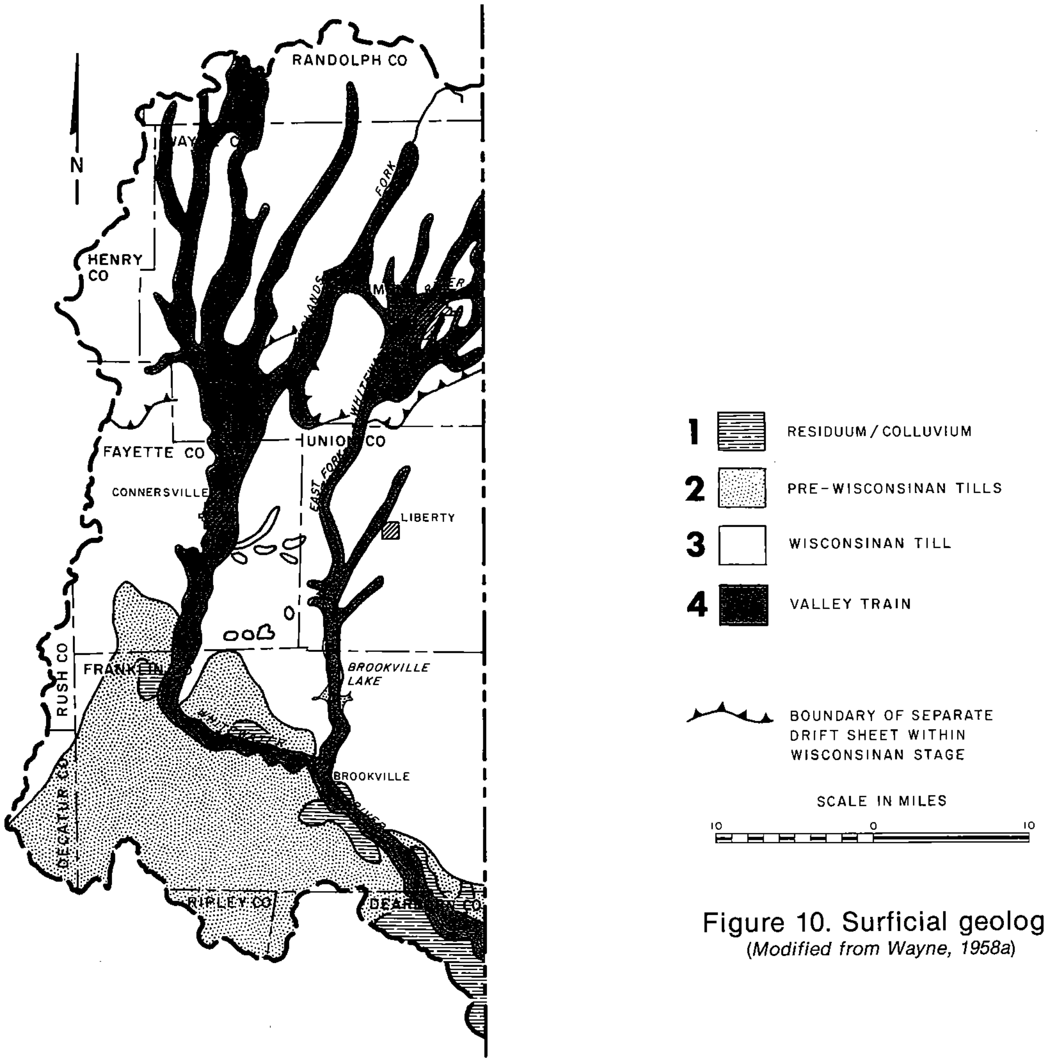


Figure 10. Surficial geology
(Modified from Wayne, 1958a)

Table 3. Types of unconsolidated surficial materials

Map region[1]	Name	Dominant material	Accessory materials	Nature of aquifers
1	Residuum/colluvium	Oxidized loam to clay	——	Minimal
2	Pre-Wisconsinan tills	Oxidized pebbly loam	Sand and gravel, silt (loess)	Thin beds (~1 ft) of unknown lateral extent
3	Wisconsinan till	Pebbly loam	Sand and gravel, clay	Moderately thick beds (~10 ft) of unknown lateral extent
4	Valley train	Sand and gravel	Pebbly loam, clay	Linear sand bodies commonly in excess of 10 ft thick

[1] Numbered map regions are shown in fig. 10.

to the south and the White River system to the north. The moraine is conspicuously bouldery in a manner similar to the boulder belt derived from the Miami Sublobe in Ohio.

Several tills of Wisconsinan age have been identified in the Whitewater River Basin (Gooding, 1963, 1966, 1975). The tills can be distinguished on the basis of interlayered, stratified sediments, especially organic silt beds, which apparently were deposited during ice retreats.

Two late Wisconsinan tills, the Shelbyville and Fayette Tills, record two glacial advances to the Wisconsinan margin at about 21,000 and 20,000 years before present, respectively. In southeast Fayette and eastern Franklin County, the Fayette Till overlies a paleosol that is the subsurface continuation of the soil developed on the older drifts south of the Wisconsinan margin. In the northern part of Union County, however, the Fayette Till is separated from the paleosol by numerous other till units. These units have been interpreted as early Wisconsinan in age, but this cannot be proved in the absence of a regional, physically defined *stratigraphy*.

Some of the till units of terrain 3 may have regional significance, and laterally extensive aquifers may occur where tills are separated by sand and gravel beds. Other tills, however, are probably of local significance only, and interbedded sands and gravels would be of limited lateral extent. Of more significance, however, is the fact that Wisconsinan till units as well as multiple older till units occur together in a complex vertical succession commonly no thicker than 60 feet.

Sand and gravel beds within the Wisconsinan tills are normally less than 10 feet thick. These beds are significantly thicker than sand and gravel beds in older till units, which suggests greater lateral extent and more potential as aquifers. In addition, because two or more such beds commonly are stacked within a till sequence, the total thickness of potential aquifers in a given area is increased.

The thickest deposits of sand and gravel in the basin occur as valley-train deposits within the valleys of the Whitewater River and its tributaries, especially the East Fork Whitewater River (terrain 4; fig. 10). Valley-train deposits north of the Wisconsinan terminal moraine probably originated as intra-ice drainageways and apparently formed during the same period of time as the surrounding till. These deposits consist of poorly sorted sand and gravel *intercalated* with till beds of variable thickness and lateral extent. The uppermost unit of the deposits within the valleys most commonly is a till bed that may be as much as 15 feet thick near the margins of the valleys and in their upper reaches.

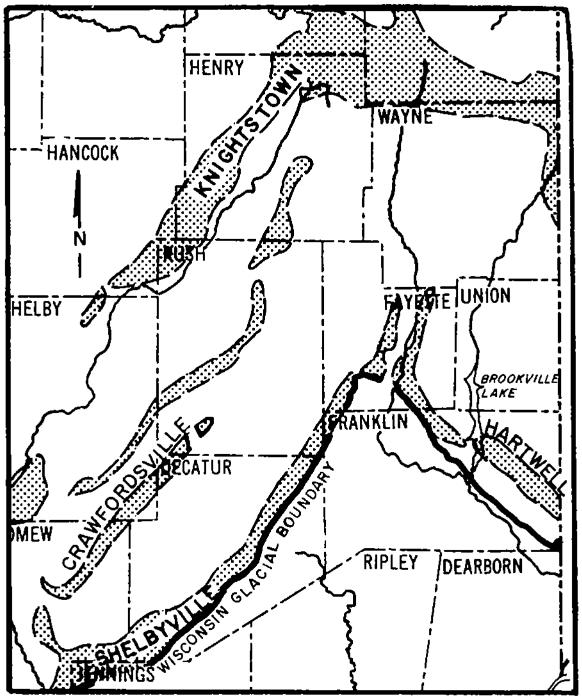


Figure 11. Glacial moraines
(Modified from Wayne, 1965)

Valley-train deposits south of the Wisconsinan terminal moraine are finer grained and better sorted, and occur in more consistent vertical sequences than those to the north. Sand and gravel units are much thicker, and they contain no till beds. Although lacustrine silts and clays occur in these deposits, the degree to which they affect aquifer properties is not known.

BEDROCK GEOLOGY

The Whitewater River Basin sits along the crest of the Cincinnati Arch, a major geologic structure in the Midwest (fig. 12). Hence, younger rocks at the bedrock surface occur along the margins of the Whitewater Basin and older rocks occur in the center. Rocks at the basin margin to the west, north, and north-

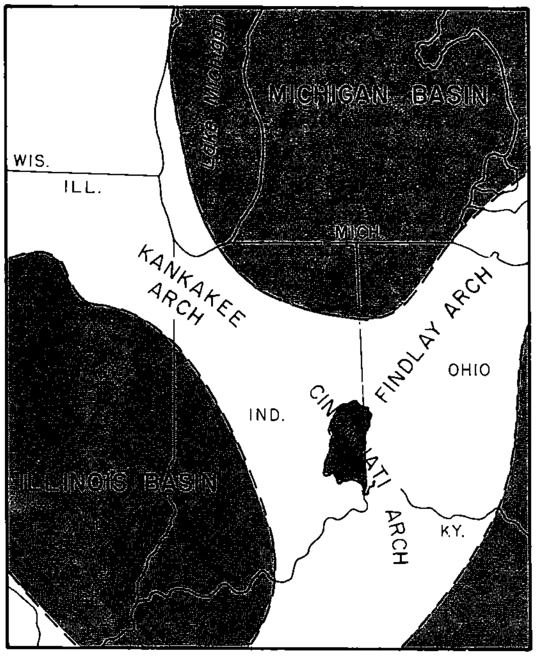


Figure 12. Regional geologic structure

east are of Silurian age (fig. 13). The large central area of the basin is underlain by Ordovician rocks, the oldest of which are limited to a small downstream area of the basin (fig. 13). Table 4 summarizes the characteristics of exposed Silurian and Ordovician rock units, while app. 4 describes the units in more detail.

Still older Ordovician and Cambrian rocks are present in the subsurface above the basement complex of *igneous* and *metamorphic* rocks. A brief description of these rocks is included in app. 5, but the likelihood of successfully developing water wells in them is considered small.

The highest bedrock elevation in the Whitewater River Basin exceeds 1050 feet m.s.l. and occurs in the northeast portion of the basin near the Wayne-Randolph county line (pl. 1). Despite its elevation, this bedrock high is buried by more than 100 feet of glacial deposits. The lowest elevation of the bedrock surface as based on drilling records is approximately 440 feet m.s.l. and occurs in Dearborn County where the Whitewater River valley leaves Indiana (pl. 1).

Table 4. Characteristics of exposed stratigraphic units

		Unit	Thickness (feet)	Description
Silurian System		Salamonie Dolomite	40	Gray and tan cherty limestone, argillaceous in lower part to south
		Brassfield Limestone	0 - 18	Yellowish-brown, salmon or gray, medium- to coarse-grained fossiliferous limestone
Ordovician System	Maquoketa Group	Whitewater Formation	90	Upper part - argillaceous fossiliferous limestone interbedded with calcareous shale; Saluda Dolomite Member (lower part) - varicolored fine-grained dolomite that includes a thin coralline zone
		Dillsboro Formation	300	Thin-bedded fossiliferous limestone alternating with calcareous shale
		Kope Formation	250 - 550	Bluish- to brownish-gray shale including about 5 percent discontinuous beds of fossiliferous limestone

Perhaps the most interesting feature of the bedrock surface is the large *buried valley* in western Wayne County and eastern Henry County. This valley, now filled with 200-300 feet of glacial sediment, appears to have been the major pre-glacial drainageway in the northern basin area. Originally carrying a northwest-flowing stream, the valley was blocked by ice and filled with glacial drift. After glacial retreat, the modern south-flowing drainage was established on this depositional surface.

Most wells in the northern parts of the basin are completed in the glacial materials overlying the bedrock surface. Depth to bedrock data is therefore sparse and the bedrock surface cannot be depicted in detail as it is in southern areas of the basin. The lack of bedrock data is especially acute in areas of the deeply buried valley because most wells encounter water-bearing zones above bedrock. Therefore, the buried valley is defined largely on the basis of seismic data provided by the Indiana Geological Survey rather than on well data. Deep drilling would help define this and other buried valleys in northern parts of the basin.

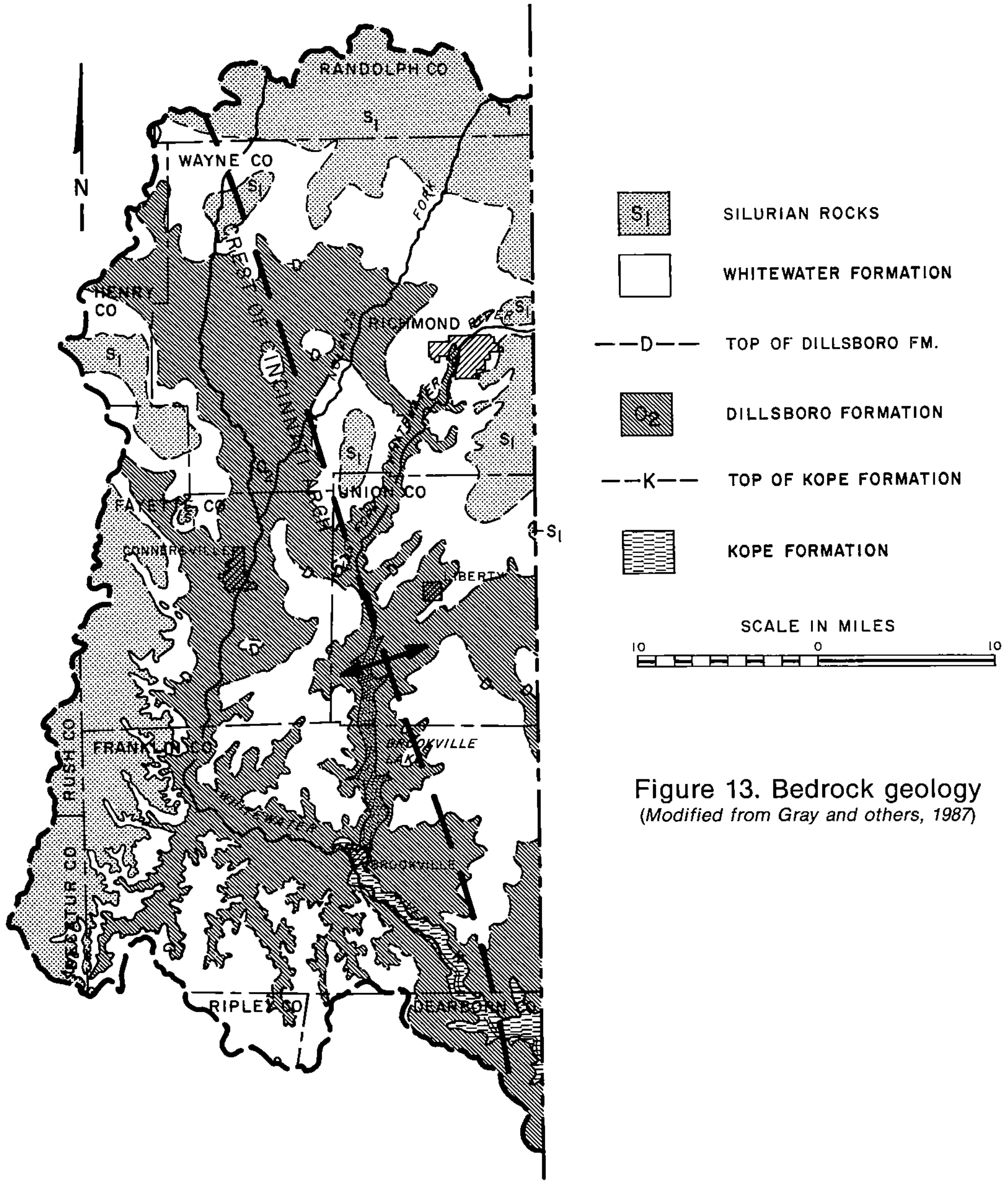


Figure 13. Bedrock geology
(Modified from Gray and others, 1987)

BASIN HYDROLOGY

CLIMATE

The climate of east-central Indiana, classified as temperate continental, is characterized by warm, occasionally hot summers, cold winters, and considerable daily variations in temperature.

East-central Indiana frequently encounters *cyclonic* disturbances generated by the interactions of northeast-moving tropical and south-moving arctic air masses. Locally heavy amounts of rain or snow associated with the eastward passage of low pressure centers are often recorded, although basinwide, precipitation is fairly evenly distributed throughout the year.

Spring is generally mild and rather wet, and is often characterized by periods of prolonged rainfall over large areas. Summers have some extended periods of hot and sultry weather alternating with more pleasant conditions. Summer rainfall often occurs as local thunderstorms of short duration. Autumn is relatively dry and mild, and winter is characterized by short periods of freezing weather alternating with several days of milder temperatures.

Other climatic characteristics of the Whitewater Basin include moderate to high humidities, light to moderate winds (typically from the southwest), and a large proportion of partly cloudy to cloudy days interspersed with clear days. The frost-free *growing season* for most crops generally extends from late April or early May through middle or late October. Severe local storms generated by daytime convection or by the passage of cold fronts are most common in spring and early summer. These storms may produce frequent lightning, strong winds, and large hail, as well as occasional funnel clouds and tornadoes.

Although parameters such as wind, solar radiation, relative humidity, and soil temperature constitute an area's climate, only air temperature and precipitation will be summarized here. Temperature defines the growing season and largely controls the process of *evapotranspiration*, which consumes about 70 percent of the average annual precipitation in east-central Indiana. Precipitation is the source of fresh water either on the surface or in the subsurface of the earth. The amount, distribution, and type of precipitation help to define a region's water supply and its hydrologic regime.

Climatic Data

Climatic data in the Whitewater River Basin are gathered as part of several statewide networks operated by federal and state agencies. The most extensive networks are operated and maintained by the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA). Climatic data are collected at NWS cooperative observer stations operated by water and wastewater utilities, municipalities, or private citizens.

Additional precipitation data in the basin are gathered by about seven amateur radio operators as part of a statewide volunteer network which aids the NWS river and flood forecasting program. Other precipitation data are collected by the U.S. Army Corps of Engineers, U.S. Geological Survey, and the Indiana Department of Natural Resources, Division of Water for hydrologic and hydraulic studies and daily water management operations.

Table 5 lists climatic stations in and within 10 miles of the Whitewater River Basin. Locations of stations lying within the basin boundary are shown in fig. 14. Amateur radio stations are neither tabulated nor mapped, because the statewide network changes frequently.

The majority of temperature and precipitation data from NWS stations are published by NOAA in monthly and annual summaries. However, measurements of temperature, hourly rainfall, pan evaporation, relative humidity, and soil temperature at the Liberty station remain unpublished. Temperature and precipitation data from seven of the NWS stations in table 5 are periodically published in climatic summaries (National Oceanic and Atmospheric Administration, 1976, 1982a, 1983, 1985). Data from networks operated by the Corps of Engineers, U.S. Geological Survey, and Division of Water are not published but are available at each office.

The distribution of National Weather Service stations, the availability of published and unpublished precipitation data, and the availability of published climate summaries are sufficient for the Division of Water's present and anticipated climatic data needs in the Whitewater Basin.

Temperature[2]

Normal annual temperature within the Whitewater Basin averages 51° F (degrees Fahrenheit) and ranges from near 50° F in northernmost areas to 52° F in the far southwest near Greensburg. Normal seasonal

Table 5. Climatic stations in and near the Whitewater River Basin

Agency: National Weather Service (NWS); U.S. Army Corps of Engineers (USCE); Division of Water (DOW); U.S. Geological Survey (USGS).

Element: Precipitation (P); Temperature (T); Additional parameters (A) - e.g., evaporation, relative humidity, soil temperature.

Gage: Recording precipitation gage (R) - data automatically recorded at selected intervals; non-recording precipitation gage (NR) - data manually collected once daily.

Publication: Precipitation and/or temperature data published monthly and annually by the National Oceanic and Atmospheric Administration (p); unpublished (up).

Station	County	Agency	Element	Gage	Publication
Alpine 2NE	Fayette	NWS	P	R	p
Batesville Waterworks[1]	Ripley	NWS	P	R	p
Brookville	Franklin	NWS	P,T	NR	p
Brookville Lake (at dam)	Franklin	USCE	P,T	R	up
Brookville (at mainstem gage)	Franklin	USGS	P	R	up
Cambridge City	Wayne	NWS	P,T	NR	p
Franklin 1	Franklin	DOW	P	NR	up
Franklin 2	Franklin	DOW	P	NR	up
Greensburg[1]	Decatur	NWS	P,T	NR	p
Henry 1[1]	Henry	DOW	P	NR	up
Lewisville[1]	Henry	NWS	P	R	p
Liberty	Union	NWS	P (T,A)	NR (R)	p (up)
New Castle[1]	Henry	NWS	P,T	NR	p
Richmond Waterworks	Wayne	NWS	P,T	R,NR	p
Ripley 1[1]	Ripley	DOW	P	NR	up
Rushville Sewage Plant[1]	Rush	NWS	P,T	NR	p
Springersville	Fayette	USCE	P	R	up
Winchester Airport[1]	Randolph	NWS	P,T	NR	p

[1] Within 10 miles of basin boundary.

temperatures average 50° F in spring (March-May), 71° F in summer (June-August), 53° F in autumn (September-November), and 28° F in winter (December-February).

January, the coldest month, has an average monthly temperature of 26° F and an average daily minimum of 16° F. In contrast, the warmest month of July has an average temperature of 73° F and an average daily maximum of 85° F.

Diurnal temperature variations (the difference between normal daily maximums and minimums) typically range from about 19° F in winter to 25° F in summer and fall. Extreme temperature readings recorded for the period 1951-80 range from -28° F (Cambridge City, 1963) to 104° F (Brookville, 1951).

The growing season for most crops ranges from 165 to 175 days, although the extreme southwestern part of the basin has a slightly longer season. Vegetative cover, soils, impervious surfaces, and obstructions to wind are factors which can influence climatic features, particularly the length of growing season. However, these factors typically affect climate only over small areas.

Precipitation

Normal annual precipitation in the basin averages about 40 inches and ranges from less than 38 inches in northernmost areas to more than 40 inches in far southwestern regions.

Although variations in annual precipitation totals generally are not extreme, yearly amounts recorded

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[2] Temperature and precipitation data discussed here are taken or derived from data found in several NOAA publications (National Oceanic and Atmospheric Administration, 1976, 1982a, 1982b, 1983, and 1985). Data from Brookville, Cambridge City, and Richmond Waterworks for the Period 1951-80 were used to obtain the various in-basin averages and extremes, while nearby station data were used to define temperature and precipitation ranges from the northernmost to southernmost basin boundary.

EXPLANATION

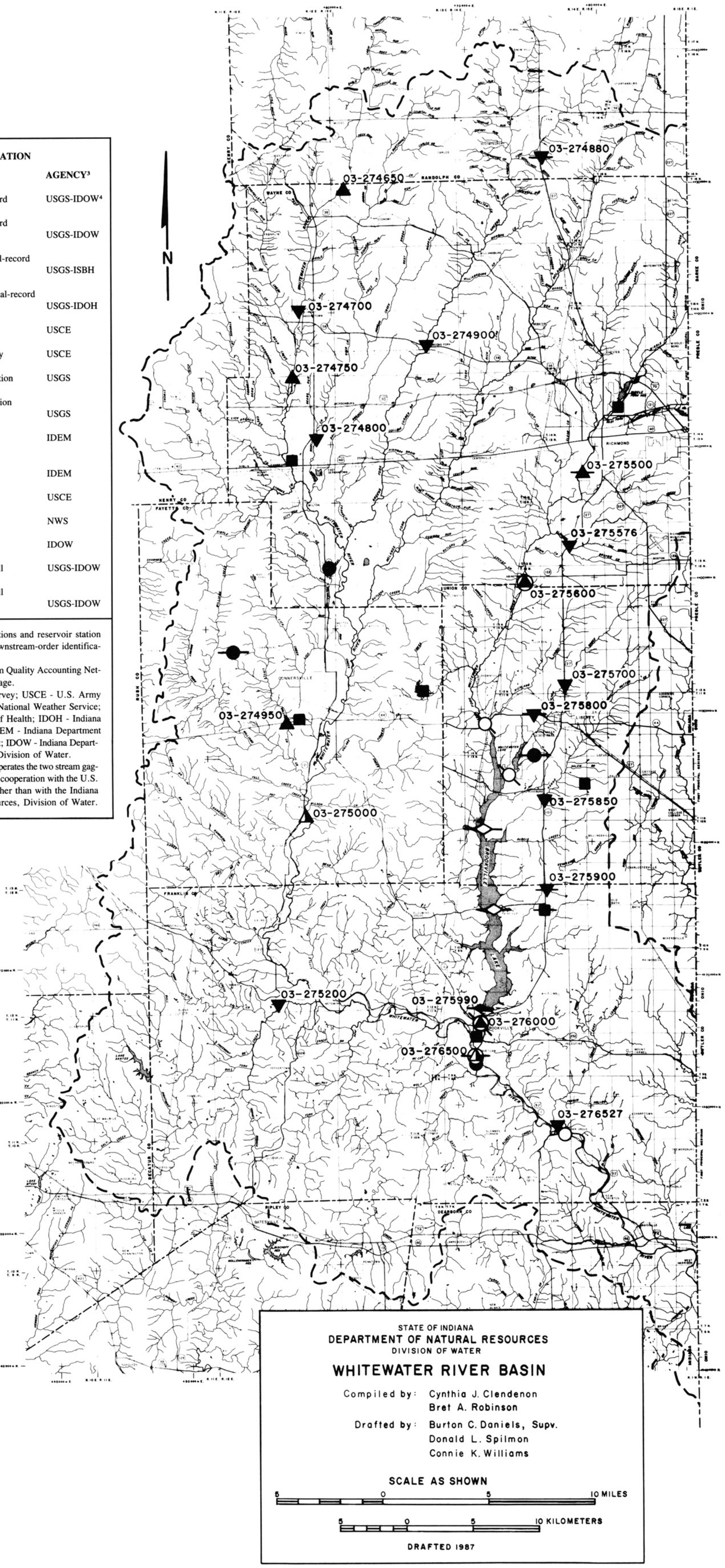
SYMBOL[1]	GAGE TYPE[2]	AGENCY[3]
▲	Continuous-record	USGS-IDOW[4]
-▲-	Continuous-record (inactive)	USGS-IDOW
▼	Low-flow partial-record (inactive)	USGS-ISBH
-▼-	Crest-stage partial-record (inactive)	USGS-IDOH
◆	Reservoir stage	USCE
-◇-	Reservoir quality	USCE
◭	NASQUAN Station	USGS
-◭-	NASQUAN station (inactive)	USGS
○	Stream quality	IDEM
-○-	Stream quality (inactive)	IDEM
⌀	Stream quality	USCE
■	Climatic	NWS
-■-	Precipitation	IDOW
●	Observation well	USGS-IDOW
-●-	Observation well (inactive)	USGS-IDOW

[1] Symbols for stream-flow stations and reservoir station are followed by an 8-digit downstream-order identification number.

[2] NASQUAN - National Stream Quality Accounting Network; at continuous-record gage.

[3] USGS - U.S. Geological Survey; USCE - U.S. Army Corps of Engineers; NWS - National Weather Service; ISBH - Indiana State Board of Health; IDOH - Indiana Department of Highways; IDEM - Indiana Department of Environmental Management; IDOW - Indiana Department of Natural Resources, Division of Water.

[4] The U.S. Geological Survey operates the two stream gaging stations near Brookville in cooperation with the U.S. Army Corps of Engineers rather than with the Indiana Department of Natural Resources, Division of Water.



STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

WHITEWATER RIVER BASIN

Compiled by: Cynthia J. Clendenon
Bret A. Robinson

Drafted by: Burton C. Daniels, Supv.
Donald L. Spilmon
Connie K. Williams

SCALE AS SHOWN

5 0 5 10 MILES

5 0 5 10 KILOMETERS

DRAFTED 1987

Figure 14. Location of hydrologic data collection stations

Table 6. Monthly and annual precipitation at selected probability levels

{From National Oceanic and Atmospheric Administration, 1985, 1983; all precipitation amounts in inches; values were determined from the incomplete gamma distribution; dash indicates no published data.}

Station 1: Richmond Waterworks.
Station 2: Cambridge City.
Station 3: Brookville.

Probability level[1]	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
.10	1	4.33	4.33	5.74	6.24	7.00	7.51	7.31	6.11	5.38	4.58	4.94	5.38	46.86
	2	4.38	4.53	5.78	7.01	6.89	7.49	7.80	6.04	5.34	4.98	5.49	5.53	47.84
	3	5.26	4.69	6.26	6.25	7.53	6.71	7.26	6.90	5.29	4.94	4.99	5.58	47.93
.30	1	3.12	2.74	3.99	4.45	4.97	5.13	4.88	3.98	3.29	3.01	3.49	3.52	—
	2	3.17	2.81	4.07	4.82	4.99	5.10	5.07	4.07	3.30	3.08	3.77	3.52	—
	3	3.46	2.91	4.33	4.39	5.19	4.92	5.51	4.51	3.30	3.14	3.42	3.56	—
.50	1	2.43	1.90	3.01	3.44	3.82	3.81	3.55	2.84	2.21	2.16	2.67	2.52	38.37
	2	2.48	1.91	3.10	3.61	3.90	3.78	3.60	2.99	2.24	2.09	2.82	2.45	39.30
	3	2.48	1.99	3.25	3.35	3.88	3.88	4.48	3.22	2.26	2.19	2.55	2.48	40.22
.70	1	1.85	1.26	2.21	2.59	2.87	2.74	2.49	1.94	1.40	1.49	1.99	1.74	—
	2	1.89	1.23	2.31	2.62	2.98	2.71	2.45	2.12	1.44	1.34	2.04	1.63	—
	3	1.71	1.29	2.37	2.49	2.82	3.01	3.58	2.20	1.47	1.46	1.84	1.66	—
.90	1	1.19	0.62	1.33	1.64	1.80	1.60	1.39	1.02	0.64	0.80	1.24	0.93	30.98
	2	1.23	0.58	1.42	1.55	1.94	1.57	1.28	1.20	0.68	0.63	1.20	0.81	31.84
	3	0.92	0.61	1.41	1.53	1.66	2.00	2.52	1.17	0.70	0.73	1.08	0.83	33.38

[1] Probability that precipitation will be equal to or greater than the indicated amount.

Table 7. Normal monthly and annual precipitation, 1951-80

{Data from National Oceanic and Atmospheric Administration, 1982a; values in inches.}

Month	Richmond Waterworks	Cambridge City	Brookville
January	2.63	2.68	2.85
February	2.25	2.30	2.39
March	3.33	3.40	3.60
April	3.74	4.01	3.68
May	4.17	4.21	4.32
June	4.26	4.24	4.17
July	4.03	4.17	4.73
August	3.28	3.37	3.71
September	2.69	2.70	2.70
October	2.48	2.52	2.58
November	2.93	3.14	2.84
December	2.91	2.89	2.92
Annual	38.70	39.63	40.49

during very dry and wet years have ranged from about 29 inches to nearly 50 inches. There is a 90 percent probability, however, that annual precipitation over a long period of time will average at least 31 inches in northern areas of the basin to 33 inches in southern areas. Annual and monthly precipitation amounts at selected probability levels are given in table 6 for Richmond, Cambridge City, and Brookville.

Monthly precipitation totals for the period 1951-80 have varied from zero to nearly 12 inches, but monthly normals range from about 2 to 5 inches (table 7). Seasonal normals average roughly 8 inches in fall and winter, and between 11 and 12 inches in spring and summer.

Approximately 21 inches, or 54 percent of the average annual precipitation, falls from May through October, the growing season for most crops. During this six-month period, monthly amounts average slightly less than 3.6 inches. In any one crop season, however, extended periods of little to no rainfall may occur.

Daily precipitation is quite variable due to the periodic passage of frontal systems, and 24-hour amounts for the period 1951-80 have ranged from zero to more than 5 inches. Although precipitation events are generally interspersed among several dry days, daily normals fall between 0.08 and 0.14 inch, as determined from monthly normals at Indianapolis (National Oceanic and Atmospheric Administration, 1982b).

Average annual snowfall in the basin ranges from about 24 inches in northern areas to 19 inches in the south. Annual snowfall averages 22 inches basinwide, which is roughly equivalent to 2.2 inches of rain. On average, snowfall in the basin accounts for less than 6 percent of the normal annual precipitation.

Evapotranspiration

The amount of water lost through evaporation from the soil and surface-water bodies and by plant transpiration is referred to as evapotranspiration. By far the largest consumptive use of water in the basin, evapotranspiration consumes about 70 percent of the average annual precipitation (J. Newman, Purdue University, personal communication, 1987).

Newman (1981) has used the Thornwaite method as described in Palmer and Havens (1958) to estimate annual evapotranspiration for nine regions in Indiana. According to Newman's regional estimates based on 1941-70 climatic data, normal annual evapotranspiration in the Whitewater River Basin ranges from about 27 inches in northern areas to 28 inches in southern areas. These values are regional averages which may be expected over a period of many years; however, variations in temperature and other climatic factors can produce significant variations in evapotranspiration from year to year.

SURFACE-WATER HYDROLOGY

Drainage Characteristics

Drainage in the Whitewater Basin is well developed, particularly in southern areas where glacial deposits are older or absent. The Whitewater River and its major tributaries have long and fairly straight valleys with many small *first-order* and *second-order* streams feeding directly into the trunk channels.

The Whitewater River is entrenched in glacial drift along its upper reaches. Lower reaches in Franklin and Dearborn Counties are cut into bedrock and are flanked by high ridges of limestone and shale which often exceed 300 feet in relief. Limestone and shale is also exposed along much of the deeply entrenched East Fork Whitewater River, especially near Richmond and in the vicinity of Brookville Lake.

Tributary channels have relatively low relief in their headwater areas and then lose elevation rapidly as they leave the uplands and drop to the level of the major valley bottoms. Average *channel slopes* of 20 to 40 ft/mi (feet per mile) are not uncommon for western tributaries of the Whitewater River, and some short tributaries have even greater slopes. Several tributaries of the East Fork Whitewater River upstream of Brookville Lake have gradients exceeding 20 ft/mi.

The channel slope of the East Fork Whitewater River decreases from 12.8 ft/mi at Richmond to 9.2 ft/mi at Brookville (Glatfelter, 1984). These slopes are among the highest in the state for rivers draining more than 100 sq. mi. The gradient of the Whitewater River at Brookville (7.3 ft/mi) is the highest for Indiana rivers draining more than 1000 sq. mi.

Stream-Flow Data

The U.S. Geological Survey, in cooperation with other government agencies, has collected daily streamflow records in the Whitewater River Basin since 1915. Although daily stage readings were obtained for the Whitewater River at Cedar Grove between 1915 and 1917, the two earliest long-term stations were Whitewater River at Brookville (established in 1915) and Whitewater River near Alpine (established in 1928).

As data needs grew and funding became available, a network of stream gaging stations gradually developed. Currently, records of daily discharge are collected at four *continuous-record stations* on the Whitewater River (Economy, Hagerstown, Alpine and Brookville), at two stations on the East Fork Whitewater River (Abington and Brookville), and on Little Williams Creek at Connersville (table 8). From 1949 to 1978, data had also been collected for the East Fork Whitewater River at Richmond.

The two active gaging stations near Brookville are operated by the U.S. Geological Survey in cooperation with the U.S. Army Corps of Engineers. The other five stations are part of a cooperative program between the U.S. Geological Survey and the State of Indiana. Stream-flow data for these seven gages are published in U.S. Geological Survey reports prepared annually for the entire state.

Records of stream discharge during periods of low flow and high flow have been collected at *partial-record stations* where daily discharge data were not available.

Table 8. Stream gaging stations and selected stream-flow characteristics

Station number: Numbers are U.S. Geological Survey downstream-order identification numbers; station locations are shown in fig. 14. Lettered abbreviations are as follows: discontinued gaging station (D); low-flow partial-record station (L); crest-stage partial-record station (C); telemark station (T); satellite station (S); occasional regulation at low flow by upstream powerplant, and some effect by diversion for municipal water supply (OR); regulation by Brookville Lake since January 1974 (R).

Total drainage area: Data from Glatfelter and others (1985), Stewart (1983), or Glatfelter (1984), depending on station type.

Period of record: Refers to calendar year or portion thereof; in some cases, records are not continuous.

Station number and name		Total drainage area (sq mi)	Period of record	Average discharge		7-day, 10-year low flow	
				cfs[1]	cfs/sq mi	cfs[2]	cfs/sq mi
03-274650	Whitewater River near Economy	10.4	1970-	10.8	1.04	0.4	0.03
03-274700 L	Whitewater River at Hagerstown	29.2	1969	—	—	—	—
03-274750	Whitewater River near Hagerstown	58.7	1970-	67.9	1.16	7.1	0.12
03-274800 L	Martindale Creek near Cambridge City	58.1	1960-67	66.5	1.14	1.2	0.02
03-274880 C	Greens Fork tributary near Lynn	0.78	1973-82	—	—	—	—
03-274900 L	Greens Fork at Greens Fork	66.7	1968-75	76.0	1.14	1.6	0.02
03-274950	Little Williams Creek at Connersville	9.16	1968-	10.2	1.11	0.4	0.04
03-275000 T	Whitewater River near Alpine	522	1928-	552	1.06	45.5	0.09
03-275200 L	Salt Creek near Metamora	115	1954-67	126	1.10	0.9	0.01
03-275500 D, OR	E.F. Whitewater River at Richmond	121	1949-78	115[3]	0.95	4.2[4]	0.04
03-275576 L	Elkhorn Creek at Richmond	27.5	1954	35.2	1.28	0	0
03-275600	E.F. Whitewater River at Abington	200	1965-	229	1.14	18.9	0.09
03-275700 L	Silver Creek near Liberty	9.67	1960-67	11.1	1.15	0	0
03-275800 C	West Run near Liberty	0.26	1973-	—	—	—	—
03-275850 L	Hanna Creek near Roseburg	22.3	1959-78	25.5	1.14	0.3	0.01
03-275900 C	Templeton Creek near Fairfield	5.39	1973-82	—	—	—	—
03-275900 T	Brookville Lake at Brookville	379	1974-	—	—	—	—
03-276000 R	E.F. Whitewater River at Brookville	380	1954-	396	1.04	20[5]	0.05
03-276500 S, R	Whitewater River at Brookville	1224	1915-	1273	1.04	89[5]	0.07
03-276527 L	Big Cedar Creek at Cedar Grove	29.6	1980	33.8	1.14	0	0

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[1] Data for continuous-record stations from Glatfelter and others (1985) and through water year 1984 except as noted; data for partial-record stations estimated with regression equation.

[2] Data for continuous-record stations from U.S. Geological Survey data and through climatic year 1984 except as noted; data for partial-record stations from Stewart (1983) and through climatic year 1978.

[3] Data from Stewart (1983) and through water year 1978 (station discontinued).

[4] Data from Stewart (1983) and through climatic year 1978 (station discontinued).

[5] Data from Stewart (1983) and through climatic year 1974; represents low flows before regulation by Brookville Lake.

Additional measurements of discharge have been obtained at miscellaneous sites. Data from partial-record and miscellaneous sites are primarily used in regional hydrology studies to estimate flow characteristics at both gaged and ungaged locations.

Table 8 lists continuous-record gaging stations in the Whitewater Basin as well as 11 partial-record stations for which discharge-frequency data has been published in Stewart (1983) and Glatfelter (1984). Gaging locations are shown in fig. 14. Miscellaneous station listings and locations are not tabulated or mapped.

Table 8 also indicates continuous-record stations equipped with telemetering instruments for transmitting encoded information over telephone lines or via an earth-orbiting satellite. Data obtained from telemetered stations are primarily used for flood hydrology, flood forecasting, and the operation of Brookville Lake.

As water management programs develop further, additional stream-flow data may be needed to better define regional hydrology, determine low-flow and flood frequency discharges, and relate stream-flow characteristics to local and regional hydrogeology. Neyer (1985) has recommended that the establishment of gaging stations should be considered on Greens Fork or Nolands Fork, Salt Creek or Pipe Creek, and Middle Fork of the East Fork Whitewater River (upstream of Middle Fork Reservoir). These gages would provide regional hydrology data for non-urbanized basins. Reinstatement of the Richmond gage as a low-flow partial-record station was also suggested to provide low-flow data for an urban river reach.

To help balance the cost of these possible additions, Neyer also recommended that the currently operating gages near Connersville, Economy, and Hagerstown be discontinued by 1990. The 20 years of record at these three sites are sufficient for regional hydrology functions. Other gages in the basin, used for regional hydrology, flood forecasting, and the operation of Brookville Lake, should remain in operation.

Reservoirs

Although there are no natural lakes in the Whitewater River Basin, hundreds of small manmade lakes, ponds, and gravel pits are scattered throughout the area. The lakes and ponds, generally only a few acres in size, are primarily used for recreation, stock watering, or aesthetic purposes.

Whitewater Lake, the largest manmade, single-purpose recreational lake in the basin, covers 200 acres and has a 1.1 billion gallon storage capacity at normal pool elevation. Lake Santee (261 acres, 0.9 billion gallons) is primarily used for recreation, but also serves as a water supply source for a nearby subdivision.

Middle Fork Reservoir in eastern Wayne County supplies more than half of Richmond's water needs. Completed in 1960, this reservoir is located 2 miles north of Richmond on the Middle Fork of the East Fork Whitewater River (fig. 14). The reservoir covers 161 acres and has a storage capacity of 881 million gallons, as determined from a recent Division of Water survey (see fig. 34).

Brookville Lake is a flood control, recreational, and water supply reservoir on the East Fork Whitewater River (fig. 14). The dam is about 1.5 miles north of Brookville in Franklin County, and upstream areas of the reservoir extend northward to near Brownsville in Union County. The lake controls runoff from a drainage area of 379 sq. mi. Table 9 summarizes storage and lake area data at different pool elevations. Fig. 15 shows the typical operation schedule.

Construction of Brookville Lake began in November 1965, and outlet works were completed in January

Table 9. Storage and area of Brookville Lake

Designation	Elevation range (ft msl)	Allocated storage		Lake area	
		ac-ft	bg	acres	sq mi
Minimum pool	713	55,600	18.1	2250	3.5
Water supply pool (winter)	713 - 740	89,300	29	4510	7.0
Seasonal pool (summer)	740 - 748	39,000	12.7	5260	8.2
Flood control pool	740 - 775	214,700	70	7790	12.2

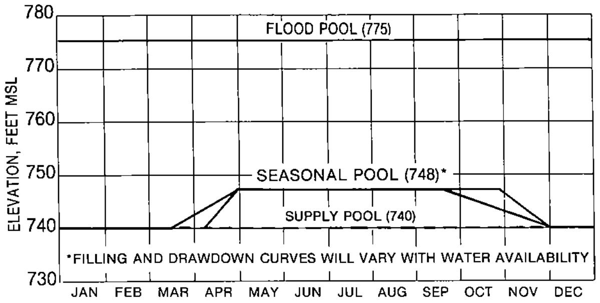


Figure 15. Typical operation schedule for Brookville Lake

1968. Since impoundment began in January 1974, the reservoir has been operated by the U.S. Army Corps of Engineers as part of a general plan to reduce flooding in the Ohio River Basin. The lake not only reduces flood stages in the Whitewater Valley, but also contributes to flood hazard mitigation along the Ohio River (U.S. Army Corps of Engineers, 1981). Flood damages prevented since January 1974 are estimated to be $2,560,000 (C. Schumann, U.S. Army Corps of Engineers, Louisville District, personal communication, 1987).

At emergency spillway crest (elevation 775 feet m.s.l.), total storage capacity of Brookville Lake is 359,000 acre-feet, or 117 billion gallons (see table 9). Depending on the season, from 175,700 to 214,700 acre-feet of this total storage capacity is available for flood control. During flood periods, the upstream end of the lake extends 24 miles northward to near Brownsville.

At summer pool elevation (748 feet m.s.l.), Brookville Lake extends northward about 16 miles, and has a total storage capacity of 183,900 acre-feet (60 billion gallons). Of this capacity, 39,000 acre-feet (12.7 billion gallons) is allocated for seasonal recreation and fish and wildlife purposes. About 16,450 acres of reservoir land and water have been leased to the State of Indiana for these two purposes.

From mid-September to mid-April, the lake level is maintained at 740 feet m.s.l. in order to allow storage of winter and spring runoff (fig. 15). Of the total winter storage capacity of 144,900 acre-feet below 740 feet m.s.l., 89,300 acre-feet is allocated for water supply. This water supply storage has been purchased by the State of Indiana from the U.S. Government for sale to any interested party. The State of Indiana has a contract with the Franklin County Water Association that allows the IDNR to sell up to an annual average of 500,000 gallons per day. (For more information on water supply, see the "Surface-Water Availability" section later in this report).

Stream-Flow Characteristics

Although the amount of available precipitation determines the theoretical upper limit of stream flow, the following factors affect the spatial and temporal distribution of flow: climate; soils and land cover (vegetation, lakes, impervious surfaces); topography and physiography (including drainage area, *drainage density*, channel geometry); geology (surficial and bedrock); interactions of surface water with ground water (areas of recharge, areas of discharge); and man-made modifications (stream channelization, dams, diversions, and pumpage).

Geographic variations of these factors account for the diversity of stream-flow characteristics within and among basins. Data on flow characteristics are needed for a wide range of hydrologic and hydraulic applications, including the determination of the water supply potential of streams. Selected hydrologic parameters derived from discharge records provide a semi-quantitative framework for characterizing the basin's surface-water system.

Average Flows

Of all hydrologic parameters, average discharge is the most easily understood and one of the most widely used. Average discharge is the arithmetic average of daily flows for all complete water years of record, whether consecutive or not.

The combined effects of the factors listed in the previous section are reflected in average discharge, which can be interpreted as follows: if it were possible to store, in a single hypothetical reservoir, all the water that flows from a watershed during a specified period and then release it at a uniform rate over the same period, that rate would be the average flow. This flow represents the theoretical upper limit of the long-term yield which can be developed from a stream, even with *regulation*.

Average daily discharges of record are given in table 8. Based on average discharge and flow duration data reported by Stewart (1983), average discharges at continuous-record stations in the Whitewater Basin are equaled or exceeded 25 percent of the time. This percentage, which is less than exceedence percentages for average flows in northern Indiana, primarily reflects the higher flood discharges in the Whitewater Basin. In some northern Indiana basins characterized by slight topographic relief, poorly developed drainage, and extensive, highly permeable outwash deposits, for example, average discharge would be expected to more closely approximate the *median* discharge.

If average discharge is divided by the area drained, the similarity of *unit discharges* becomes apparent. As table 8 shows, average unit discharge for continuous-record stations in the Whitewater River Basin is slightly more than 1 cfs (cubic foot per second) per square mile.

Average runoff, which is the depth to which a drainage area would be covered if the average discharge for a given time period were uniformly distributed, represents the amount of water leaving a basin as both surface-water runoff and ground-water discharge. Except for flows at Richmond, *runoff* at continuous-record stations averages about 14.5 inches per year.

Low Flows

Low-flow discharge information is essential to the planning, management, and regulation of activities associated with surface-water resources. Low-flow data are used in the design and operation of wastewater treatment facilities, power plants, engineering works (such as dams, reservoirs and navigation structures), and water supply facilities. Low-flow information is also used to evaluate water quality and its suitability for various uses. Some low-flow parameters may also be used in the development of regional draft-storage relations, in the forecasting of seasonal low flows, or as indicators of the amount of ground-water influx to streams.

Low-flow characteristics are commonly described by points on low-flow frequency curves prepared from daily discharge records at continuous-record gaging stations. Correlation techniques can be used to estimate

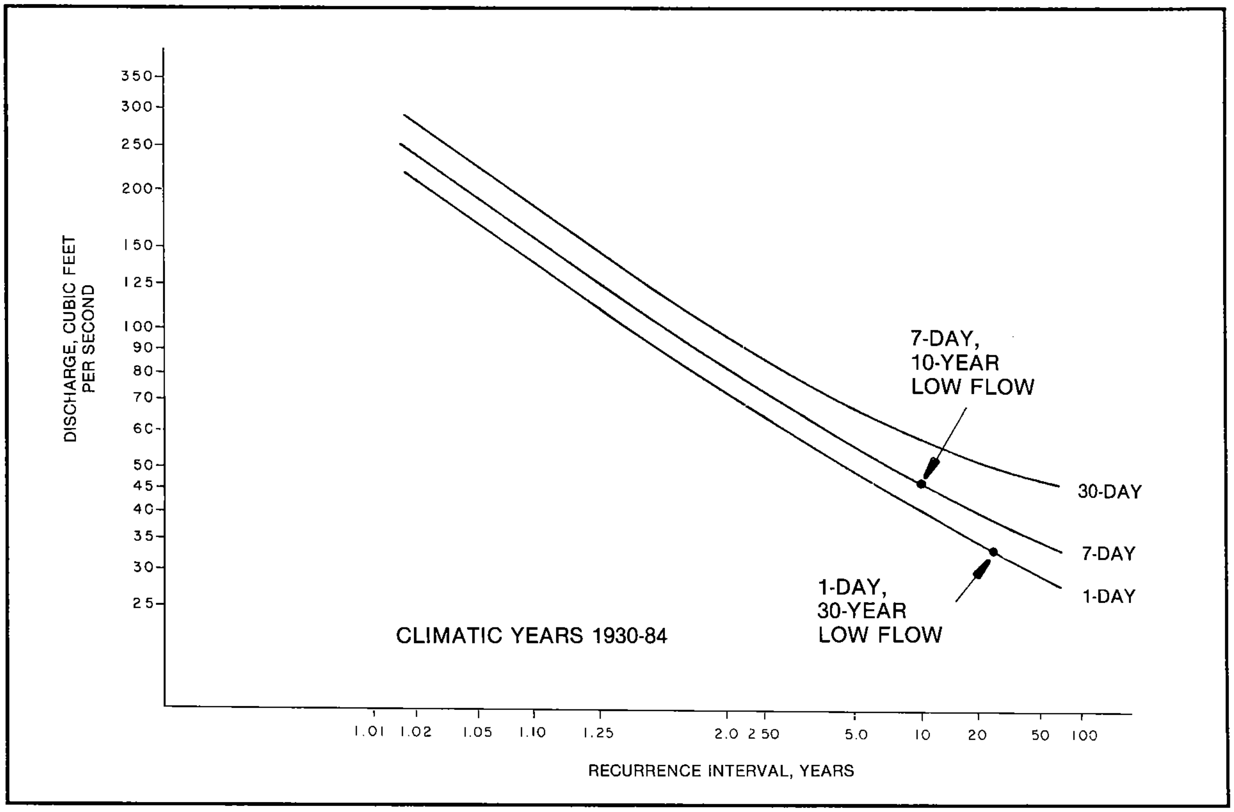


Figure 16. Low-flow frequency curves, Whitewater River near Alpine

curves, or selected points on curves, for stations where short-term records and/or *base-flow* measurements are available.

Curves can be developed from a *frequency analysis* of annual minimum flows for selected numbers of consecutive days. Fig. 16 shows the relation of annual minimum average discharges for 1-day, 7-day, and 30-day periods for the Whitewater River near Alpine during *climatic years* 1930-84. In this report, the following points on the 1-day and 7-day curves have been selected as indices of low flow: the minimum daily (1-day average) flow having a 30-year *recurrence interval*, and the annual minimum 7-day average flow having a 10-year recurrence interval.

The 1-day, 30-year low flow is the annual lowest 1-day mean flow that can be expected to occur once every 30 years, on the average. In other words, it is the annual lowest daily mean flow having a 1-in-30 chance of occurrence in any given year. In this report, the 1-day, 30-year flow indicates the dependable supply of water without storage, and is discussed further in the ''Surface-Water Availability'' section.

The 7-day, 10-year low flow is the annual lowest mean flow for 7 consecutive days that can be expected to occur, through a long period, on the average of once every 10 years. There is a one-in-ten chance that the annual minimum 7-day average discharge in any given year will be less than this value. Based on data reported by Stewart (1983), stream flows at continuous-record stations in the Whitewater Basin are greater than 7-day, 10-year values about 99.5 percent of the time.

In Indiana, the 7-day, 10-year low flow is the index for water quality standards. This flow is used for siting, design, and operation of wastewater treatment plants, for evaluating wastewater discharge applications and assigning wasteload limits to industrial and municipal dischargers, and as an aid in setting minimum water release requirements below impoundments. In the future, 7-day, 10-year low flows or other low-flow parameters may be utilized by the IDNR to establish minimum flows of selected streams.

Table 8 presents annual 7-day, 10-year low flows at continuous-record gaging stations as calculated through *water year* 1984. The non-concurrency of data among these seven stations prevents a strict comparison of low-flow parameters. However, the tabulated values are statistically more representative of each site because the maximum lengths of record were used.

The 7-day, 10-year values tabulated for the two stations downstream of Brookville Lake represent pre-reservoir (unaffected) flows. These values are considered more appropriate low-flow characteristics than values which include 10 additional years of affected data. (The effect of Brookville Lake on downstream flows is discussed in a later section.)

Unit low flow is one indicator of the degree to which stream flow is sustained by ground-water contribution. The highest 7-day, 10-year unit low flow at a continuous-record gaging station occurs on the Whitewater River near Hagerstown. This value (0.12 cfs/sq. mi.) was calculated for a selected base period 1972-84. The next highest unit flow at an unaffected continuous-record site occurs farther downstream near Alpine. This concurrent value (0.11 cfs/sq. mi.) is slightly higher than the long-term value shown in table 8, which includes flows measured during drought periods of the 1930s and 1940s. The third highest unit flow for the period 1972-84 occurs on the East Fork Whitewater River at Abington. This value does not differ significantly from the value shown in table 8 for the period 1965-84.

At partial-record stations, unit low flows are highest for Martindale Creek and Greens Fork in Wayne County. Similar unit flows are expected along middle reaches of Nolands Fork, which drains an area of similar size, basin shape, and surficial geology.

As table 8 shows, low flows for Martindale Creek and Greens Fork are significantly less than flows at the three continuous-record sites near Hagerstown, Alpine, and Abington. Although Martindale Creek and Greens Fork, like upper reaches of the Whitewater River and its east fork, drain watersheds developed primarily on outwash sand and gravel deposits, the degree of ground-water contribution to these two tributary reaches appears to be considerably less.

Low flows for tributaries of Brookville Lake in Union County and for tributaries of the Whitewater River in Franklin County either approach or equal zero (table 8). These tributary basins contain large quantities of glacial till and minimal amounts of sand and gravel; therefore, precipitation quickly leaves these watersheds as surface runoff. During periods of little or no rainfall, the streams cease flowing due to limited ground-water discharge.

Surface- and Ground-Water Interactions

Interactions between surface- and ground-water systems in the Whitewater Basin account for much of the diversity of stream-flow characteristics, particularly low flows. The use of unit flow as an indicator of ground-water inflow was discussed in the previous section. Other semi-quantitative approaches described below are also useful for making inferences regarding system interactions and for generalizing the water supply potential of selected streams. Additional analyses which define available stream flow and storage requirements are discussed in the "Surface-Water Availability" section later in this report.

Flow Duration

The flow duration curve is a cumulative frequency curve that shows the percent of time that specified discharges are equaled or exceeded during a given period of record. For example, daily mean flows of the Whitewater River at Brookville were at least 135 cfs during 95 percent of the time for water years 1956-73 (as derived from fig. 17). Daily flows for this period exceeded 11,750 cfs only 1 percent of the time.

Even though all chronological sequence of daily discharges is lost in a duration analysis, a duration curve can be taken as a probability curve that the flow distribution over several years will be approximately equal to that of prior years (Rohne, 1972). Because duration data provide a great deal of information on a stream's overall flow regime, such data are useful for water supply and hydroelectric power studies, industrial and waste treatment plant siting, reservoir design, and pollution control.

The shape of the duration curve is an index of the natural storage within a basin that is utilized by the stream. The more nearly horizontal the curve, the greater is the storage effect, and the greater the potential for high sustained yields from both surface and ground water.

If duration curves are plotted on a per-square-mile (unit) basis for a concurrent period, comparisons of storage can be made among drainage basins in areas of differing geology. For example, the three curves in fig. 17 show that the ability of a drainage system to accommodate high flows and sustain low flows

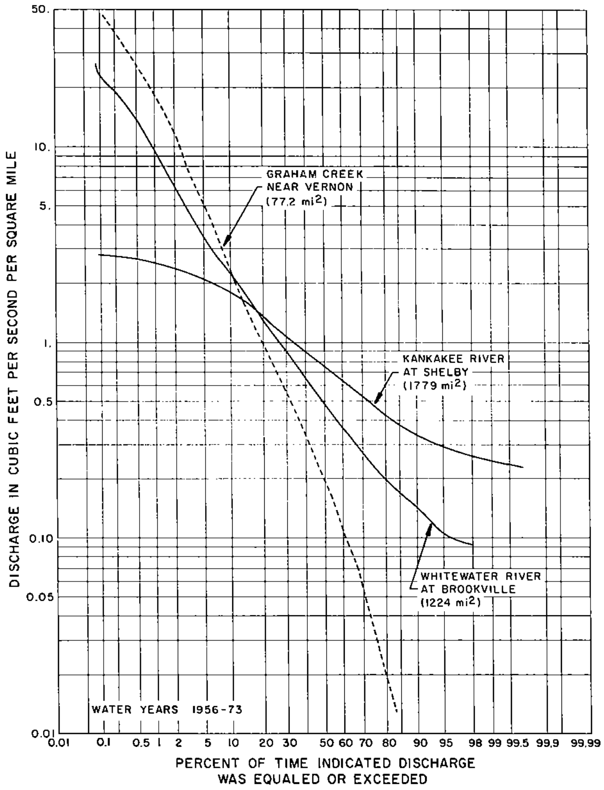


Figure 17. Flow duration curves for selected stream gages in Indiana

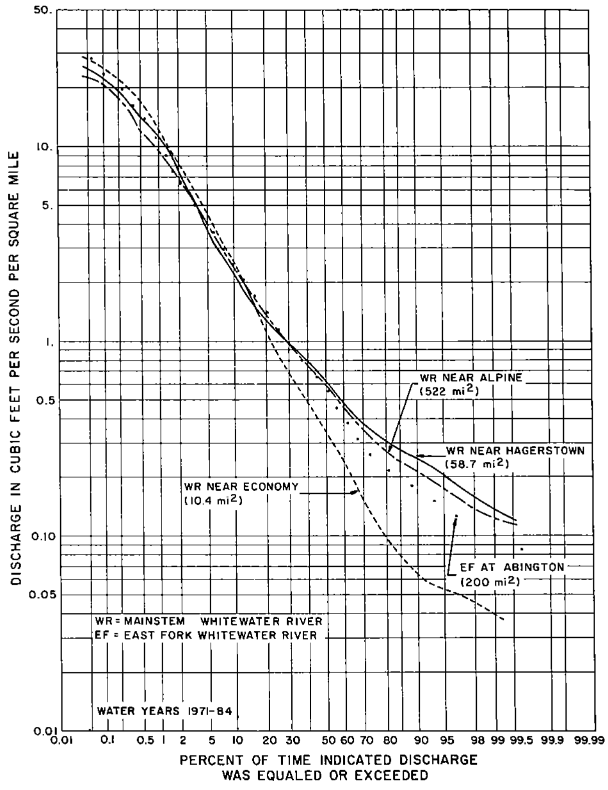


Figure 18. Flow duration curves for major stream gages in the Whitewater River Basin

varies from northern to southern Indiana due to variations in geology.

In general, the greater storage capacity of permeable outwash materials in northern Indiana valleys tend to reduce high stream flows. The release of stored water during dry periods augments low stream flows. The combination of these two factors produces a fairly flat duration curve, as represented by the Kankakee River curve in fig. 17. The particularly flat portion at the upper end of the curve in fig. 17 is primarily the result of the large amount of overbank storage available in the Kankakee valley.

In contrast to the Kankakee River's flat duration curve, the duration curve for Graham Creek is quite steep (fig. 17). This narrow channel in southeast Indiana flows across bedrock and thin till of low permeability. Because basin storage is limited, Graham Creek has sharp, rapid flood peaks during storm events, and often ceases to flow during dry periods.

Finally, the curve for the Whitewater River south of Brookville before the completion of Brookville Lake (fig. 17) characterizes a stream system with moderate variability of flow. The fairly high peak flows may be explained by the well-developed drainage system which in its lower reaches covers non-glaciated, highly dissected terrain. The presence of outwash deposits along the major river valleys probably accounts for the moderately sustained low flows.

Within the Whitewater Basin, unit curves for three gages on the Whitewater River (fig. 18) further illustrate the effects of surficial geology on water storage, and subsequently on stream-flow characteristics. The limited amount of ground-water inflow upstream of the Economy gage, as indicated by the steeper low-flow end of the duration curve, can probably be attributed to the small drainage basin and the predominance of till. The flatter duration curves for the Hagerstown and Alpine gages indicate a greater amount of ground-water contribution to these stream reaches, probably from outwash sands and gravels underlying the river valley. The Hagerstown duration curve may reflect a particularly high degree of ground-water discharge to stream reaches near Hagerstown from thick glacial drift filling a bedrock valley (fig. 8).

In contrast to differences in low-flow characteristics along the Whitewater River, higher stream flows per unit of drainage area exhibit close similarity (fig. 18). The similarity of duration curves at unit discharges having exceedance probabilities less than 20 mainly reflects the similarity of climate, land use, and vegetative cover near these three gage sites (see Searcy, 1959). The similarity of flow distribution between the Whitewater River and its east fork is also apparent in fig. 18, as shown by data points for the Abington gage.

Water-Level Correlation

In central Franklin County, the stream gaging station on the Whitewater River and the observation well Franklin-5 are located less than one-quarter mile apart and about 1 mile south of Brookville (fig. 14). Because the Whitewater River at this location and throughout most of its length is developed on outwash sands and gravels, a high degree of hydrologic connection is expected between the river and the ground-water system.

A plot of water-level *hydrographs* for the two monitoring sites near Brookville (fig. 19) provides a graphical comparison of water-level changes in the Whitewater River and the underlying outwash. The figure shows not only the close similarity of water-level changes but also the quick response of the surface-water and ground-water systems to precipitation (as measured in the town of Brookville).

Based on the close similarity of hydrographs, it appears that the Whitewater River is hydrologically connected to the underlying outwash aquifer. However, because a variety of geologic, geomorphic, and topographic factors influence hydrologic interactions between surface-water and ground-water systems, additional data are needed to better characterize these interconnections in the Whitewater River valley.

Hydrograph Separation

Hydrograph separation can be used to divide stream flow (total runoff) into its component parts: surface runoff, interflow, and *ground-water discharge* (base flow). *Surface runoff* is the combination of precipitation falling directly upon the stream and water flowing over the land surface toward the stream (*overland flow*). *Interflow* occurs when precipitation that has infiltrated into the soil moves laterally through the soil to the stream. For convenience, interflow and surface runoff are sometimes combined into one category, *direct runoff*. Base flow represents the portion of stream discharge that is contributed largely or entirely from the ground-water system.

The amount of base flow relative to direct runoff depends on a number of variables, including intensity of precipitation, soil moisture conditions, soil infiltration capacity, underlying geology, and areal basin characteristics. The amount of base flow is one measure of the degree to which stream flow is sustained

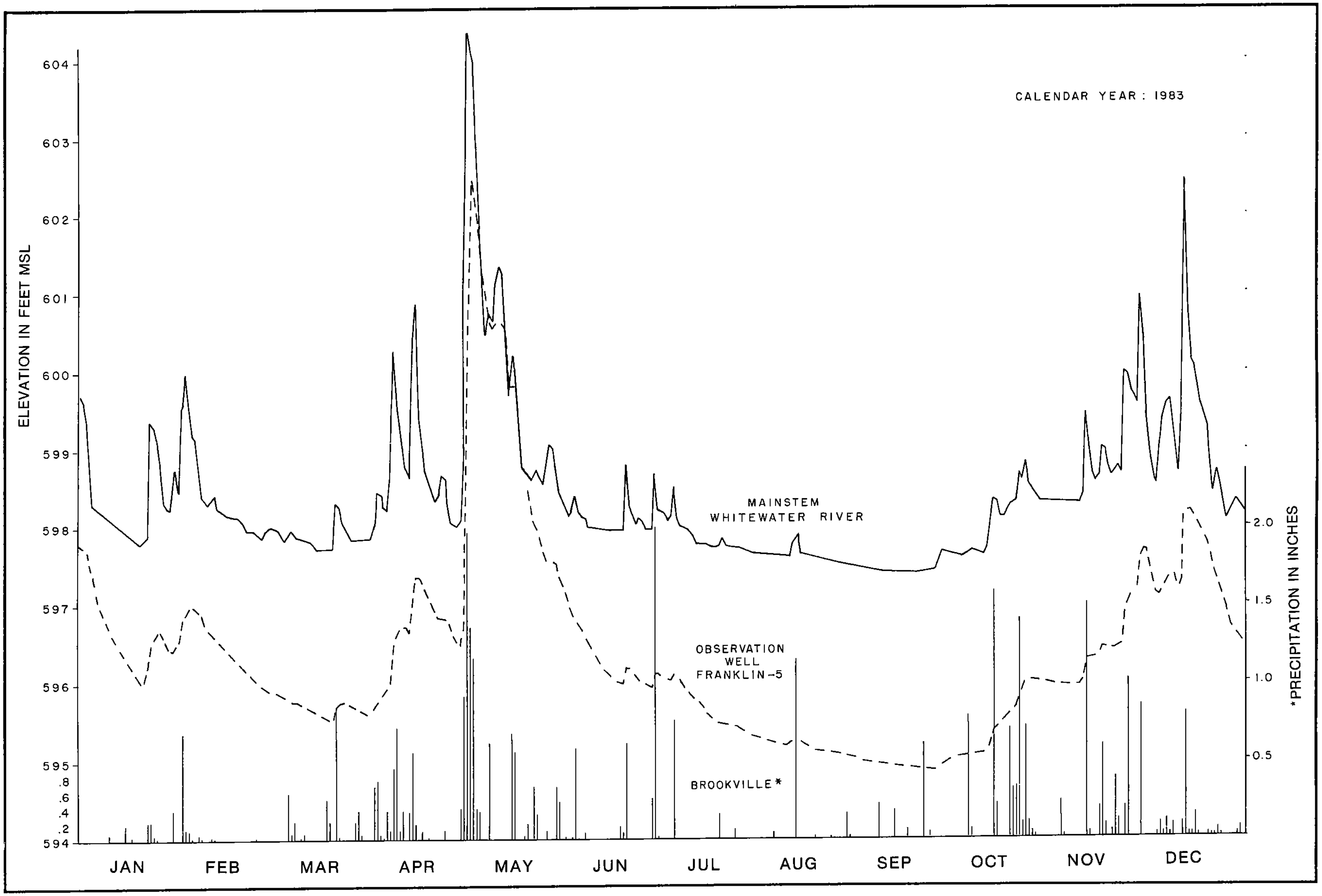


Figure 19. Water-level hydrographs and total daily precipitation near Brookville

Table 10. Ground-water contribution to stream flow based on hydrograph separation

Station number and name		Total drainage area (sq mi)	Water year[1]	Total runoff (inches)	Direct runoff		Ground water	
					inches	percent	inches	percent
03-274650	Whitewater River near Economy	10.4	1977-d	4.25	2.41	57	1.84	43
			1974-n	12.90	7.46	58	5.44	42
03-274750	Whitewater River near Hagerstown	58.7	1977-d	5.87	2.27	39	3.60	61
			1974-n	15.49	6.88	44	8.61	56
03-274950	Little Williams Creek at Connersville	9.16	1977-d	8.83	4.87	55	3.96	45
			1974-n	16.95	9.61	57	7.34	43
03-275000	Whitewater River near Alpine	522	1977-d	5.60	2.40	43	3.20	57
			1974-n	15.61	7.36	47	8.25	53
03-275500	E.F. Whitewater River at Richmond[2]	121	1977-d	4.82	1.95	40	2.87	60
			1974-n	12.20	5.41	44	6.79	56
03-275600	E.F. Whitewater River at Abington	200	1977-d	6.27	2.63	42	3.64	58
			1974-n	15.36	6.97	45	8.39	55
03-276500	Whitewater River at Brookville[3]	1224	1977-d	6.72	2.22	33	4.50	67
			1974-n	13.20	5.01	38	8.19	62

[1] Dry year (d) - 1977; normal year (n) - 1974.
[2] Upstream flow may be affected by municipal water supply diversion.
[3] Flow regulated by Brookville Lake dam since January 1974.

by ground-water contribution.

Graphical techniques exist to separate base flow from the stream-flow hydrograph. App. 6 illustrates a hydrograph separation for a one-year period (water year 1974) at the gage on East Fork Whitewater River at Abington. The base-flow hydrograph shown in app. 6 was used to compute the annual volume of base flow, which was then converted to inches by dividing the calculated volume by drainage area. The percent of base flow was then calculated by dividing the inches of base flow by inches of total runoff. The percent of direct runoff was calculated by dividing the inches of direct runoff by inches of total runoff.

This graphical technique was used to determine the amounts of base flow and direct runoff contributions at seven stream gaging sites in the Whitewater Basin. Hydrograph separations were made for a dry year (1977) and a normal year (1974) to determine if any significant difference exists in the percent of ground-water contribution.

As the results in table 10 show, ground water appears to constitute a slightly higher percentage of total runoff during the dry year analyzed than during the normal year analyzed. In addition, the ground-water contributions for both years are larger than the direct runoff contributions at all gages except Whitewater River near Economy and Little Williams Creek at Connersville. The larger ground-water contributions are on the main channels of the Whitewater drainage system where sand and gravel deposits are more abundant. Because the tributary valleys have less sand and gravel, the tributaries also have less potential *bank storage* and therefore flows are not as well sustained as in the main channels during dry periods.

Effects of Brookville Lake on Downstream Flows

Stream flows at two gaging stations downstream of Brookville Lake are modified by operations at the dam. At the *tailwater* gage on the East Fork Whitewater River (fig. 14, station 03-276000), daily mean flows are noticeably affected. For example, the daily discharge was zero on July 27, 1982 as a result of maintenance activities at the dam. On several other occasions during the post-reservoir period 1975-84, daily mean discharges near zero have been recorded. These unusually low flows typically were interspersed among discharges exceeding 300 cfs.

These extreme variations in daily stream flows are also apparent farther downstream on the mainstem Whitewater River (fig. 14, station 03-276500). At this station, the last 10 years of data reflect not only regulated outflow from the 382 sq. mi. watershed of the East Fork Whitewater River but also unaffected discharge from the 842 sq. mi. Whitewater River subbasin above the east fork. Therefore, reservoir-induced modifications of stream flow at the mainstem gage are somewhat masked. Despite this consideration, however, stream-flow records at the mainstem gage were utilized for the following discussion, primarily because 50 years of pre-reservoir data were available.

The reduction of flood discharges downstream of Brookville Lake can be illustrated by coordinated discharge-frequency values prepared by the Division of Water in cooperation with three federal agencies (Indiana Department of Natural Resources, 1986a). According to these determinations, the *100-year flood* on the Whitewater River at Brookville, as modified by the reservoir, is 59,000 cfs. This flood discharge is 30,000 cfs less than the estimated peak of 89,000 cfs which would have been expected in the absence of reservoir regulation. The 25-year flood is reduced from 68,000 cfs to 45,500 cfs, and the 10-year flood is reduced from 56,000 cfs to 40,000 cfs.

Flow duration curves can illustrate the decreased flood discharges for events of lesser magnitude (for example, discharges less than the 2-year, or average annual flood). A graphical relation for the pre-reservoir period 1929-73 was established between flow duration curves for the Alpine and Brookville stations on the Whitewater River. This graphical relation, assumed to remain valid for the period 1975-84, was then used to estimate the natural (unregulated) flow duration curve for the Brookville gage. The estimated curve for natural conditions was then compared to the actual curve derived from measured discharges during the same 10-year period.

As the resulting curves in fig. 20 show, the flood discharge being equaled or exceeded only 0.1 percent of the time is reduced from 26,000 cfs to 18,000 cfs due to flood control operations at the dam. The 1.0-percent duration discharge is reduced from 13,000 cfs to 8,600 cfs.

To estimate the effect of Brookville Lake on average discharge, the area under the affected duration curve in fig. 20, which represents the average discharge for the entire 10-year period of reservoir regulation, was compared to the area under the curve for unaffected conditions. The resulting values show that the 10-year average discharge for reservoir-affected conditions (1341 cfs) is 2.5 percent less than the unaffected average discharge (estimated to be 1375 cfs). Of this 34 cfs difference, approximately 23 cfs can be attributed to evaporative losses from the large reservoir surface.

Occasional maintenance activities and other infrequent operations at the Brookville Lake dam probably explain the decrease in extremely low stream flows, which is apparent from the lower end of the affected duration curve for the Whitewater River (fig. 20).

The effect of seasonal reservoir operations (fig. 15) on stream flows of the Whitewater River was illustrated by an analysis of monthly mean flows. Regression equations derived from monthly mean flows for March, April, October, and November at Alpine and Brookville were used to estimate monthly means which would have occurred at Brookville each year during

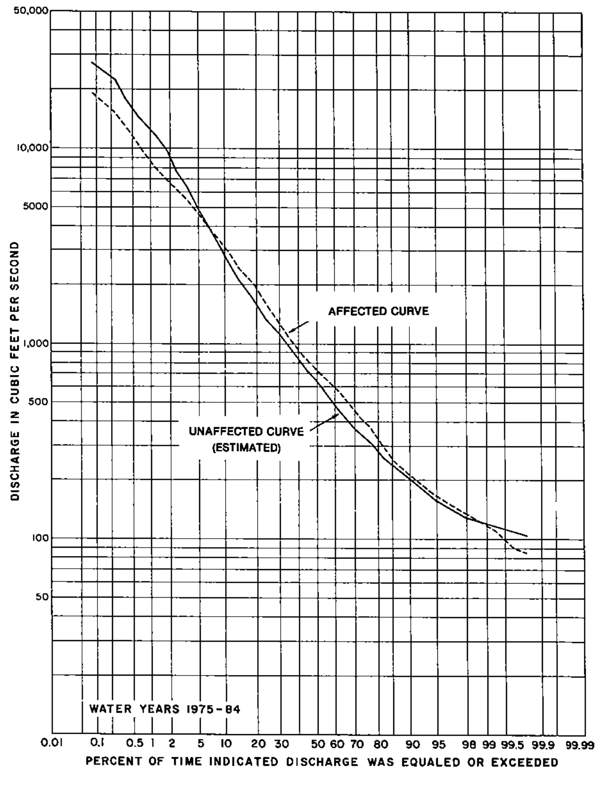


Figure 20. Flow duration curves for Whitewater River at Brookville showing the effects of Brookville Lake

the period 1975-84. These estimated means were then compared to values derived from Brookville's post-reservoir discharge records. This analysis showed that during reservoir filling in March and April, monthly mean stream flows at the Brookville gage are less than flows which would have been expected under natural conditions. Conversely, monthly means during reservoir *drawdown* in October and November are greater than means that would normally have been expected.

Surface-Water Quality

Water quality standards for several designated uses have been adopted by the former Indiana Stream Pollution Control Board (1985) and the former Indiana Environmental Management Board (1979). At the time of this report, these standards are being revised by the Indiana Water Pollution Control Board (1987). App. 7 summarizes state and federal standards current as of early 1987 for public water supply, as well as recommended criteria for aquatic life, irrigation, and livestock watering.

Standards for recreation are intended to maintain the aesthetics of a body of water and to protect the public from possible health risks. Concentrations of *fecal coliform* are used to monitor the suitability of surface water for body-contact recreation. More stringent limits for fecal coliform have been established for *whole-body contact* recreation (swimming— a single sample maximum of 400 cells per 100 ml) than for *partial-body contact* (wading—2000 cells per 100 ml).

In the Whitewater Basin, all lakes and reservoirs, as well as the Whitewater River below its east fork are designated for whole-body contact recreation from April through October (the recreation season), and for partial-body contact recreation from November through March. The remainder of streams in the basin are presently designated for partial-body contact recreation year-round. However, these recreational use designations and standards will be modified to include all waters for whole-body contact if proposed water quality revisions are adopted by the Indiana Water Pollution Control Board (1987).

Two streams in Franklin County are designated for "limited use." The amount of flow and habitat in Richland Creek and its unnamed tributary are insufficient to support diverse communities of fish and other aquatic life. During dry periods, treated effluent from a rubber manufacturing plant provides the only flow in the two streams. The only viable uses for Richland Creek are wading and livestock watering. The unnamed tributary to Richland Creek has no potential for recreational or agricultural uses (Indiana State Board of Health, 1982).

"Exceptional use" streams are high-quality waters which provide exceptional aquatic habitat, support unique assemblages of aquatic organisms, or are integral features of protected or particularly scenic areas. Although no exceptional use streams have been designated in the Whitewater River Basin, a 28-mile segment of the Whitewater River in Franklin County has been recommended for inclusion in Indiana's Natural, Scenic, and Recreational Rivers System (Indiana Department of Natural Resources, 1986b). Inclusion in this system would at least partially protect the river segment from detrimental human impacts.

Surface-Water Quality Data

Surface-water quality data in the Whitewater River Basin can be grouped into two categories, streams and reservoirs. Since 1980, stream quality data have been collected quarterly as near-surface *grab samples* by the Indiana Department of Environmental Management at two stations, the East Fork Whitewater River at Abington and the Whitewater River at Brookville. (Prior to 1980, samples were generally collected on a monthly basis.) Until 1987, the stations at Abington and Brookville were located at the U.S. Geological Survey's stream-flow gaging sites (fig. 14). Recently, however, the stream quality station at Brookville was moved downstream to Cedar Grove.

The stream quality stations at Abington and Brookville (Cedar Grove) are operated as part of a statewide surface-water quality monitoring network established in 1957 by the Indiana State Board of Health. Water quality data for the entire state are published in reports prepared annually by the Department of Environmental Management (and formerly prepared by the Board of Health). App. 8 summarizes water quality constituents at the Abington and Brookville stations having at least 15 values published over a selected 10-year period, 1976-85.

The U.S. Geological Survey collected data for sediment and selected chemical constituents at their Abington stream-flow gage from 1969-76, and some sediment data at the Hagerstown and Alpine gages (fig. 14), primarily during the same period. From 1974-86, the Whitewater River gaging station at Brookville was part of the National Stream Quality Accounting Network (NASQUAN), a nationwide program established in 1972 by the U.S. Geological Survey to statistically test for long-term regional trends in the quality of the nation's surface waters. The NASQUAN site was moved to the station near Alpine in late 1986.

App. 9 is taken from a more comprehensive statistical summary for the NASQUAN gage at Brookville for the 7-year period, 1974-81 (Smith and Alexander, 1983). The appendix lists mean concentrations of 22 common water quality constituents, as well as estimated medians of trace metals for which the detection limit was exceeded in at least half the samples analyzed.

Water quality data for Silver Creek downstream of Whitewater Lake, the East Fork Whitewater River near Liberty, and the East Fork Whitewater River below Brookville Lake dam (fig. 14) are periodically collected by the U.S. Army Corps of Engineers. App. 10 summarizes selected river quality constituents having at least 15 concentration values and for which the detection limit was exceeded in at least half the samples analyzed over the period of record, 1972-86. Fig. 21 illustrates mean concentrations of selected constituents at the three Corps stations and at the U.S. Geological Survey's NASQUAN gage.

Water quality data for Brookville Lake are periodically collected by the U.S. Army Corps of Engineers, primarily at three sites (fig. 14). App. 11 summarizes selected constituents having at least 15 concentration values and for which the detection limit was exceeded in at least half the samples analyzed over the period of record, 1974-86.

Water quality data for Whitewater Lake have been collected primarily as part of special studies by the U.S. Environmental Protection Agency (1976a) and the Indiana State Board of Health (data unpublished). In addition, bacterial counts at the swimming beach are monitored weekly by the Board of Health during the recreation season.

The Indiana-American Water Company's Richmond District withdraws approximately 60 percent of its water from Middle Fork Reservoir, and 40 percent from ground water. Water quality parameters affecting water treatment and public health are monitored daily by the utility. Measured parameters for reservoir water include turbidity, iron, manganese, pH, hardness, alkalinity, odor, bacteria, and chlorine residual. Additional samples from the reservoir are collected twice a year for determination of major inorganic ions, trace metals, and organic pollutants.

Streams

Based upon available data, water quality is generally considered good in the Whitewater River and its east fork. Standards for public water supply and aquatic life have not been exceeded in samples collected by the In-

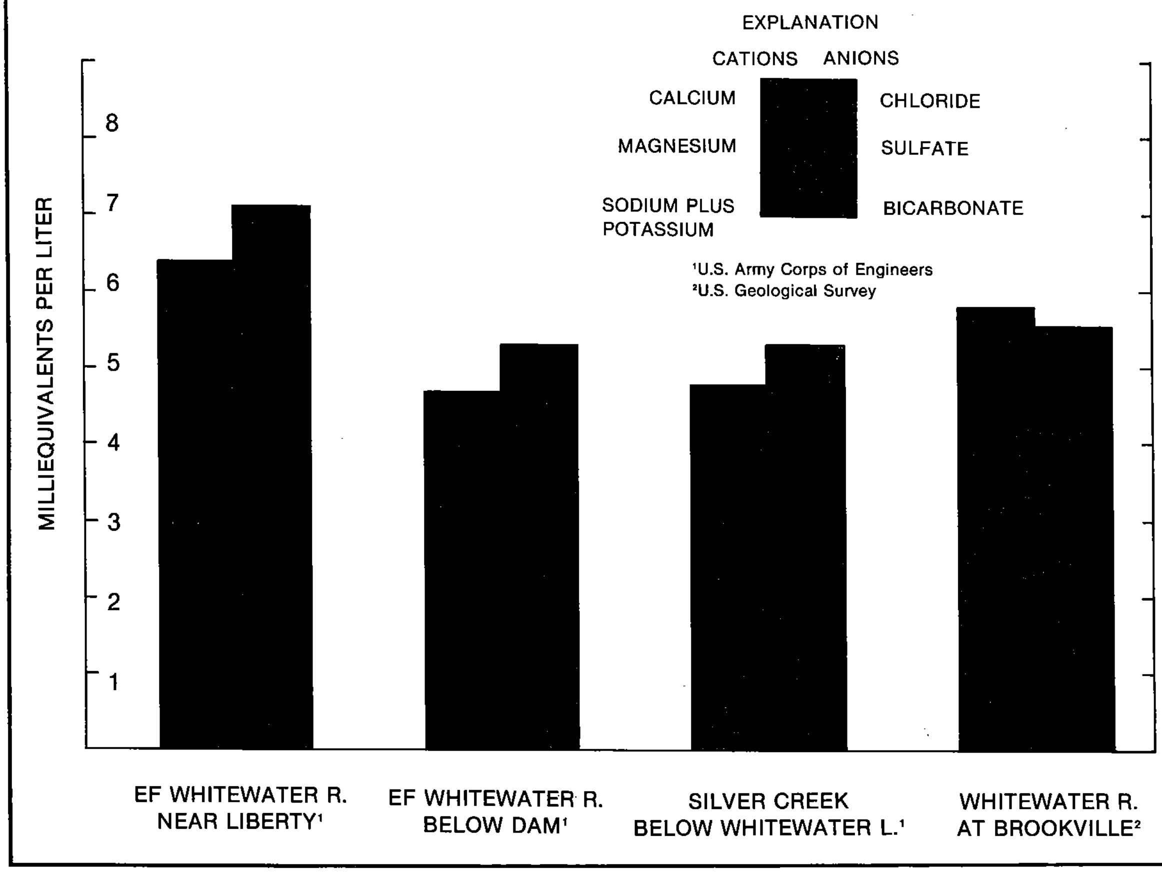


Figure 21. Comparison of major chemical constituents at selected stream quality stations

diana Department of Environmental Management at their Abington and Brookville stations during the past 10 years (1976-85). Nutrients (phosphorus and inorganic nitrogen) have sometimes been present in concentrations greater than those recommended for the prevention of nuisance algal growth in flowing waters, but excessive *phytoplankton* populations have not been recorded, and mean nutrient values are fairly low. High fecal coliform concentrations occasionally found in the Whitewater River and its east fork, however, indicate the presence of point and/or non-point sources of pollution. High fecal coliform counts often are associated with municipal discharges, *combined sewer overflows*, and/or agricultural runoff.

On the Whitewater River at Brookville, fecal coliform concentrations from April through November sometimes exceed the standard for whole-body contact recreation (400 cells per 100 ml). Violations recorded by the Indiana Department of Environmental Management (IDEM) at their former monitoring site ranged from 610 to 110,000 cells per 100 ml during the 10-year period, 1976-85. These and other excessive values, although interspersed among much lower concentrations, produce a skewed mean, as app. 8 shows.

At the Brookville monitoring station, located about 0.4 mile downstream of the Brookville sewage treatment plant, nearly two-thirds of the samples collected by the IDEM from 1976-79 during the recreation season violated the whole-body contact standard. About half of the quarterly samples collected from 1980-85 during the recreation season violated the standard. In contrast, only 6 percent of the samples collected from November to March for the period 1976-79 violated the standard for partial-body contact recreation (2000 cells per 100 ml), while one-third violated the standard from 1980-85.

Only occasional fecal coliform violations of the partial-body contact standard have been recorded downstream of the Connersville wastewater treatment plant, the largest point-source discharge on the Whitewater River. Dissolved oxygen and ammonia violations downstream of Connersville seldom occur (Indiana Department of Environmental Management, [1986]).

On the East Fork Whitewater River downstream of Richmond, fecal coliform standards for partial-body contact recreation (2000 cells per 100 ml) have been violated in only 10 to 20 percent of the samples collected by the IDEM during the period 1976-85. The average frequency of occurrence during the past 10 years has remained about the same (approximately one violation per year per sample set). Although the river reach near Abington is not designated for whole-body contact recreation, nearly 60 percent of the samples collected from 1976-85 had fecal coliform values less than 400 cells per 100 ml, the maximum permissible concentration in other waters which are used for whole-body contact recreation.

Reservoirs

Middle Fork Reservoir, Whitewater Lake, and Brookville Lake represent three moderately *eutrophic* lakes of either large acreage (Brookville Lake) or shallow mean depth. According to the lake classification system used by the Indiana Department of Environmental Management (1986), water quality problems in these lakes are infrequent, and designated aquatic life and recreational uses are rarely if ever impaired. To help maintain the good conditions in these lakes, the IDEM has recommended the control of nutrient input via phosphorus removal at wastewater treatment facilities, landuse management, and the control of septic tank seepage.

The IDEM uses 10 trophic parameters to derive a composite numerical index scaled from 0 to 75, which defines a generic four-tiered classification of lakes throughout Indiana. An index of 75 and a Class 4 designation would represent the most eutrophic conditions, for example. According to this classification scheme, Middle Fork Reservoir has a Eutrophication Index of 18 and is designated as a Class 1 lake (Indiana Department of Environmental Management, 1986).

Compared with the other two lakes of record in the basin, Middle Fork Reservoir is considered by the IDEM to be the least eutrophic. The reservoir is characterized by low nutrient concentrations, low turbitity, and small, diverse populations of phytoplankton and *macrophytes*. With respect to primary and secondary drinking-water regulations (app. 7), only concentrations of iron and manganese in raw water samples occasionally exceed the secondary levels for finished drinking water. Other inorganic parameters have been within acceptable limits, and no organic pollutants have been detected (K. Cooper, Indiana-American Water Company, personal communication, 1987).

Whitewater Lake, the most eutrophic of the three basin lakes, is an Index 29, Class 2 lake. When the U.S. Environmental Protection Agency sampled 27 Indiana lakes in 1973 for a combination of six parameters, Whitewater Lake ranked 24th in overall trophic quality (U.S. Environmental Protection Agency, 1976a).

Subsequent sampling by the Indiana State Board of Health in 1975 and 1976 showed an improvement in Whitewater Lake's trophic condition, as evidenced by a decrease in nutrient concentrations, phytoplankton counts, and turbidity. Although the lake is still considered eutrophic, recreational uses at the beach have rarely been impaired due to excessive algal or macrophyte development or high coliform counts (W. McInerny, IDNR Division of Engineering, personal communication, 1987). However, because of a recurring problem with siltation, the lake has been dredged periodically since 1978 (M. Gentry, IDNR Division of State Parks, personal communication, 1987).

Brookville Lake, Indiana's second deepest manmade reservoir, is a large, moderately eutrophic lake of good water quality (Index 21, Class 1). The eutrophication index computed by the IDEM in 1985 is only two eutrophy points less than the index calculated in 1979, which indicates a stability of the lake's overall water quality.

Epilimnetic total phosphorus in Brookville Lake was the lowest of 12 Indiana lakes and reservoirs recently sampled by the IDEM, and phosphorus levels were less than the detection level of 0.03 mg/l in all three sections of the lake that were tested. (The maximum total phosphorus concentration recommended for prevention of nuisance algal production in non-flowing waters is 0.05 mg/l; Hardy, 1984). Fish and sediment samples collected in 1985 contained no *toxic* substances such as metals, *polychlorinated biphenyls*, and pesticides in amounts great enough to be of concern (Indiana Department of Environmental Management, [1986]).

Both beneficial and detrimental effects on water quality can result from impounding water. Some beneficial effects of Brookville Lake on the water quality of East Fork Whitewater River include reductions in turbidity, alkalinity, hardness, and biochemical oxygen demand, primarily due to the decreased turbulence and longer residence time of reservoir water. The reduction in bicarbonate, the major component of alkalinity, is apparent from fig. 21 for the two stations on the East Fork Whitewater River upstream and downstream of Brookville Lake. The figure also shows the reduction of calcium and magnesium, the principal components of hardness.

A major detrimental effect due to impounding river water results from thermal stratification and the consequent degradation of water quality in the lower layer of the reservoir, or *hypolimnion*. Summer stratification of Brookville Lake, which occurs when surficial waters are heated by the sun, can be illustrated by depth profiles of selected constituents in the lake's deepest basin (fig. 22).

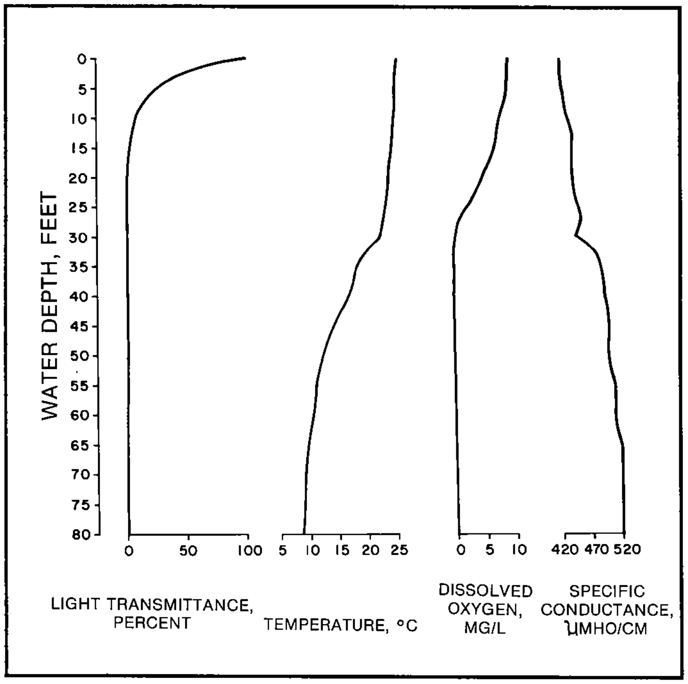


Figure 22. Depth profiles of selected physical parameters at Brookville Lake near dam

(Data from the Indiana Department of Environmental Management, August 1985)

As is typical in a thermally stratified lake, the abundance of suspended matter limits the penetration of sunlight to the hypolimnion; consequently, oxygen-producing photosynthesis does not occur and the hypolimnion becomes anoxic (fig. 22). Although the anoxic conditions can impact downstream water quality if hypolimnetic lake water is released, no detrimental impacts have been documented. An anoxic hypolimnion also limits the usefulness of bottom waters as fish habitat, but no significant decrease in the quality of fisheries has been observed (D. Kingsley, IDNR Division of Fish and Wildlife, personal communication, 1987). Other effects and potential effects of impoundment on water quality and biota are discussed in an environmental impact statement by the U.S. Army Corps of Engineers (1974).

GROUND-WATER HYDROLOGY

Ground-Water Data

Ground-water data for the Whitewater River Basin come from several sources, including water-well records, the observation well network, lithologic logs, seismic information, and localized project data (for example, pumping tests and other analytical and mathematical models).

Since 1959, water-well drilling contractors have been required to submit a complete record to the IDNR of every water well that is drilled. More than 3000 water-well records maintained in the IDNR, Division of Water files for the Whitewater River Basin were reviewed and screened for the ground-water assessment portion of this study. Most of the records are for wells less than 150 feet in depth.

Water-level data in the Whitewater River Basin have been collected from observation wells by the U.S. Geological Survey in cooperation with the IDNR (formerly the Department of Conservation) since 1946. In northwestern Fayette County (fig. 14), observation well Fayette-2 monitored ground-water levels from 1946 to 1970. In central Union County, observation well Union-6 began recording in 1966, but was discontinued in 1974. Fayette-2 was used to record water-level changes within till and Union-6 monitored the ground water in limestone bedrock.

From 1966 to present, water-level data have been collected from observation well Wayne-6 located in southwestern Wayne County (fig. 14). In central Franklin County, observation well Franklin-5 has recorded ground-water level data for the periods of 1968 to 1971 and 1974 to present. The two wells monitor natural fluctuations in water levels within Pleistocene outwash deposits.

The water-level fluctuations for Wayne-6 and Franklin-5 (fig. 23) are typical of the changes expected for outwash *aquifers*. During the wet seasons of winter and spring, the water level plots show a rise in the *piezometric surface*. In the summer and autumn, the water levels fall in response to decreased aquifer *recharge*. Data for all of the years plotted in fig. 23 show this same pattern. Also, the extremes of ground-water levels during the 5-year period plotted in fig. 23 only cover a range of 7.5 feet. This relatively small amount of fluctuation is an indicator of the large volume of ground water held in storage.

Based upon a Division of Water review, the two observation wells in the Whitewater Basin are adequate for monitoring water-level fluctuations in outwash valley-train deposits commonly used for water supply. Because the potential for high-capacity pumpage elsewhere in the basin is quite small, no additional observation wells are needed at this time.

Piezometric Surface

The ground-water level within an aquifer constantly fluctuates in response to rainfall events, evapotranspiration, ground-water movement (including recharge and discharge), and ground-water pumpage. Maximum fluctuations recorded at four observation wells in the Whitewater Basin average 8 feet. Because the natural fluctuations are small, static water levels from wells can be used to approximate regional ground-water flow direction.

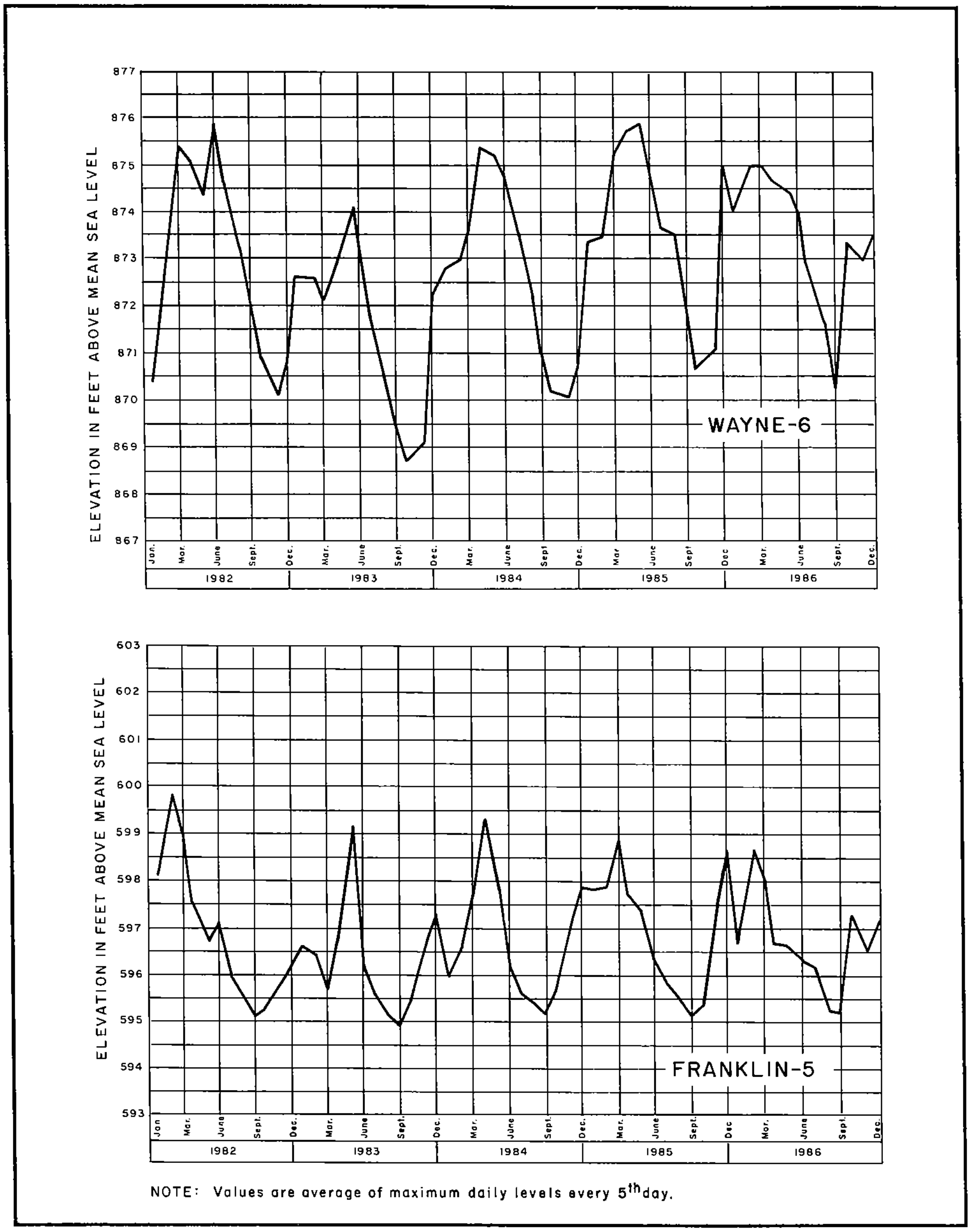
Static water levels used to develop the piezometric surface map for the Whitewater River Basin (pl. 2) include data for aquifers at various depths. The map represents a composite of water levels of the major aquifer systems, and it may or may not be a true representation of water levels in very shallow or very deep aquifers.

The piezometric surface map (pl. 2) can be used to define the probable flow path of contaminants and to identify significant areas of ground-water recharge and discharge. In a general way, the piezometric surface approximates overlying topography and intersects the land surface at major streams. The map can also be used to calculate expected depths to water in a well, but not to determine recommended depths of wells. At any specific site, the appropriate well depth can only be determined by an understanding of the local geologic conditions.

In the Whitewater River Basin, ground-water levels range from an elevation of 1165 feet m.s.l. in Randolph County to a low of about 500 feet m.s.l. where the Whitewater River enters the state of Ohio. Regional ground-water flow, which generally reflects regional topographic drainage, is toward the Whitewater River and its major tributaries (pl. 2).

Whitewater River Basin Aquifer Systems

The aquifer systems of the Whitewater River Basin can be broadly divided into two classes, unconsolidated aquifer systems and the underlying bedrock aquifer systems. The unconsolidated systems include the *intratill* Wayne-Henry, Fayette-Union, and Dearborn Aquifer Systems and the Whitewater Valley Aquifer System (pl. 3). These unconsolidated systems, sub-



NOTE: Values are average of maximum daily levels every 5th day.

Figure 23. Monthly water levels in observation wells Wayne-6 and Franklin-5

divided on the basis of similar aquifer and geologic conditions, are mainly composed of glacially derived tills, lacustrine clays, and sands and gravels of perhaps pre-Illinoian to Wisconsinan age. The bedrock systems, subdivided on the basis of water-producing rock strata, are the Ordovician Aquifer System and the Silurian Aquifer System. These systems are composed primarily of sequences of limestones, dolomites, and shales. Table 11 summarizes selected characteristics of the unconsolidated and bedrock systems within the Whitewater Basin.

Wayne-Henry Aquifer System

The Wayne-Henry Aquifer System is approximately bounded to the north by the Knightstown Moraine (fig. 11). The surficial deposits in this area are Wisconsinan tills identified by Burger and others (1971) and Gray and others (1972) as ground moraine or end moraine. Aquifer characteristics are not distinctly different between areas mapped as end moraine (the Knightstown Moraine) and areas mapped as ground moraine.

The dominant aquifers within the Wayne-Henry System are intratill sand and gravel lenses. These aquifers are highly variable in depth and lateral extent and are *confined* by variably thick clay or till sequences. Aquifer materials range from very fine sand or muddy sand to coarse gravel. Individual aquifers within this system are usually not traceable beyond small, limited areas. One exception occurs west and southwest of Richmond, where well data show a fairly extensive, definable aquifer (see Centerville Subsystem in pl. 3).

The thickness of the Wayne-Henry System ranges from 30 feet or less over areas of high bedrock to 300 feet or more in buried bedrock valleys. The thickness of aquifer materials within the system ranges from 0 feet (all clay, often a *dry hole*) to 40 feet. Common thicknesses are less than 10 feet.

The Wayne-Henry Aquifer System contrasts sharply with the Whitewater Valley Aquifer System, which transects it (pl. 3). The intratill Wayne-Henry aquifers are generally deeper than the Whitewater aquifers and are confined within till sequences dominated by clays. Water-bearing units of the Whitewater Aquifer System are *unconfined*, usually fairly shallow, and are characterized by thick sequences of sand and gravel with little clay.

The boundary between the Wayne-Henry Aquifer System and the Fayette-Union Aquifer System which borders it to the south is not distinct. Although both are intratill systems, the Wayne-Henry System has thicker, more numerous, and more productive sand and gravel zones than the Fayette-Union System.

Well depths in the Wayne-Henry System are highly variable and are influenced by the bedrock elevation and the depth to productive sand and gravel zones within the tills. Although well depths in this system vary from 14 to 254 feet, most wells range from 70 to 150 feet deep. The deepest wells are associated with buried bedrock valleys filled with till. The shallowest wells, 30 feet deep or less, are usually *bucket-rig wells* drawing water from thin sand and gravel layers or from clays overlying bedrock highs.

The elevations of water-bearing zones in the Wayne-Henry System vary substantially. In general, aquifer elevations reflect surface elevations and therefore are highest along basin boundaries and lowest near major drainageways. Aquifer elevations generally decline toward the south. Elevations in northern parts of the system range from 900 to 1150 feet m.s.l. but are usually in the range of 1030 to 1120 feet m.s.l. Along the southern boundary of the system, aquifer elevations range from 790 to 1065 feet m.s.l., but most wells produce from aquifers of elevation 850 feet m.s.l. or higher.

The confined intratill aquifers within the Wayne-Henry System often have only slight hydrologic connections; therefore, static water levels may differ significantly within a small area. Static water levels throughout the Wayne-Henry System range from 0 feet (land surface or above) to 105 feet. Most static water

Table 11. Summary of unconsolidated and bedrock aquifer systems

Aquifer system	Area (sq mi)	System type	Avg. aquifer thicknesses (ft)	Range of well yields (gpm)	Expected well yields (gpm)	Static water levels (ft)
Wayne-Henry	448	Intratill	10	0 - 150	6 - 15	20 - 50
Fayette-Union	362[1]	Intratill	2 - 4	0 - 60	2 - 10	20 - 40
Dearborn	464	Intratill	0 - 2	0 - 20	0 - 2	3 - 40
Whitewater	103	Valley train	25 - 75	50 - 1200	500	0 - 30
Ordovician	1034[1]	Bedrock	10 - 100	0 - 50	0 - 8	15 - 50
Silurian	342[1]	Bedrock	10 - 100	0 - 60	10	<50

[1] Includes area of the county to the Ohio border outside the basin boundary.

levels, however, range from 20 to 50 feet below land surface. *Flowing wells*, although quite rare, occur sporadically throughout the system.

Well yields in the Wayne-Henry Aquifer System are usually adequate for domestic supply purposes; however, low-yield wells and dry holes have sometimes been reported. Most wells yield 15 gpm (gallons per minute) or less, but reported yields range from 0 to 150 gpm. High-capacity wells (70 gpm or greater) are fairly uncommon.

In the area west and southwest of Richmond, a fairly consistent intratill sand and gravel zone has been delineated (see Centerville Subsystem in pl. 3). This zone ranges from 1 to 25 feet in thickness but is usually about 5 feet thick. Wells range from 50 to 120 feet deep. The elevation of the top of the subsystem is between 960 and 990 feet m.s.l. Static water levels range from 13 to 80 feet but are usually between 25 and 50 feet. Wells yield from 6 to 30 gpm, and most wells produce at least 10 gpm.

Fayette-Union Aquifer System

The Fayette-Union Aquifer System is bounded to the north by the gradational contact with the Wayne-Henry Aquifer System (pl. 3). The southern boundary is also gradational but approximately coincides with the Hartwell Moraine (fig. 11), which marks the southern limit of Wisconsinan glaciation in the Whitewater Basin.

The Fayette-Union Aquifer System is mainly composed of glacial tills which contain intratill sand and gravel aquifers of limited thickness and extent. The grain size of aquifer materials in the intratill deposits varies locally and ranges from fine or muddy sand to coarse gravel.

Thickness of intratill sand and gravel lenses ranges from 0 to 30 feet throughout the Fayette-Union Aquifer system, but generally is about 2 to 4 feet. Thicker layers occasionally are found in areas near the Whitewater Valley Aquifer System, which occupies the Whitewater River Valley.

The boundary between the Fayette-Union and Whitewater Valley Aquifer Systems is distinct (pl. 3). The thick outwash sands and gravels of the Whitewater System contrast sharply with the clay-rich composition of the Fayette-Union System. To the south, the boundary between the Fayette-Union Aquifer System and Dearborn Aquifer System is gradational and not clearly defined (pl. 3). Both systems have clay-rich till sequences overlying bedrock; however, the Fayette-Union System has thicker deposits of Wisconsinan till, whereas the Dearborn System has thinner deposits of predominantly pre-Wisconsinan age. In general, sand and gravel zones in the Fayette-Union Aquifer System are thicker, more numerous, and more productive than those in the Dearborn Aquifer System.

Well depths in the Fayette-Union Aquifer System are influenced by bedrock elevation and the depth to productive sand and gravel layers within the thicker tills. Well depths range from 11 to 260 feet, but most wells are 30 to 70 feet deep. The shallowest wells are usually found in thin tills overlying bedrock highs or in thin, shallow outwash deposits in minor tributary valleys of the Whitewater River. The deeper wells are in areas where thick till occurs within buried bedrock valleys.

Intratill aquifer elevations range from 780 to 1078 feet m.s.l. Aquifer elevations are highest along the basin's western topographic boundary in western Fayette County, along the eastern boundary in eastern Union County, and on the drainage divide between the east and west forks of the Whitewater River. The lowest aquifer elevations occur in areas adjacent to the Whitewater Valley Aquifer System. Aquifers most commonly occur between 900 and 1030 feet m.s.l. in upland areas and between 780 and 900 feet m.s.l. in lowland areas.

Most wells of the Fayette-Union Aquifer System produce from intratill sand and gravel deposits and are therefore confined by some thickness of clay or till. Static water levels range from 0 to 90 feet but are usually between 20 and 40 feet. Flowing wells are extremely rare.

Well yields in the Fayette-Union Aquifer System are variable, but generally only fair to poor yields may be expected. Wells drilled in this system produce from 0 to 60 gpm; however, most wells average only 2 to 3 gpm, and supplemental storage is often required in order to meet peak demands for domestic needs. Although ground-water conditions in the Fayette-Union Aquifer System are limited, dry holes are uncommon. Most wells can produce at least the minimum amount necessary for small household domestic purposes (1 to 2 gpm). Because significant sand and gravel aquifer zones are commonly absent in much of the Fayette-Union Aquifer System, bucket-rig wells are frequently used. These wells draw water from thin sand zones or from seepage from fractures within the till. Few high-capacity wells are present, nor can they be reasonably expected, in this aquifer system.

A small area of the Fayette-Union System in northeast Union County has been subdivided because of the more frequent occurrence of notable sand and gravel deposits (see Liberty Subsystem in pl. 3). Sand and gravel aquifers in the Liberty Subsystem average about 4 feet in thickness, and aquifer elevations are usually between 950 and 1050 feet m.s.l. Drilled wells, which range from 33 to 130 feet deep, have yields ranging from 4 to 40 gpm. Most wells yield about 10 gpm, a sufficient amount for a typical domestic supply. Bucket-rig wells are less common due to the presence of thicker, more productive sand and gravel layers.

Dearborn Aquifer System

The Dearborn Aquifer System, which covers the southern portion of the Whitewater Basin, has the most limited ground-water resources of the unconsolidated aquifer systems (pl. 3). Unconsolidated materials of the Dearborn Aquifer System consist of thin, eroded residuum and predominantly pre-Wisconsinan tills.

Thin layers of intratill sand and gravel occasionally occur, but most often only clay is encountered above bedrock. Sand and gravel lenses can approach 15 feet in total thickness but are more commonly only 1 to 2 feet thick. Bucket-rig wells may produce water from thin sands, gravels, or clay or till units in this system.

The Whitewater Valley Aquifer System cuts through the Dearborn System (pl. 3). The boundary between these two systems is sharply defined by geologic materials, aquifer elevations, and water availability.

The depths of wells in the Dearborn System range from 25 to 70 feet, although most wells are less than 50 feet deep. Aquifer elevations are typically at or above 900 feet m.s.l. Static water levels range from 3 to 40 feet. Well yields range from 0 to 20 gpm, although most wells produce only a few gpm. Dry holes are fairly common. No flowing wells have been reported.

Whitewater Valley Aquifer System

The Whitewater Valley Aquifer System occupies the valleys of the Whitewater River and its major tributaries. This system has long, narrow, north-south trending branches which cut through the other unconsolidated aquifer systems in the basin (pl. 3).

The system contains large volumes of sand and gravel which were deposited by glaciers and now fill the major stream valleys. As the glaciers melted, sediment contained within them was delivered to adjacent streams in quantities too large for the streams to transport. As a result, the increased sediment load was stored in the valleys as vertical and lateral accretionary deposits. As long as the retreating glaciers continued to provide sediment in quantities too large for the streams to transport, the valleys continued to be filled. In this way, thick deposits of outwash sand and gravel accumulated in the valleys of the Whitewater River and its tributaries.

The sand and gravel deposits of the Whitewater Valley Aquifer System range from less than 10 feet to more than 100 feet in thickness. In most areas of the system, outwash deposits are between 25 and 75 feet thick. Throughout the basin, the thick sands and gravels of the Whitewater Valley Aquifer System abruptly contrast with the clay-rich or bedrock environments of the surrounding aquifer systems.

Well depths in the Whitewater System range from 10 to 120 feet, but most wells are between 30 and 60 feet deep. The elevation of the aquifer system varies uniformly from north to south. Along the basin boundary in Randolph County, the aquifer system elevation is about 1110 feet m.s.l. Where the system leaves the state in Dearborn County, the elevation is approximately 600 feet m.s.l. for the upper terraces and approximately 500 feet m.s.l. for the modern valley outwash.

Because the system is largely unconfined, static water levels are more consistent than in the surrounding aquifer systems and are generally shallower. Average static water levels of 30 feet or less are common throughout the system.

The Whitewater Valley Aquifer System is by far the most productive aquifer system in the basin, and is the only system with the potential to consistently meet the needs of high-capacity users. Well yields of 500 gpm can be expected throughout most of the system. Presently there are a few wells which have the capacity to produce up to 1200 gpm.

In some areas of the Whitewater Valley Aquifer System, thick zones of sand and gravel have been covered by a layer of clay or till (see cross-hatched area on pl. 3). These areas are surficially similar to the adjacent Wayne-Henry Aquifer System, but the sand and gravel aquifer zones are depositionally related to the Whitewater System.

Thickness of the sand and gravel zones in these areas ranges from 12 to 54 feet. Most well logs show 20 to 30 feet of sand and gravel, although the upper portions are often unsaturated. Well depths range from 34 to 87 feet. The elevation of the top of the sand and gravel zone ranges from about 900 to 940 feet m.s.l. Static water levels are between 10 and 46 feet. Domestic wells in this area yield from 10 to 18 gpm, and one high-capacity well producing 140 gpm was reported.

Ordovician Bedrock Aquifer System

Ordovician bedrock aquifers, which occur in the central portion of the Whitewater River Basin, underlie a much larger portion of the basin than the Silurian bedrock aquifers. Most of Wayne, Fayette, Union, Ripley, and Dearborn Counties are underlain by the Ordovician Bedrock Aquifer System (pl. 3).

Although the Ordovician bedrock is only marginally productive, it nonetheless is used as a water source, especially in the southern portions of the basin where other potential aquifers are often absent. Records for wells penetrating Ordovician rocks in the Whitewater Basin usually indicate multiple layers of limestone and shale, occasionally only shale, and rarely only limestone.

Wells completed in the Ordovician Bedrock Aquifer System range from 40 to 350 feet deep. Well depths are highly variable throughout the basin but generally decrease from north to south. Well depth depends on bedrock elevation and drift thickness. The amount of penetration into the bedrock is also highly variable, and ranges from about 10 to more than 100 feet. Well productivity does not appear to be significantly correlated with the amount of bedrock penetration. Elevation of the top of the bedrock surface is shown on pl. 1. Static water levels range from 0 to 140 feet but are usually between 15 and 50 feet.

Wells in the Ordovician Bedrock Aquifer System generally produce from 0 to 8 gpm. A well yielding 50 gpm was recorded, although wells producing significantly more than 10 gpm are rare. Dry holes are fairly common. *Drawdowns* associated with wells in the Ordovician Bedrock Aquifer system are often extreme. Even with low pumping rates, wells will often pump dry and drawdowns of more than 50 feet are commonly reported.

Silurian Bedrock Aquifer System

Silurian bedrock aquifers are found along the north, northeast, and west margins of the Whitewater Basin (pl. 3). Records for wells in the Silurian System usually indicate fairly thick sequences of limestone. Some shale is occasionally reported, most commonly near the Silurian-Ordovician contact. Depths of wells vary from about 100 to 330 feet, but most wells are 150 to 200 feet deep. Some wells penetrate 15 to 60 feet into the limestone, although 30 feet or less is usual. Static water levels range from 20 to 70 feet but are typically 50 feet or less.

Well yields in the Silurian Bedrock Aquifer System range from 0 to 60 gpm. The best Silurian bedrock production is in Randolph County along the northern edge of the basin. Although one dry hole was reported in this area, nearly all wells produce more than 10 gpm, and wells producing 30 to 60 gpm are common. Farther south in the basin, the capacity of the Silurian Bedrock Aquifer System decreases. In areas within a few miles of the Silurian-Ordovician contact, wells usually produce 10 gpm or less and dry holes are occasionally reported. Drawdown values are high in these areas and wells may pump dry.

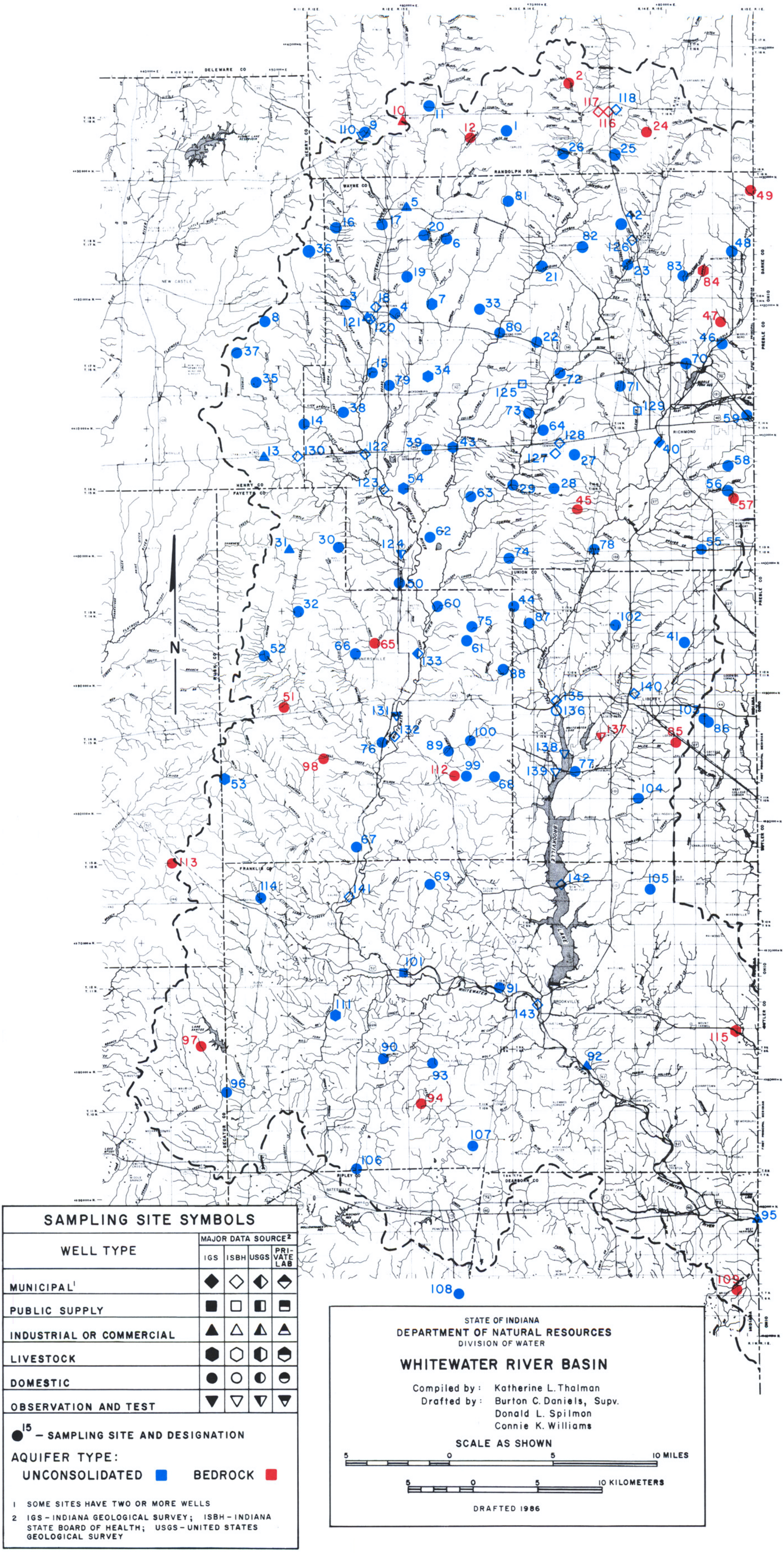
Ground-Water Quality

Chemical data on water samples from a total of 153 wells were used to characterize the ground-water quality of the unconsolidated and bedrock aquifer systems defined in the Whitewater River Basin (fig. 24). Major sources of information included: 1) 114 ground-water samples collected from domestic, stock, industrial, municipal, and public supply wells in a cooperative effort between the Division of Water and the Indiana Geological Survey (fall 1985); 2) Indiana State Board of Health analyses of municipal, public supply, and test wells; and 3) U.S. Geological Survey analyses of observation and municipal wells. Most data summarized in this report were collected between 1974 and 1985; however, older data were occasionally utilized. Data for individual wells are tabulated in app. 12.

The distribution of sample sites reflects water availability in the basin. For example, only nine wells were sampled in the Dearborn Aquifer System. In this area, ground-water resources are limited and fewer wells, which are predominantly bucket-rig wells, were available for sampling.

Data from wells in the Whitewater Basin are treated as point values; however, the data actually represent the average concentration of a certain unknown volume of the aquifer. The extent of aquifer representation primarily depends on the depth of the well in question, the *hydraulic conductivity* of the aquifer, and the rate of pumping (Sasman and others, 1981). In addition, water collected from deep bedrock wells can be a mixture of water from different production zones.

A number of factors may cause the alteration of original aquifer water before and after sampling, such as contact with plumbing, residence time in a pressure tank, method of sampling, and time elapsed between sampling and laboratory analysis. In addition, bucket-rig wells were not completely flushed of well water that had been exposed to the atmosphere. Because the



SAMPLING SITE SYMBOLS

WELL TYPE	MAJOR DATA SOURCE[2]			
	IGS	ISBH	USGS	PRIVATE LAB
MUNICIPAL[1]	◆	◇	⬖	⬘
PUBLIC SUPPLY	■	□	◧	⬒
INDUSTRIAL OR COMMERCIAL	▲	△	◭	▲
LIVESTOCK	⬢	⬡	⬢	⬢
DOMESTIC	●	○	◐	◓
OBSERVATION AND TEST	▼	▽	⧨	▼

●15 – SAMPLING SITE AND DESIGNATION

AQUIFER TYPE:

UNCONSOLIDATED 🟦 BEDROCK 🟥

1 SOME SITES HAVE TWO OR MORE WELLS

2 IGS – INDIANA GEOLOGICAL SURVEY; ISBH – INDIANA STATE BOARD OF HEALTH; USGS – UNITED STATES GEOLOGICAL SURVEY

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

WHITEWATER RIVER BASIN

Compiled by: Katherine L. Thalman
Drafted by: Burton C. Daniels, Supv.
Donald L. Spilmon
Connie K. Williams

SCALE AS SHOWN

5 0 5 10 MILES

5 0 5 10 KILOMETERS

DRAFTED 1986

Figure 24. Ground-water quality sampling locations

degree to which these factors affect original aquifer water is unknown, the ground-water analyses used in this study generally typify the quality of ground water at the tap rather than the composition of in-situ aquifer water. Despite these potential sources of variability, results of the sample analyses can provide valuable information on ground-water quality characteristics of aquifer systems in the Whitewater River Basin.

National Interim Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 1986a, 1986c) and National Secondary Drinking-Water Regulations (U.S. Environmental Protection Agency, 1979) were examined to determine the suitability of ground water in the Whitewater Basin for public supply (app. 7; also see table 12). The primary regulations list *maximum contaminant levels* for inorganic constituents considered toxic. Although these concentration limits are enforceable only in public water supply systems, they can be used to assess ground-water quality for privately owned wells. The secondary regulations specify *contaminant* levels for inorganic constituents that are not known to be harmful to health but that have undesirable aesthetic effects (taste and odor). Secondary drinking-water standards are not mandatory and are commonly exceeded in ground-water supplies. General water quality criteria for irrigation and stock are also given in app. 7; however, they will not be discussed in detail.

Table 12. Significance of selected chemical constituents

Constituent	Remarks	Constituent	Remarks
Sulfate	Concentrations greater than 250 mg/l, the secondary maximum contaminant level, in combination with ions (especially sodium and magnesium) can impart odors and a medicinal or bitter taste to water. Amounts above 600 mg/l may have a laxative effect for people unaccustomed to sulfate-rich water.	Iron	Concentrations exceeding 0.3 mg/l, the secondary maximum contaminant level, cause staining of laundry, utensils and fixtures and may impart a metallic taste to water. Values above 0.5 mg/l may cause well screens to become encrusted. Large quantities stimulate the growth of iron bacteria.
Chloride	Concentrations in excess of 250 mg/l, the secondary contaminant level, in combination with high sodium may impart a salty taste. Amounts above 1000 mg/l may be physiologically unsafe. Large amounts may accelerate corrosion.	Manganese	Concentrations above 0.2 mg/l discolors food during cooking and stains laundry utensils and fixtures black. Food and water may have a metallic taste at amounts above 0.5 mg/l. Amounts as low as 0.1 mg/l stimulate growth of certain bacteria. Manganese tends to precipitate at concentrations above 0.05 mg/l, the secondary maximum contaminant level, and may form a filter clogging sludge or slime.
Fluoride	Fluoride concentrations ranging from 0.7 to 1.4 mg/l help prevent tooth decay. Amounts above 2 mg/l, the secondary maximum contaminant level, may cause mottled teeth. Crippling skeletal defects may occur with concentrations above 4 mg/l, the maximum contaminant level.		
Nitrate as nitrogen	Concentrations above 20 mg/l impart a bitter taste to drinking water. Concentrations greater than 10 mg/l, the maximum contaminant level, may cause infant methemoglobinemia, a disease characterized by cyanosis or a bluish coloration of the skin.	Total Dissolved Solids	Water with concentrations greater than 500 mg/l, the secondary maximum contaminant level, may have a disagreeable taste. Amounts greater than 1000 mg/l may accelerate corrosion of well screens, pumps and casings and cause foaming and scaling in boilers.

References: Hunn and Rosenshein, 1969; Governor's Water Resource Study Commission, 1980; Lehr and others, 1980; Todd, 1980; and U.S. Environmental Protection Agency, 1986a.

Factors Affecting Ground-Water Chemistry

The chemical composition of both recharge water infiltrating through the soil zone and ground water in an aquifer is the result of the interrelationship of many complex factors, including the composition and solubility of rock or rock materials in the soil or aquifer, water temperature, partial pressure of carbon dioxide gas, acid-base reactions, and oxidation-reduction reactions. Furthermore, mixing of ground water from adjacent strata, the loss or gain of constituents as water percolates through clay layers (adsorption-desorption), and the residence time of water are also important factors which affect the composition of aquifer water.

Rain and snow, the major sources of recharge to ground water, contain small amounts of dissolved solids and gases such as carbon dioxide, sulfur dioxide, oxygen, nitrogen, and argon. As the rain infiltrates through the soil, biologically-derived carbon dioxide reacts with the water, forming a weak solution of carbonic acid. The reaction of free oxygen with reduced iron minerals such as pyrite is an additional source of acidity. Concentrations of chemical constituents such as bicarbonate, sodium, calcium, magnesium, chloride, iron, and manganese are increased or added as the slightly acidic water dissolves soluble rock material. As ground water slowly moves along a flow path in the zone of saturation (aquifer), the composition of water continues to change, usually by the addition of dissolved constituents (Freeze and Cherry, 1979).

With longer residence time, concentrations of dissolved solids in ground water usually increase as reactions approach equilibrium. Ground water in recharge areas commonly contains lower concentrations of dissolved constituents than water occurring deeper in the same aquifer or in shallow discharge areas (Freeze and Cherry, 1979). Also, because recharge to intratill aquifers travels slowly through clay- and silt-rich materials of low permeability, these aquifers usually contain ground water with greater concentrations of dissolved solids than outwash aquifers, which are composed of more permeable sand and gravel deposits.

Elevated concentrations of natural inorganic components and of organic components may be induced by man. The susceptibility of an aquifer to contamination depends on the geologic setting. Contamination is less likely to occur in intratill aquifers because they are protected by layers of low-permeability clay which retard the vertical and horizontal migration of potential pollutants. In contrast, valley-train aquifers are highly susceptible to contamination because protecting clay layers are either discontinuous or absent. Protection of bedrock aquifers from contamination depends on the thickness of overlying outwash, till, or soil. Pl. 3 briefly summarizes the susceptibility to contamination of six aquifer systems identified within the Whitewater Basin.

Basin Assessment

Ground water in the Whitewater River Basin is primarily of the calcium bicarbonate type, which is characterized by high alkalinities, high hardness, and mostly basic pH. Major chemical constituents include bicarbonate, calcium, magnesium, sodium, sulfate, and chloride. Less abundant components include iron, potassium, manganese, fluoride, and nitrate. Concentrations of these constituents, except bicarbonate, are given in app. 12 for each of the 153 selected wells. Additional information is on file at the Division of Water for bromide, phosphate, zinc, barium, strontium, and silica for most wells; however, such data are not presented in this report.

Alkalinity, the capacity of water to neutralize acid, can be produced by bicarbonate, carbonate, silicate, hydroxide, borates, and certain organic compounds. In ground water of the Whitewater Basin, alkalinity is predominantly produced by bicarbonate, which is mainly derived from 1) the atmosphere, 2) carbon dioxide produced in the soil zone, and 3) the solution of carbonate minerals (calcite and dolomite).

Median alkalinity values in the basin are high, and values range from 260.6 mg/l (milligrams per liter) as $CaCO_3$ (calcium carbonate) in the Dearborn Aquifer System to 355.2 mg/l as $CaCO_3$ in the Ordovician Aquifer System (fig. 25). The lowest concentrations of alkalinity (less than 300 mg/l as $CaCO_3$) occur primarily within the Dearborn Aquifer System and Whitewater Valley Aquifer System (fig. 26).

Lower alkalinity concentrations found in the Dearborn Aquifer System may be explained by two factors: 1) fewer carbonate minerals are available to produce alkalinity because these minerals have been leached from thick soils developed on the older pre-Wisconsinan till (Alfred and others, 1960); and 2) alkalinities are decreased as carbon dioxide is lost to the atmosphere from ground water stored in bucket-rig wells and carbonate minerals are precipitated (Gibb and others, 1981). The lower median alkalinity value in the Whitewater Valley Aquifer System may be explained by the shorter residence time of the ground water.

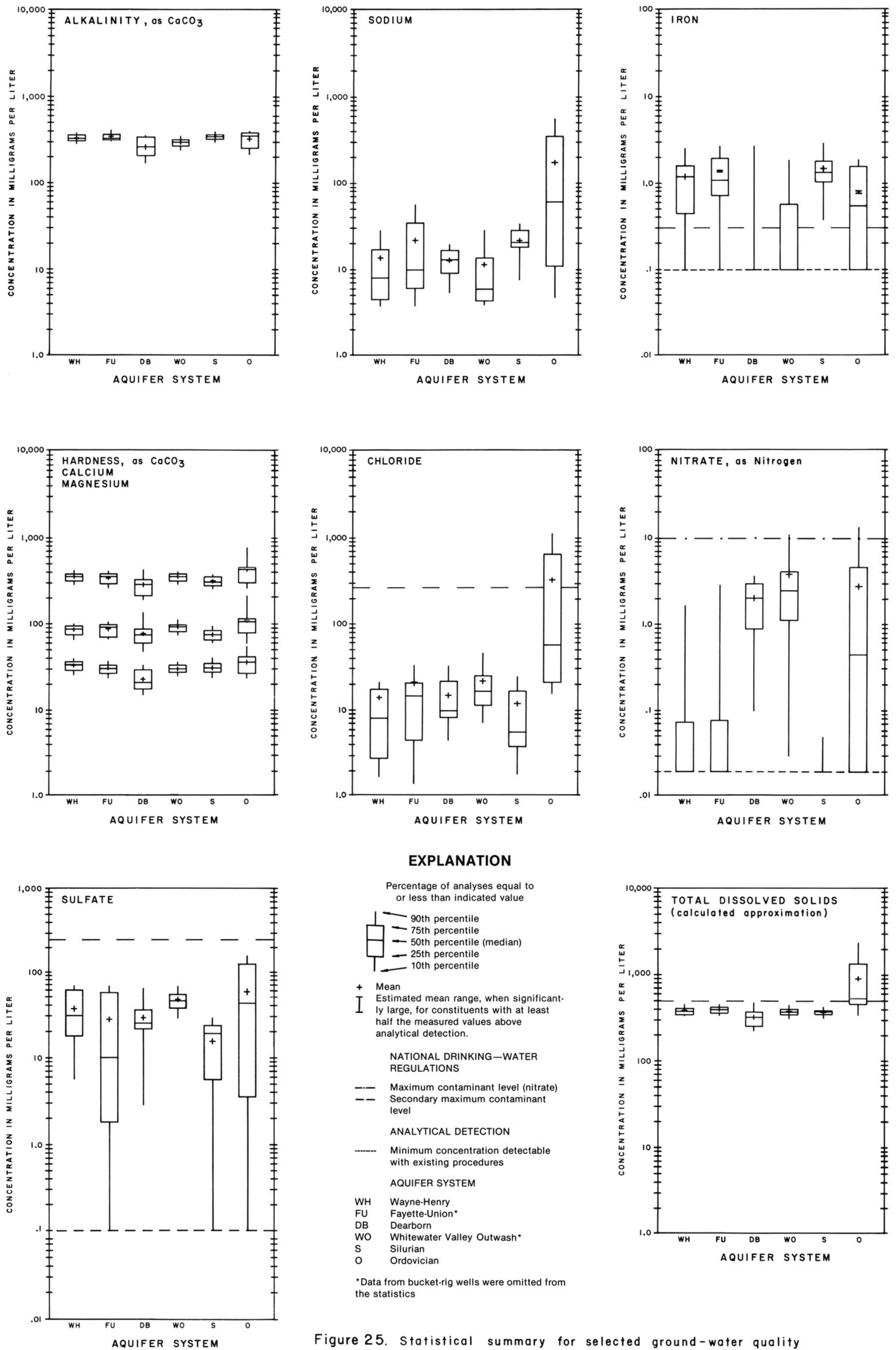


Figure 25. Statistical summary for selected ground-water quality constituents

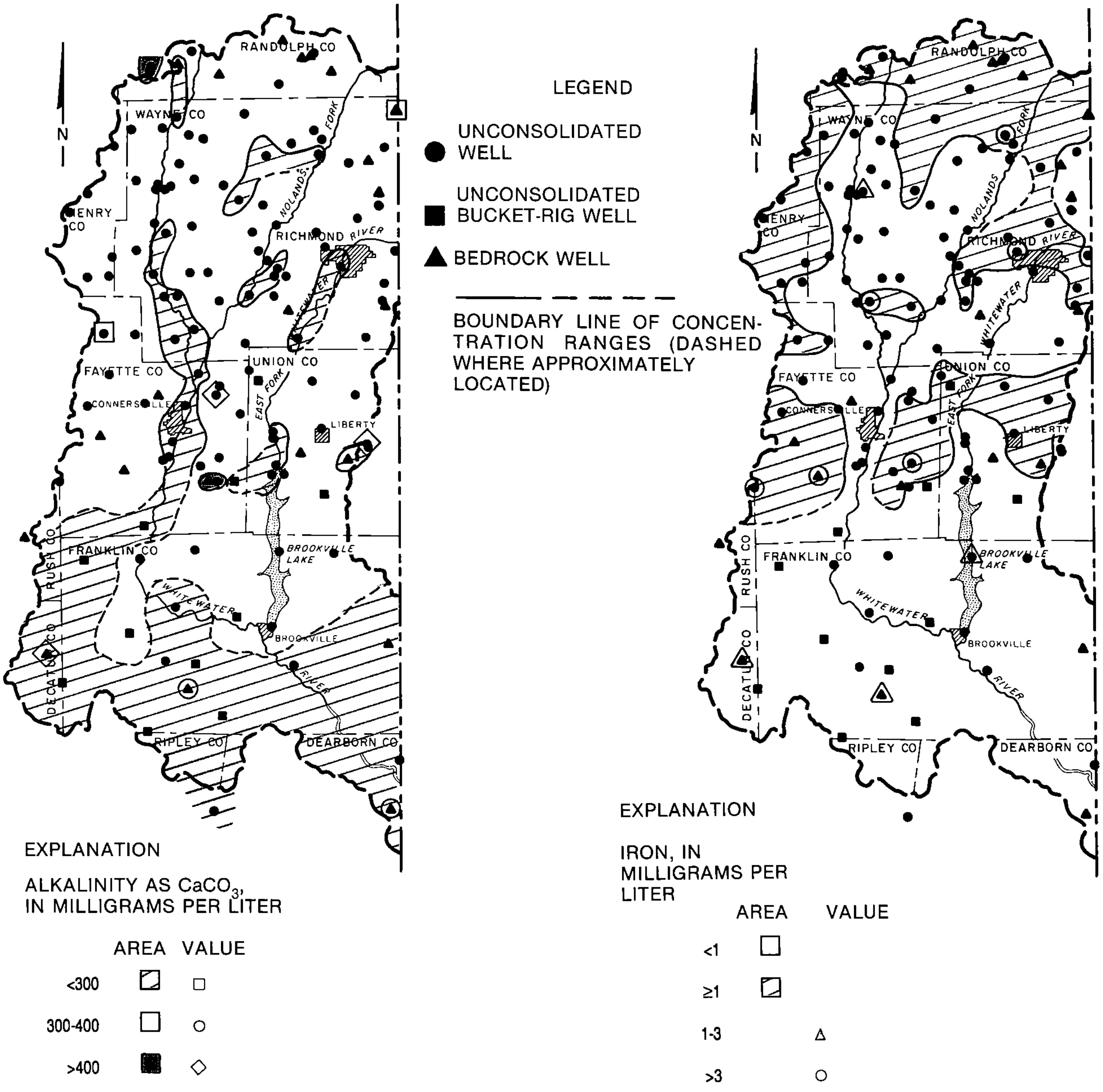


Figure 26. Generalized areal distribution of alkalinity and iron concentrations

Hard water and soft water are relative terms because water considered hard in one region might be considered soft by inhabitants of another region. For discussion purposes, however, the following scale can be used: soft water, 0—60 mg/l as $CaCO_3$; moderately hard water, 61—120 mg/l; hard water, 121—180 mg/l; and very hard water, more than 180 mg/l (Hem, 1985). Hardness is principally caused by calcium and magnesium. Hard water consumes excessive amounts of soap and detergents and forms an insoluble scum. In addition, hard water causes scale to encrust water heaters, boilers, and pipes, thus decreasing their capacity and heat transfer properties.

Median hardness values for all aquifer systems in the basin are significantly greater than 180 mg/l (fig. 25); in other words, ground water is very hard. Median hardness values are nearly identical for the Wayne-Henry, Fayette-Union, and the Whitewater Valley Aquifer Systems.

Median hardness, calcium, and magnesium values are lowest for the Dearborn Aquifer System and highest for the Ordovician Aquifer System (fig. 25). Lower calcium concentrations and hardness in the Dearborn Aquifer System may be caused by a lesser abundance of calcium minerals in the older leached pre-Wisconsinan till, and/or by precipitation of calcium carbonate in large-diameter bucket-rig wells as carbon dioxide is lost from stored water (Gibb and others, 1981). Higher concentrations in the Ordovician System may be explained by longer residence time of ground water in the aquifer.

The hydrogen ion activity in water (pH) is expressed on a scale of zero to 14. Water with a pH less than 7 is acidic, greater than 7 is basic, and equal to 7 is neutral. The pH of ground water in the basin is predominantly basic, but values range from 6.1 to 8.5 (slightly acidic to basic). Median values for all aquifer systems are similar and range from 7.0 to 7.3.

Sulfate, chloride, and sodium are major chemical constituents of ground water in the basin, although concentrations are usually less than bicarbonate and calcium. Sulfate concentrations did not exceed the secondary maximum contaminant level of 250 mg/l for drinking water in any of the wells sampled (fig. 25; table 12); however, values can be locally high. Three out of eight wells sampled in the Ordovician Aquifer System contained chloride concentrations which exceeded the recommended level of 250 mg/l (fig. 25; table 12). In addition, these three wells had sodium concentrations greater than 300 mg/l. A deep well completed in sediments overlying a buried bedrock valley in the Fayette-Union System and a shallow well in the Wayne-Henry System also contained elevated concentrations of chloride and sodium between 95 and 210 mg/l. A secondary maximum contaminant level has not been established for sodium; however, sodium in excess of 500 mg/l, when combined with chloride, produces a salty taste.

Median values of sulfate range from 10.2 mg/l in the Fayette-Union Aquifer System to 45.1 mg/l in the Whitewater Valley Aquifer System (fig. 25). In general, sulfate concentrations are greater for shallow wells where dissolved oxygen is present (oxidizing conditions) than deep wells where oxygen has been depleted (reducing conditions). Large percentile ranges of sulfate concentrations, characteristic of some aquifer systems (fig. 25), may be explained by the presence of variable concentrations of dissolved oxygen reacting with sulfide minerals. The high median sulfate value and small percentile range for the Whitewater Valley Aquifer System suggest the presence of a more consistent oxidizing environment and a source of sulfur such as the minerals pyrite and gypsum.

The bedrock aquifer systems have median chloride values of 5.7 mg/l in the Silurian Aquifer System and 57.4 mg/l in the Ordovician Aquifer System (fig. 25). In unconsolidated systems, median chloride values range from 8.2 mg/l in the Wayne-Henry System to 16.8 mg/l in the Whitewater Valley System (fig. 25). The Silurian and Ordovician Systems have median sodium values of 20.7 mg/l and 61.5 mg/l, respectively, and median values range from 6.0 mg/l to 13.2 mg/l in the unconsolidated aquifer systems (fig. 25). High median values of sodium and chloride in the Ordovician System may be explained by two factors: 1) inclusion of ancient seawater in the fine-grained shale, or the presence of sodium chloride-cementing material in the rock; or 2) longer residence time of the ground water. Bedrock wells containing high chloride concentrations were 290, 208, and 100 feet deep.

The secondary maximum contaminant level of iron in drinking water (0.3 mg/l) was commonly exceeded in wells sampled in the Wayne-Henry, Fayette-Union, Silurian, and Ordovician Aquifer Systems, and less commonly exceeded in the Dearborn and Whitewater Valley Aquifer Systems (figs. 25, 27; also see table 12). Manganese exceeded the detection limit of 0.1 mg/l in all aquifer systems except the Dearborn System (fig. 27; table 12). However, because the detection limit was twice the secondary maximum contaminant level of 0.05 mg/l, the percent of wells exceeding the standard could not be determined.

Median iron values are highest for the Silurian, Wayne-Henry, and Fayette-Union Aquifer Systems and lowest for the Dearborn and Whitewater Valley Aquifer Systems (fig. 25). Median values in the latter two systems were both less than the 0.1 mg/l detection limit. Iron concentrations in the Silurian Aquifer System are similar to those in the overlying glacial till, its major source of recharge. Ground water in the Wayne-Henry Aquifer System, the Knightstown Moraine and underlying Silurian bedrock are characterized by high concentrations of iron greater than 1 mg/l (fig. 26).

Lower iron concentrations in the Dearborn Aquifer System may be explained by two factors: 1) the reduction and transfer of iron in the pre-Wisconsinan till may have decreased the iron minerals available for solution (Nickell, 1981); 2) the iron originally present may have been oxidized and precipitated out before sampling when ground water stored in bucket-rig wells was exposed to the atmosphere (Hem, 1985). Lower concentrations in the Whitewater Valley System may be explained by the oxidizing conditions in the aquifer and

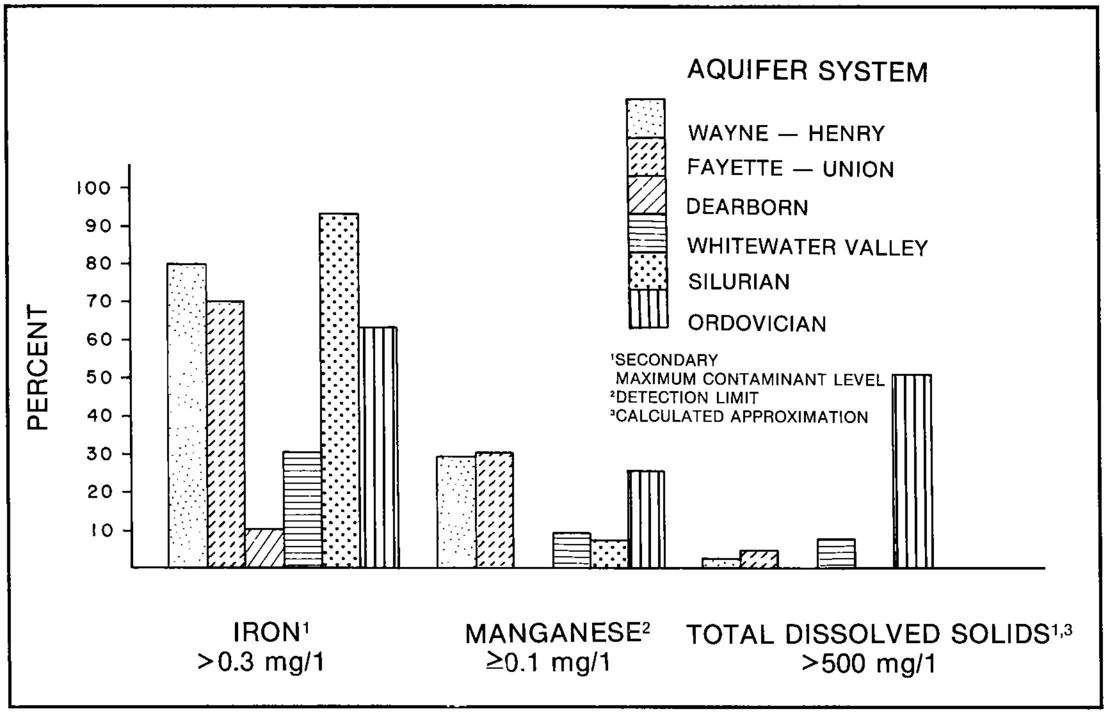


Figure 27. Percent of water samples exceeding selected concentration limits

the lower abundance of iron minerals in the sand and gravel. In general, average iron concentrations are greater in deep wells (greater than 100 feet deep) than in shallow wells (less than 60 feet deep).

Total dissolved solids (TDS) is a measure of the concentration of mineral constituents dissolved in water (table 12). TDS values used in this discussion and shown in app. 12 are the calculated sum of major constituents expected in an anhydrous residue of a groundwater sample. A good approximation of the determined residue on evaporation is calculated when 1) the concentrations of major ions are known, and 2) bicarbonate ions present in solution are converted to carbonate in the solid phase by a gravimetric factor, and the resulting carbonate value is used in the summation (Hem, 1985). App. 12 also includes values for total dissolved solids, "as reported," which is the sum of major constituents in which no adjustment of bicarbonate was made.

TDS values in the basin range from 224 to 2377 mg/l. In the wells sampled, concentrations of TDS did not exceed the secondary maximum contaminant level for drinking water of 500 mg/l in the Dearborn and Silurian Aquifer Systems. A small percentage of the wells sampled in the Wayne-Henry, Fayette-Union and Whitewater Valley Aquifer System contained concentrations of TDS above the standard. Concentrations of TDS in fifty percent of the wells sampled in the Ordovician Aquifer System exceeded the secondary maximum contaminant level (fig. 27).

Areas with higher concentrations of TDS (greater than 400 mg/l) occur primarily in the Wayne-Henry and Fayette-Union Aquifer Systems (fig. 28). Lower values of TDS (less than than 300 mg/l) are found mainly in the Dearborn Aquifer System. The median TDS value is lowest for the Dearborn System, which has the lowest median values of alkalinity, calcium, and magnesium (fig. 25). The median TDS value is

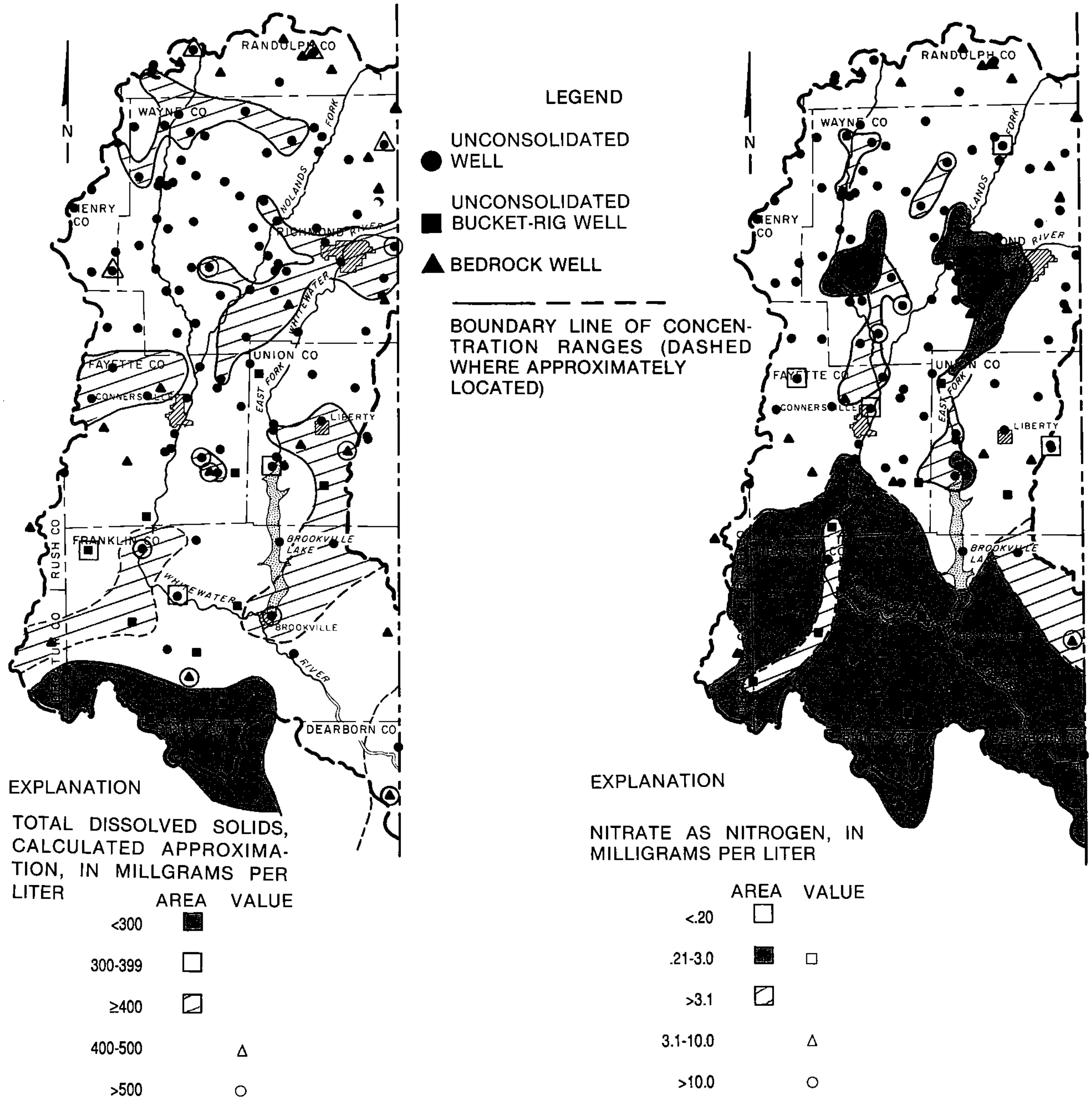


Figure 28. Generalized areal distribution of total dissolved solids and nitrate concentrations

highest for the Ordovician System, which has the highest median values of alkalinity, calcium, sodium, chloride, and magnesium. The remaining aquifers have median TDS values which range between 377 and 402 mg/l (fig. 25).

Natural concentrations of nitrate in ground water originate from the atmosphere and from living and decaying organisms. The majority of wells sampled in the Whitewater Basin contained concentrations of nitrate (as nitrogen) less than 0.20 mg/l (fig. 28). Concentrations less than this value are assumed by Madison and Brunett (1984) to represent natural background concentrations. Concentrations of nitrate (as nitrogen) between 0.21 and 3.0 mg/l that may or may not represent human influence are considered transitional (Madison and Brunett, 1984). Wells containing these concentrations are found primarily in the Dearborn and Whitewater Valley Aquifer Systems (fig. 28).

High levels of nitrates can result from leachates of industrial and agricultural chemicals or decaying organic matter such as animal waste or sewage. Concentrations of nitrate (as nitrogen) between 3.1 and 10 mg/l may indicate elevated concentrations of nitrate resulting from human activity (Madison and Brunett, 1984). Wells containing these levels are found mainly in the Whitewater Valley Aquifer System, which has been designated as highly susceptible to contamination (Indiana Department of Environmental Management, [1986]).

Four domestic wells sampled in the basin contained nitrate (as nitrogen) levels greater than 10 mg/l, the maximum contaminant level for public water supplies (app. 7; also see table 12). Three of the wells are located in the Whitewater Valley System and one well is located in the Ordovician Aquifer System (fig. 28). Insufficient grouting or infiltration of contaminated water through fractures in the 25-foot till cover may account for high nitrate (as nitrogen) concentrations in the Ordovician well.

Median concentration values of nitrate (as nitrogen) are greatest for ground water in the Whitewater Valley and Dearborn Aquifer Systems. Median values for the Wayne-Henry, Fayette-Union, and Silurian Systems are all less than the detection limit of 0.02 mg/l (fig. 25). In general, average nitrate (as nitrogen) concentrations are higher for shallow wells than deep wells, probably because deep ground water is protected from surface contamination by overlying materials.

Natural sources of fluoride in ground water include clay minerals, apatite, and fluorite. In the wells sampled, fluoride concentrations did not exceed the maximum contaminant level of 4 mg/l (table 12), except in one well in the Whitewater System which had an anomalously high concentration of 4.7 mg/l. Median values were highest in the Silurian (0.7 mg/l) and Wayne-Henry (0.6 mg/l) Aquifer Systems. The remaining aquifers had median values which range from 0.2 to 0.4 mg/l.

Natural sources of barium in ground water include the minerals barite and witherite. In wells sampled, barium concentrations did not exceed the maximum contaminant level of 1.0 mg/l except in one well in the Silurian Aquifer System which had a concentration of 1.6 mg/l. Median concentration values for barium for the Wayne-Henry, Fayette-Union, and Silurian Aquifer Systems are all 0.2 mg/l. The remaining systems have median values below the detection limit of 0.1 mg/l.

Ground-Water Contamination

A ground-water supply that otherwise would be plentiful can be diminished by contamination from man's activities. As defined by the Indiana Department of Environmental Management [1986], contamination occurs when concentrations of chemicals exceed public drinking-water standards, proposed standards, or health protection guidance levels from the U.S. Environmental Protection Agency (USEPA). To protect Indiana's ground water resource, officials of the USEPA, IDEM, and Indiana State Board of Health are working in a cooperative effort for prevention, detection, and correction of ground-water problems in Indiana.

One important step in developing a ground-water management and protection program is identifying geographic areas most susceptible to ground-water contamination. The IDEM has designated 11 counties in Indiana, including Wayne County, as geographic areas where ground-water protection may be most needed. Screening criteria used to identify Wayne County include: 1) the susceptibility of the Whitewater Valley Aquifer System to contamination; 2) the presence of 11 public water wells and nearly 28,500 private wells; 3) the potential for significant increases in water use; 4) ground-water contamination sites; and 5) the presence of potential sources of contamination. Potential contamination sources identified by IDEM include 40 hazardous waste treatment, storage, and disposal facilities; two sanitary landfills; hazardous material spills (38 of which were documented by IDEM in 1985-86); and two abandoned hazardous waste disposal sites on the U.S. Environmental Protection Agency's Superfund Inventory list.

Since 1981, the USEPA has been conducting a survey of 26 volatile organic compounds in Indiana's public ground-water supplies serving more than 25 customers. Volatile organic compounds are a broad class of synthetic chemicals used commercially as degreasing agents, paint thinners, varnishes, glues, dyes, and pesticides which can contaminate ground water if improperly disposed. In the Whitewater River Basin, detectable levels of at least one VOC were found in six public water supplies in Wayne, Union, and Franklin Counties (Indiana Department of Environmental Management, [1986]). If the levels were a risk to public health, corrective action was taken; otherwise, levels are continuing to be monitored.

WATER USE AND PROJECTIONS

EXISTING WATER USE

Indiana's Water Resource Management Act requires owners of significant water withdrawal facilities to register these facilities with the Natural Resources Commission through the Department of Natural Resources, Division of Water and to report annual water usage. "Significant" facilities are those capable of withdrawing 100,000 gallons per day of surface water, ground water, or surface and ground water combined.

The Division of Water recognizes six water use categories for registered facilities: public supply, irrigation, industrial, rural, energy production, and miscellaneous. As table 13 shows, the 44 registered facilities in the Whitewater Basin withdrew a total of 16.56 mgd in 1986. About 85 percent (14.11 mgd) of the total withdrawals in 1986 were for public supply uses, and about 15 percent (2.45 mgd) were for industrial uses.

Table 13. Total water use by category

{All values in million gallons per day; no basin facilities are registered in the energy production, rural, and miscellaneous categories.}

County[1]	Year	Public supply	Industrial	Irrigation
Dearborn	1985	0.32	0.24	0
	1986	0.35	0.25	0
Decatur	1985	0.04	0.04	0
	1986	0.05	0.05	0
Fayette[2]	1985	4.22	0.02	0.01
	1986	4.46	0.03	0
Franklin	1985	0.77	0.29	0
	1986	0.80	0.28	0
Henry	1985	0.12	0	0
	1986	0.12	0	0
Randolph	1985	0.11	0	0
	1986	0.10	0	0
Union	1985	0.13	0	0
	1986	0.13	0	0
Wayne	1985	7.91	1.67	0
	1986	8.10	1.84	0
Total[3]	1985	13.62	2.26	0.01
	1986	14.11	2.45	0.00

[1] Rush and Ripley Counties have no registered facilities within the Whitewater Basin boundary.

[2] The irrigator in Fayette County used 0.001 mgd in 1986.

[3] The 1986 total for all uses combined does not equal the total in table 14 due to round-off differences.

Non-registered withdrawals, which primarily include domestic self-supplied uses and livestock operations, accounted for 6.41 mgd. Hence, registered and non-registered water withdrawals in the Whitewater Basin totaled nearly 23 mgd in 1986.

Fig. 29 shows the locations of the 44 facilities registered in the basin as of July 1987. The figure also shows the number of wells or intakes, the total withdrawal capability, and the reported 1985-86 usage for each facility. Reported water use is determined by metering devices, the multiplication of pump capacity and total time of pumpage, or by other methods approved by the Division of Water.

The term "withdrawal capability" represents the amount of water which could theoretically be withdrawn if all pumps were operating at their rated capability 24 hours a day. Because few if any facilities

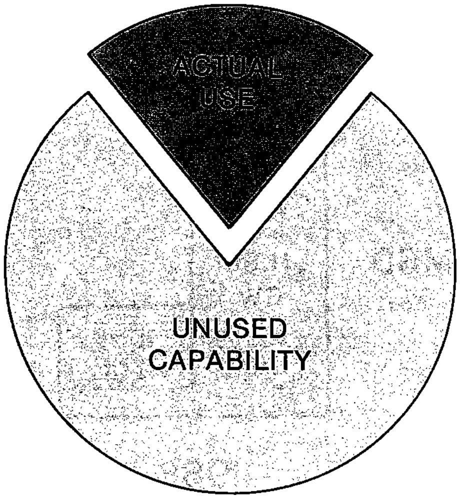


Figure 30. Comparison of 1986 water use with registered capability

Table 14. Total water withdrawal capability and use for all categories combined

{All values in million gallons per day.}

County	Year	No. of facilities	Withdrawal capability			Reported use		
			Ground water	Surface water	Combined	Ground water	Surface water	Combined
Dearborn	1985	2	3.60	0.00	3.60	0.56	0.00	0.56
	1986	2	3.60	0.00	3.60	0.60	0.00	0.60
Decatur	1985	2	0.11	3.02	3.13	0.04	0.04	0.08
	1986	2	0.11	3.02	3.13	0.04	0.05	0.09
Fayette	1985	7	15.34	0.86	16.20	4.23	0.02	4.25
	1986	7	15.34	0.86	16.20	4.46	0.03	4.49
Franklin	1985	7	7.75	0.72	8.47	1.01	0.05	1.06
	1986	7	8.61	0.72	9.33	1.05	0.02	1.07
Henry	1985	1	0.86	0.00	0.86	0.12	0.00	0.12
	1986	1	0.86	0.00	0.86	0.12	0.00	0.12
Randolph	1985	1	0.65	0.00	0.65	0.11	0.00	0.11
	1986	1	0.65	0.00	0.65	0.10	0.00	0.10
Union	1985	2	1.24	0.00	1.24	0.13	0.00	0.13
	1986	2	1.24	0.00	1.24	0.13	0.00	0.13
Wayne	1985	21	18.99	23.18	42.17	4.96	4.62	9.58
	1986	21	18.99	23.18	42.17	5.32	4.62	9.94
Basin total	1985	43	48.54	27.78	76.32	11.16	4.73	15.89
	1986	43	49.40	27.78	77.18	11.82	4.72	16.54

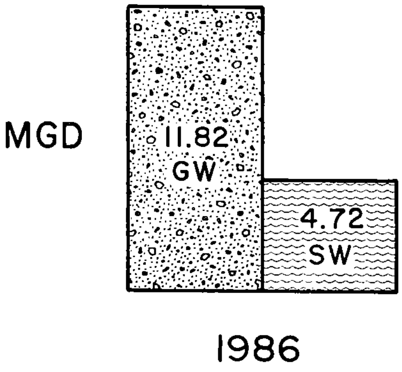
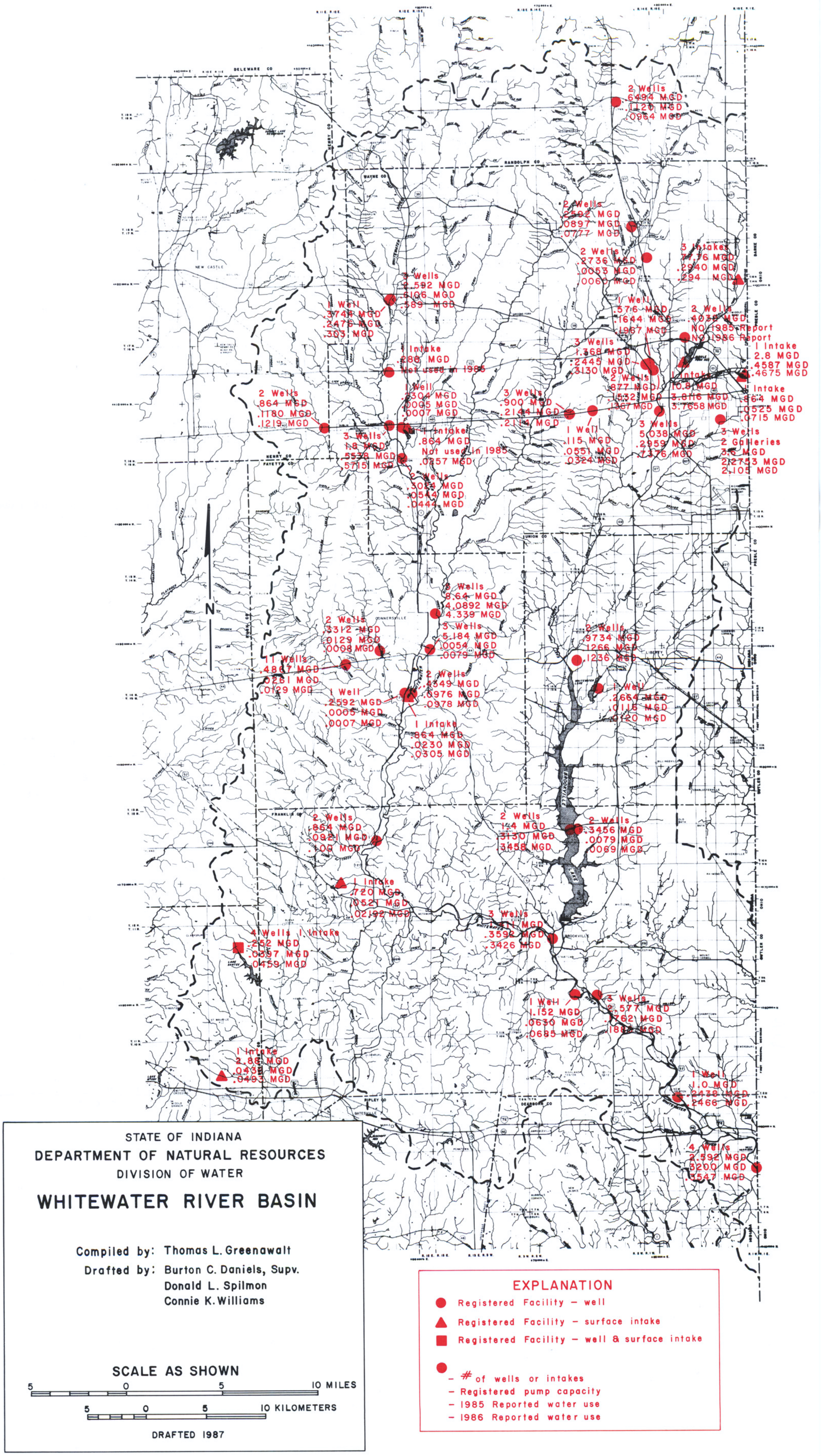


Figure 31. Total water use by source

in the basin operate in this manner, reported use constitutes only a small percentage of the total withdrawal capability, as fig. 30 illustrates.

Table 14 summarizes, by water source, the withdrawal capability and reported use by registered facilities in 1985-86. As the table shows, ground water was the source of 11.82 mgd, or 71 percent of all water withdrawn by registered facilities in 1986 (also see fig. 31). Eighty-three percent of ground-water withdrawals occurred within Wayne and Fayette Counties, primarily for public supply uses. Surface water was the source of 4.72 mgd of total registered withdrawals in 1986. Ninety-eight percent of surface-water withdrawals occurred in Wayne County (table 14), mainly for public supply and industrial uses.

Of the water withdrawn for various uses, a portion is generally returned to a ground- or surface-water system. However, a portion of the withdrawn water



STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

WHITEWATER RIVER BASIN

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Connie K. Williams

SCALE AS SHOWN

DRAFTED 1987

EXPLANATION

- ● Registered Facility – well
- ▲ Registered Facility – surface intake
- ■ Registered Facility – well & surface intake

●
- # of wells or intakes
- Registered pump capacity
- 1985 Reported water use
- 1986 Reported water use

Figure 29. Location of registered water withdrawal facilities

may be evaporated, transpired by plants, incorporated into a product, or otherwise made unavailable for reuse within a short time period. The greater the amount of water consumed, the greater the potential for significant impacts on surface- or ground-water levels.

The percentage of withdrawn water that is consumed depends on the type of water use. Irrigation, livestock watering, and domestic self-supplied uses consume 80 to 100 percent of the utilized water. Public supply and industrial uses generally consume only 5 to 25 percent.

Table 15. Types of public water supply utilities

County	Name	Type
Dearborn	Tri-Township Water Corp.	Rural
Decatur	Santee Utilities, Inc.	Subdivision
Fayette	Pleasant View	Subdivision
	Everton Water Corp.	Rural
	Connersville Utilities	Municipal
Franklin	Brookville Water Works	Municipal
	Brookville Reservoir	—
	Franklin County Water Assn.	Rural
	Laurel Water Works	Municipal
	Oldenburg[1]	Municipal
Randolph	Lynn Water Works	Municipal
	L&M Regional[2]	Rural
Union	Corporation of Liberty	Rural
	Whitewater State Park	—
Wayne	Centerville	Municipal
	Fountain City	Municipal
	Northeastern Wayne Schools	—
	Hagerstown	Municipal
	Cambridge City	Municipal
	Milton Water Works	Municipal
	Indiana-American Water Co. (Richmond District)	Municipal
	Dublin[3]	Municipal

[1] Oldenburg purchases water from Batesville, which lies outside the basin boundary.

[2] Wells located just outside the basin boundary supply residents of Losantville and Modoc, which both lie within the basin.

[3] Wells are located in Henry County.

Registered Use Categories

Public supply withdrawals accounted for about 85 percent of the total water use in the Whitewater Basin in 1986. The public supply category includes withdrawals by public and private water utilities for domestic (household), industrial, and commercial purposes. Public supply systems include rural as well as municipal water supply systems. As defined by the Division of Water, public supply also refers to mobile home parks, schools, conservancy districts, not-for-profit organizations, and other facilities which have their own water supplies (usually wells) and which use water primarily for drinking water, washing, cooking, and sanitary purposes.

Of the 22 public water supply utilities in the Whitewater Basin, more than half have been identified by the Division of Water as municipal utilities (table 15). Five utilities considered as rural utilities serve residences along rural roads. Two subdivision utilities serve residences within a single development. Three utilities do not fit any of these major categories (table 15).

In some cases, public systems may purchase and/or supply water across the basin boundary. Oldenburg Water Works purchases water from outside the Whitewater Basin; hence, withdrawals for public supply uses are not included in water use computations for this report. Withdrawals by L & M Regional are not included because the wells which supply Losantville and Modoc are located outside the basin boundary. Tri-Township Water Corporation derives its water from inside the basin boundary but supplies some of the water to non-basin residents. These inter-basin water transfers affect less than four percent of the population served by public water suppliers within the Whitewater Basin.

In 1986, public supply uses in the Whitewater River Basin averaged 14.11 mgd, or approximately 28 percent of the total withdrawal capability (table 16). Five registered facilities in Wayne, Fayette, and Franklin Counties accounted for 88 percent of reported public supply uses in 1986 (fig. 32).

Seventy-three percent of the water withdrawn by all public supply registrants in 1986 was derived from ground-water sources. The remaining 27 percent of public supply water was used by the city of Richmond and was withdrawn from Middle Fork Reservoir.

Water purchased at Brookville Lake by the Franklin County Water Association is registered as a ground-water use, even though a water-supply contract with the Indiana Department of Natural Resources considers

Table 16. Water withdrawal capability and reported use for public supply

{All values in million gallons per day.}

County	Year	Withdrawal capability			Reported use		
		Ground water	Surface water	Combined	Ground water	Surface water	Combined
Dearborn	1985	2.59	0	2.59	0.32	0	0.32
	1986	2.59	0	2.59	0.35	0	0.35
Decatur[1]	1985	0.11	0.14	0.25	0.04	0	0.04
	1986	0.11	0.14	0.25	0.05	0	0.05
Fayette	1985	14.75	0	14.75	4.22	0	4.22
	1986	14.75	0	14.75	4.46	0	4.46
Franklin	1985	4.02	0	4.02	0.77	0	0.77
	1986	4.88	0	4.88	0.80	0	0.80
Henry	1985	0.86	0	0.86	0.12	0	0.12
	1986	0.86	0	0.86	0.12	0	0.12
Randolph	1985	0.65	0	0.65	0.11	0	0.11
	1986	0.65	0	0.65	0.10	0	0.10
Union	1985	1.24	0	1.24	0.13	0	0.13
	1986	1.24	0	1.24	0.13	0	0.13
Wayne	1985	14.76	10.80	25.56	4.10	3.81	7.91
	1986	14.76	10.80	25.56	4.33	3.77	8.10
Basin total	1985	38.98	10.94	49.92	9.81	3.81	13.62
	1986	39.84	10.94	50.78	10.34	3.77	14.11

[1] A public supply registrant in Decatur County used a total of 0.004 mgd of surface water in 1985-86.

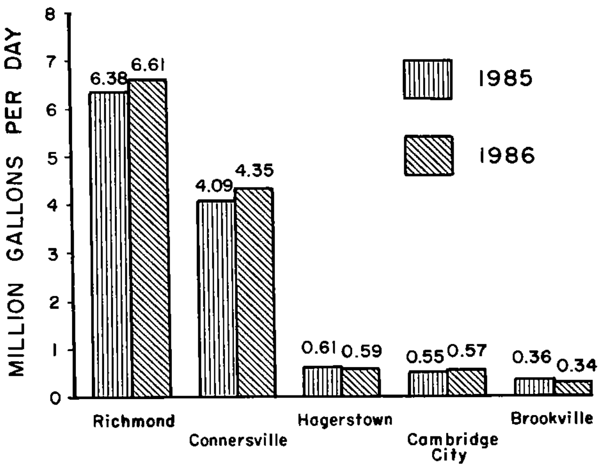


Figure 32. Public water supply use for selected municipalities

the use to be met by surface water from the reservoir. This contractual arrangement is based on the assumption that the reservoir enhances the production capability of the underlying aquifer system which supplies the utility's two wells.

Industrial water use refers to process water, waste assimilation, dewatering, and some cooling and mineral extraction uses. Under the Division of Water's categorization system, industrial use includes withdrawals by companies who develop their own water supplies. If an industry also purchases water from a public supply utility, only the water withdrawn from the industry's private water supply would be classified as industrial use. The amount purchased from the utility would be included in the public supply category.

In 1986, industrial self-supplied water use averaged 2.45 mgd, or approximately 9 percent of the total withdrawal capability (table 17). Of the total amount

Table 17. Water withdrawal capability and reported use for industry and irrigation

{All values in million gallons per day; values are for industrial use unless denoted as irrigation (IR).}

County	Year	Withdrawal capability			Reported use		
		Ground water	Surface water	Combined	Ground water	Surface water	Combined
Dearborn	1985	1.01	0	1.01	0.24	0	0.24
	1986	1.01	0	1.01	0.25	0	0.25
Decatur	1985	0	2.88	2.88	0	0.04	0.04
	1986	0	2.88	2.88	0	0.05	0.05
Fayette	1985	0.26	0.86	1.12	0	0.02	0.02
	1986	0.26	0.86	1.12	0	0.03	0.03
Fayette[1] (IR)	1985	0.33	0	0.33	0.01	0	0.01
	1986	0.33	0	0.33	0	0	0
Franklin	1985	3.73	0.72	4.45	0.24	0.05	0.29
	1986	3.73	0.72	4.45	0.26	0.02	0.28
Wayne	1985	3.54	12.38	15.92	0.86	0.81	1.67
	1986	3.54	12.38	15.92	0.98	0.86	1.84
Wayne (IR)	1985	0.69	0	0.69	—[2]	0	—[2]
	1986	0.69	0	0.69	—[2]	0	—[2]
Total	1985	9.56	16.84	26.40	1.34	0.92	2.26
	1986	9.56	16.84	26.40	1.49	0.96	2.45
Total (IR)	1985	1.02	0	1.02	0.01	0	0.01
	1986	1.02	0	1.02	0	0	0

[1] The irrigator in Fayette County used 0.001 mgd in 1986.

[2] Of the two registered irrigation facilities in Wayne County, one was not required to report 1985 or 1986 usage and the other did not utilize his irrigation equipment in 1985 or 1986.

of water used, 61 percent was derived from ground water and 39 percent from surface water. About three-fourths of the registered industrial self-supplied water usage occurred in Wayne County, primarily in or near the city of Richmond. More than half of the industrial withdrawals in the basin are for sand and gravel operations.

Of the three registered **irrigation** facilities in the basin, two are golf courses in Fayette and Wayne Counties and the third is an agricultural irrigator in Wayne County. For 1986, irrigation water use averaged only 0.001 mgd for the entire year (table 17), and was reported for only one golf course.

As of July 1987, no facilities had registered in the **energy production, rural, or miscellaneous** categories. During the interim between the compilation of water use data and report publication however, an energy production facility in Richmond was registered.

Energy Production includes any self-supplied water withdrawal related to the energy production process, such as coal preparation, oil recovery, cooling water, mineral extraction, power generation, heating/air conditioning, and dewatering. Rural usage by registered facilities includes water withdrawals by fish hatcheries and large-scale livestock operations. (Non-registered, self-supplied domestic withdrawals are not categorized as rural uses, unlike an earlier classification utilized by the Governor's Water Resource Study Commission, 1980). Miscellaneous usage includes water withdrawn

Table 18. Estimated 1985 domestic self-supplied water use

{All values in million gallons per day.}

County	Self-supplied population	Use
Dearborn	3,789	0.28
Decatur	1,226	0.09
Fayette	6,333	0.47
Franklin	11,856	0.87
Henry	5,739	0.44
Randolph	3,902	0.30
Ripley	1,199	0.09
Rush	641	0.05
Union	3,595	0.26
Wayne	16,775	1.28
	Basin total	4.13

Table 19. Estimated livestock water use by livestock category

{Water use values in million gallons per day.}

Livestock category	Estimated population within basin	Total use
Beef cattle	78,600	0.90
Dairy cattle	10,200	0.23
Hogs	234,600	0.94
Chickens	191,900	0.19
Sheep	5,100	0.01
Turkeys	37,400	0.01
	Basin total	2.28

for fire protection and for recreational purposes such as water slides and snow-making.

Non-Registered Uses

Domestic self-supplied refers to water users who obtain water from private water wells rather than from public supply systems. Table 18 lists the estimated domestic self-supplied water withdrawals for 1985. (Withdrawals for 1986 are nearly identical, and hence are not included.) The values were obtained by multiplying the estimated self-supplied population within the basin portion of each county by a calculated average daily usage per person of 76 gallons or 74 gallons, depending on the particular county (Indiana Department of Natural Resources, 1982a). As table 18 shows, about half of the domestic self-supplied water withdrawals occur in Wayne and Franklin Counties.

Livestock water use (table 19) has been determined by multiplying the estimated population of a particular livestock category by an estimate of the amount of water consumed daily per animal (Indiana Department of Natural Resources, 1982a). Almost 81 percent of the water for livestock was utilized by beef cattle and hogs.

Instream (non-withdrawal) uses primarily include recreation and fish and wildlife habitat. Other instream uses include waste assimilation, navigation, and hydroelectric power generation.

Water-based recreational activities in the Whitewater River Basin are primarily available in the vicinity of Brookville Lake, a multi-purpose reservoir in Union and Franklin Counties. The Brookville Lake dam and *tailwater* area is managed by the U.S. Army Corps of Engineers, but the reservoir itself and 11,200 acres surrounding it are managed by the IDNR. Recreational facilities at Brookville Lake include boat launching ramps, camp grounds, picnic areas, a swimming beach, a tailwater fishing area, and other facilities. Two large state recreation areas (Mounds and Quakertown) and smaller recreation areas along the shoreline provide a wide range of outdoor opportunities. A variety of activities is also available at Whitewater Memorial State Park, which is located on the northeast side of the reservoir along Silver Creek. Nearly all of these recreational areas offer easy access to good fishing waters.

Brookville Lake has become an important fishery in Indiana. The reservoir has one of the state's best walleye fisheries, supports the only population of striped bass, and is one of only two places where purebred muskellunge is stocked. The lake can support supplemental stockings of these predators because of its deep, cool water and abundant forage. Due to the large populations of these three fish, the reservoir is also used for broodstock collections.

Large naturally-reproducing populations of white crappie, white bass and channel catfish are present in Brookville Lake, in addition to populations of bluegill, largemouth bass, and smallmouth bass. A put-and-take trout fishery is maintained by IDNR in the tailwaters of the reservoir. The East Fork Whitewater River upstream of Brookville Lake provides very good fishing for white bass and walleye during annual spring spawning runs.

The Whitewater River in Franklin County is not only heavily used for canoeing, but also supports an excellent sport fishery. At least 41 species of fish have been identified in recent fisheries surveys. These include smallmouth, rock and largemouth basses, flathead and channel catfish, crappie, sunfish, bullhead, madtom and stonecats, sculpin, suckers, shad, gar, paddlefish, American eel and numerous minnows, shiners and darters. Trout from the put-and-take stockings may be present at times.

Some of the fish in Whitewater Lake include black crappie, bluegill, largemouth bass, and sunfish. Middle Fork Reservoir near Richmond contains white crappie, bluegill, channel catfish, white sucker and largemouth bass. Tiger muskellunge have been stocked in recent years by the IDNR.

A 28-mile segment of the Whitewater River in Franklin County has been recommended for inclusion in Indiana's Natural, Scenic, and Recreational Rivers System (Indiana Department of Natural Resources, 1986b). River segments included in the system are at least partially protected from detrimental impacts resulting from development and construction projects. Although the segment has not been designated by the Indiana Natural Resources Commission, the IDNR is continuing to work with riparian landowners and the local planning commission on matters involving the river.

Table 20. Public water supply projections

{All values in million gallons per day.}

County	1985[1]	1990	2000
Dearborn	0.32	0.40	0.55
Decatur	0.04	0.05	0.07
Fayette	4.22	4.20	4.12
Franklin	0.77	0.84	0.99
Randolph[2]	0.13	0.15	0.17
Union	0.13	0.14	0.16
Wayne[3,4]	7.39[4]	7.64	8.20
Total	13.00[5]	13.42	14.26

[1]Reported use.

[2]Includes withdrawals from L&M Regional.

[3]Includes withdrawals from the town of Dublin, whose wells are located in Henry County.

[4]Reported 1985 withdrawal for Wayne County was 8.03 mgd, 0.62 mgd of which was not used.

[5]Reported 1985 withdrawal for the basin was 13.62 mgd.

WATER USE PROJECTIONS

Registered Use Categories

As mentioned in a previous section, there are 22 **public supply** utilities in the Whitewater Basin, including Oldenburg, which purchases its water from Batesville. Table 20 presents the 1985 reported withdrawals and the projected withdrawals for the years 1990 and 2000.

Unlike table 16, table 20 includes reported and projected withdrawals for L & M Regional, which lies within the basin in Randolph County but derives its water from wells lying outside the basin boundary. In addition, table 20 includes reported and projected withdrawals for Dublin in the values for Wayne County, even though Dublin's wells are located in Henry County. Furthermore, because a portion of the ground water withdrawn by one of Richmond's three water treatment plants is returned to the East Fork Whitewater River, table 20 shows reported and projected use for Wayne County rather than total withdrawals.

As table 20 shows, the projected withdrawals are increasing in all counties except Fayette. Withdrawals in Fayette County are decreasing primarily because the projected daily consumption per person (gallons per capita per day) appears to be decreasing.

Although the population of Wayne County is decreasing, increases in public water supply use are projected for this county because the rate of growth of the per capita consumption is larger than the rate of decline in population.

Because Richmond is the largest city in the basin, its public water supply use was projected to the years 1990 and 2000. Water use was projected to be 5.94 mgd in 1990 and 6.37 in the year 2000.

Projections were also made for Batesville because it supplies water to Oldenburg, which lies just inside the basin boundary. Water use in Batesville, which totaled 1 mgd in 1985, is expected to increase to 1.17

Table 21. Industrial water use projections

{All values in million gallons per day.}

County	1985[1]	1990	2000
Dearborn	0.24	0.27	0.28
Decatur	0.04	0.05	0.05
Fayette	0.02	0.02	0.02
Franklin	0.29	0.31	0.28
Wayne	1.67	1.86	1.89
Total	2.26	2.51	2.52

[1] Reported use.

mgd by 1990 and 1.51 mgd by 2000. In a study of water supply in southeast Indiana (Indiana Department of Natural Resources, 1983), Batesville was reported to have a water supply capacity of 2 mgd. A reconnaissance in 1987 by the Division of Water for a future hydrographic survey indicates that only slight sedimentation has occurred in Batesville's water supply reservoirs. Hence, any reduction of this reported water supply capacity is assumed to be minimal.

Industrial self-supplied use, as defined by the Division of Water, mainly comprises manufacturing processes. However, the industrial category also includes water uses for mineral extraction processes not related to energy production (for example, sand and gravel operations).

Industrial self-supplied water use projections in tables 21-23 were derived from data of the U.S. Bureau of Census (1958, 1963, 1971, 1975, 1981, 1984b and 1986) and the U.S. Bureau of Economic Analysis (1985a and 1985b). Table 21 presents the reported and projected water withdrawals for industry in the Whitewater Basin. As table 22 shows, mining (primarily sand and gravel excavation) accounts for more than half of the withdrawals by industry. Table 23 presents reported and projected withdrawals for industries in and near Richmond.

Irrigation development is influenced by many factors, such as soils, topography, water availability, pumping distance, energy costs, crop prices, rainfall, length of growing season, and the availabilty of labor, parts, and repairs. An evaluation of soils, topography, and water availability indicates that there is little potential for significant increases in agricultural irrigation within most of the Whitewater Basin. Regions near the major streams, roughly coinciding in areal extent with the Whitewater Valley Aquifer System (pl. 3), may have a greater potential for irrigation of traditional row crops.

Non-Registered Uses

Projections for **domestic self-supplied** water uses are shown in table 24. Although withdrawals are expected to decrease in Wayne County as the self-

Table 22. Industrial water use projections by industry type

{All values in million gallons per day.}

SIC[1]	Industry	1985[2]	1990	2000
30	Rubber, misc. plastics	0.18	0.18	0.15
33	Primary metal products	0.15	0.18	0.20
34	Fabricated metal products	0.16	0.19	0.18
35	Machinery, except electrical	0.55	0.60	0.59
14	Mining (sand and gravel)	1.21	1.35	1.38
	Other	0.01	0.01	0.02
	Total	2.26	2.51	2.52

[1] Standard industrial classification code.
[2] Reported use.

Table 23. Industrial water use projections for Richmond

{All values in million gallons per day.}

SIC[1]	Industry	1985[2]	1990	2000
33	Primary metal products	0.15	0.18	0.20
34	Fabricated metal products	0.16	0.19	0.18
35	Machinery, except electrical	0.30	0.33	0.33
14	Mining (sand and gravel)	0.81	0.90	0.92
	Total	1.42	1.60	1.63

[1] Standard industrial classification code.
[2] Reported use.

Table 24. Domestic self-supplied water use projections

{All values in million gallons per day.}

County	1985[1]	1990	2000
Dearborn	0.28	0.29	0.32
Decatur	0.09	0.09	0.09
Fayette	0.47	0.48	0.49
Franklin	0.87	0.91	0.99
Henry	0.44	0.44	0.43
Randolph	0.30	0.30	0.31
Ripley	0.09	0.09	0.10
Rush	0.05	0.05	0.04
Union	0.26	0.26	0.27
Wayne	1.28	1.25	1.22
Total	4.13	4.16	4.26

[1] Estimated current use.

supplied population decreases, withdrawals in other counties are expected to increase slightly or remain fairly stable.

Table 25 shows estimates of **instream** uses and needs for six water-related activities for 1990 and 1995. These estimates were derived from surveys taken in 1976 (Indiana Department of Natural Resources, 1979). As the table shows, there are projected shortages in boating, swimming, fishing, and ice skating needs, and projected surpluses in canoeing and water skiing needs.

Table 25. Projected supply and demand for recreational instream uses

{Modified from Indiana Department of Natural Resources, 1979.}

Activity	Activity Occasions	Density Guidelines	Demand	Supply	Needs
Boating					
1990	281678	58.8 Boaters/AC/YR	4790 Acres	4363 Acres	—427 Acres
1995	284013	58.8 Boaters/AC/YR	4830 Acres	4363 Acres	—467 Acres
Canoeing					
1990	20997	1170 Canoeists/Mi/YR	18 Miles	63 Miles	+45 Miles
1995	21457	1170 Canoeists/Mi/YR	18 Miles	63 Miles	+45 Miles
Water Skiing					
1990	48616	34.4 Skiers/AC/YR	1413 Acres	1845 Acres	+432 Acres
1995	48749	34.4 Skiers/AC/YR	1417 Acres	1845 Acres	+428 Acres
Swimming					
1990	681416	76608 Swimmers/AC/YR	9 Acres	6 Acres	—3 Acres
1995	691994	76608 Swimmers/AC/YR	9 Acres	6 Acres	—3 Acres
Fishing					
1990	785815	66 Fishermen/AC/YR	11906 Acres	5429 Acres	—6477 Acres
1995	776586	66 Fishermen/AC/YR	11766 Acres	5429 Acres	—6337 Acres
Ice Skating					
1990	17754	4200 Skaters/AC/YR	4 Acres	2 Acres	—2 Acres
1995	18116	4200 Skaters/AC/YR	4 Acres	2 Acres	—2 Acres

AVAILABLE WATER SUPPLY AND FUTURE DEVELOPMENT

A theoretical maximum water supply potential for the basin may be estimated using monthly discharges to derive average long-term total runoff. These figures give a general idea of the amount of precipitation which falls on the basin and is not used consumptively on a long-term basis.

The runoff volumes in the second column of table 26 were generated for the Indiana portion of the Whitewater River Basin, a total drainage area of 1329 sq. mi. The values are based on the 10 years of monthly discharge data collected at the gaging station on Whitewater River at Brookville for the post-reservoir period 1975-84.

As discussed previously in this report, the impoundment of Brookville Lake has changed the within-year distribution of flows. It was also shown that the average discharge is estimated to have been reduced by 2.5 percent as a result of the impoundment.

Because the monthly and yearly averages based on only 10 years of post-reservoir data have very limited value for planning purposes, an estimate of the long-term (62-year) average discharge for the existing (post-reservoir) condition was made by reducing the long-term pre-reservoir average basin runoff by 2.5 percent and then adding the post reservoir data to the adjusted series. The total yearly long-term average basin runoff of 319.9 billion gallons thus found was then distributed into monthly values according to observed monthly distribution of the post-reservoir data. These values are given in the third column of table 26.

The underlying assumption for derivation of long-term post-reservoir estimates is that the effect of Brookville Lake operation on downstream flows could be assumed to remain almost the same for wetter or dryer periods as compared to the 1975-84 period. It should be emphasized that the listed potential monthly supplies represent long-term average values. During dry years, when consumptive demands are at high levels, the available water supplies can be significantly less than average.

Table 26. Mean monthly runoff volumes for Whitewater River at Brookville

{All values in billion gallons.}

Month	Runoff volume	
	10-year average[1]	62-year average[2]
April	39.3	36.6
May	37.0	34.5
June	19.9	18.5
July	17.8	16.6
August	19.7	18.3
September	8.0	7.4
October	14.8	13.8
November	23.6	22.0
December	34.4	32.0
January	33.1	30.8
February	41.0	38.1
March	55.1	51.3
Total yearly	343.7	319.9

[1] 1975-84

[2] 1916-17, 1924-73, 1975-84

Water in the basin may be used and reused many times before it is lost to evaporation or as outflow from the basin. As long as the water is not used consumptively and the quality of the resource is not altered to the point that it becomes unsuitable for some purposes, there are very few limitations on total water use. However, constraints on water use in a particular location may result from its competing value for the maintenance of reservoir levels, for recreation, for support of aquatic life, for the availability of supply for downstream domestic and industrial water users, and for the provision of assimilative capacity for thermal loadings and wastewater treatment plant effluents.

It is important to note that future developments which cause increased consumptive use would not only reduce the total yearly long-term average value in table 26, but also would usually modify the hourly, daily, monthly, and even yearly distribution of the remaining theoretical upper limit of available supplies, depending on the nature of the project.

SURFACE-WATER AVAILABILITY

Significant Surface-Water Sites

An important aspect of water resource management is the identification of sites where there will be growth in demand for surface water or where surface water supply may be developed. Also important is the identification of sites where shortages may occur.

A significant surface-water site is a location where there is one or more of the following conditions: 1) a relatively large supply; 2) a relatively large demand; or 3) an insufficient water supply.

Four sites have been selected in the Whitewater River Basin (see fig. 33). Middle Fork Reservoir (site 16) has been selected as a significant site because it supplies Richmond, Indiana, the largest city in the Whitewater Basin, with about 60 percent of its water. The reservoir with its large supply and demand was thus investigated to determine its safe yield.

Although the West Fork of the East Fork Whitewater River (site 17) has not been developed as a supply for Richmond, it could be developed for that purpose and therefore was investigated as a significant site.

Brookville Lake, the third significant site (site 25) is the largest reservoir in the Whitewater Basin and is significant because of its large water supply. Prior to construction of the reservoir, the State of Indiana entered into an agreement with the U.S. Government to purchase the 89,300 acre-feet of water stored between elevations 713 feet m.s.l. and 740 feet m.s.l. for sale to any interested party. Contracts and rates charged are negotiated and administered by the Indiana Department of Natural Resources.

The fourth significant site is Salt Creek near Oldenburg (site 13) which is in an area of the Whitewater Basin that has little ground water. Salt Creek was investigated as a source of water supply because of its proximity to Batesville, which lies just beyond the basin divide and which has water treatment facilities.

Safe Yield

Reservoirs

To plan for the future use of surface water, the dependability of the supply must be known. The yield of a water supply is the amount of water that is available for use during some period of time, such as a day, a month, or a year. The safe yield of a reservoir has been defined as the minimum yield during the life of the reservoir (Linsley and others, 1982). Typically, safe yield is determined as the minimum yield during the worst dry period of record.

The concept of safe yield is misleading, however, because there is some probability that a period drier than the worst of record will occur. Even if a reservoir could be built large enough to always supply a guaranteed minimum yield, its cost might be unacceptably high.

A better approach to specifying the dependability of a water supply is to specify the probability of supplying the required demand during the life of the reservoir. The dependability of a reservoir of a given capacity will decrease as the level of demand increases. For a specified level of dependability, the storage required increases as the level of demand increases.

The storage required to meet a specified demand depends on the average stream flow, stream-flow variability, the magnitude of the demand, and the degree of dependability desired (see McMahon and Mein, 1986). The higher the desired level of dependability, the larger the reservoir needs to be. Dependability is defined and discussed in app. 13.

Selection of a storage capacity which will satisfy water demands of all users with the highest degree of dependability is not usually warranted. For irrigation requirements, the degree of dependability is usually recommended to be in the range of 75 to 85 percent, while for domestic and industrial water supply the desired dependability is usually in the range of 95 to 98 percent. Considering the envisaged purposes of water resources development in the Whitewater Basin, the dependability level of 98 percent has been adopted in the storage-yield analyses performed in this study. This level of dependability corresponds to allowing no deficits within a 50-year period of reservoir operation.

One way of determining the storage required is from a mass curve or Rippl diagram. The mass curve is a graph of the cumulative volume of inflow to the reservoir versus time and is derived from historical streamflow data. The worst dry period of record is usually used to determine the storage required but the entire period of record may also be used. The procedure is to select a range of anticipated drafts (levels of demand) and to determine the storage required for each draft. The results can be plotted as a curve which relates storage required to draft.

A computer program by Beik (1986) entitled YIELD performs mass-curve analysis for the period of data record at a given site. This program will determine the storage required to meet a given level of demand throughout a given period of record without allowing any deficits. If desired, the program will also determine the storage required if one, two, or more years of supply cut-backs during the life of the project can be tolerated by some users. The YIELD program was used to analyze the storage required for various drafts for three sites in the Whitewater Basin.

Middle Fork Reservoir, (fig. 33, site 16, Qave = 32.2 mgd, DA = 47.2 sq. mi.) supplies about 60 percent of Richmond's water. The average water use dur-

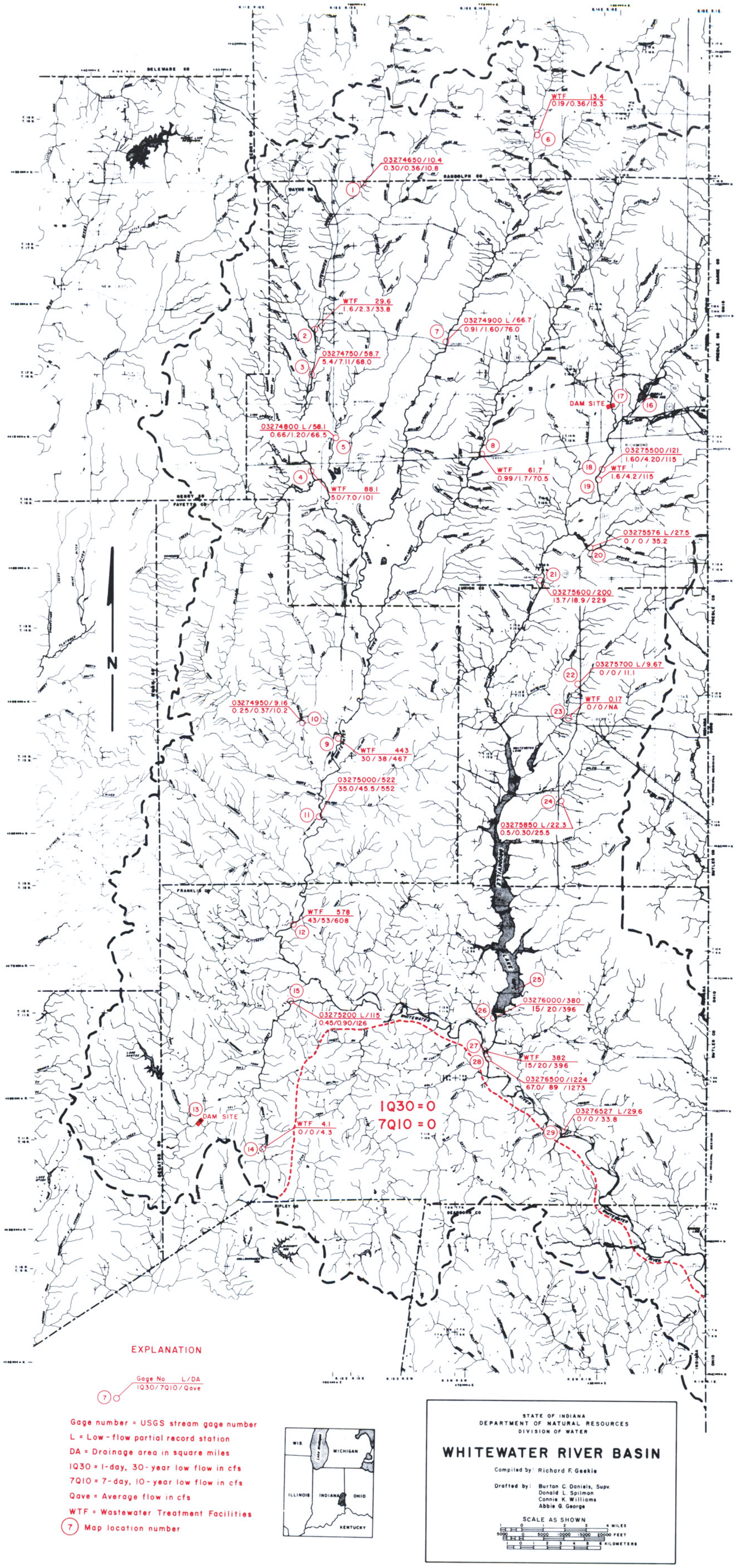


Figure 33. Surface-water availability

ing 1985 from Middle Fork was 3.8 mgd (5.9 cfs).

The original plan for Middle Fork Reservoir was to build it in two phases. Phase One had a principal ogee spillway with a crest elevation of 971 feet m.s.l. Phase Two was a plan to add Tainter gates which would raise the maximum elevation to 985 feet m.s.l. Phase Two had not occurred as of 1986 and there is presently no plan to install the Tainter gates.

The Surveying Section of the Division of Water completed a hydrographic survey of Middle Fork Reservoir in 1986. The soundings taken were used to develop the depth curves of fig. 34. Information from this survey was used to estimate the amount of sedimentation that had occurred since the reservoir was first put into operation in 1961. The original storage at elevation 971 feet m.s.l. was 1010 million gallons (3095 acre-feet). The storage at this elevation in 1986 was 881.1 million gallons (2704 acre-feet). This means that 129 million gallons (391 acre-feet) have been lost to sedimentation in 25 years of operation.

A series of monthly discharges for a period of 55 years was generated for the reservoir site based on the records available for the Alpine stream gaging station from 1929-84. Reservoir evaporation was assumed to be about 3.13 feet per year based on data available for Brookville Lake and different gages in the general area. A dead storage volume of 255 mg (782 acre-feet) was set aside for sediment accumulation in the next 50 years of life of the reservoir. This value was based on the average sedimentation rate of 5.16 mg/year (15.64 acre-feet/year) as observed in the past 25 years of operation of Middle Fork Reservoir.

To find the capabilities of the existing Middle Fork Reservoir and also evaluate the effects of adding the Tainter gates to increase the usable reservoir storage, a draft-storage relationship was calculated by running the computer program YIELD successively for different assumed values of demand. The resulting values given in the table 27 are the total storage values required at the site to meet the given level of demand (draft) with no deficits allowed. These values include active storage needed to regulate the supply, dead storage needed for sediment accumulation, and storage to account for evaporation losses.

Fig. 35 shows the above relationship in graphical form. The so-called "draft-storage curve" enables one to estimate the storage required at the site to maintain a known demand with a predetermined dependability (in this case, 98 percent dependability). Conversely, the curve also enables one to estimate the expected dependable yield of a reservoir with an assumed or known storage capacity.

Table 27. Draft-storage: Middle Fork Reservoir

Draft		Storage	
cfs	mgd	ac-ft	mg
5	3.2	980	319
7	4.5	2038	664
8	5.2	2609	850
8.2	5.3	2704	881
10	6.5	3771	1229
12	7.8	5199	1694
12.8	8.3	5800	1890

As fig. 35 and table 27 show, the existing total storage capacity of 881 mg (2,704 acre-feet) in Middle Fork Reservoir can supply a dependable draft of approximately 5.3 mgd (8.2 cfs) during the next 50 years of life of the project. Installation of the proposed Tainter gates would increase the total storage to 1,890 mg (5,800 acre-feet) and increase the capability to about 8.3 mgd (12.8 cfs).

The projected total water demand for the Richmond area in the year 2000 is about 6.37 mgd. It is assumed that 60 percent or 3.8 mgd will come from Middle Fork Reservoir. The dependable yield of Middle Fork Reservoir (5.3 mgd) exceeds this projected surface-water demand of 3.8 mgd for the year 2000.

The draft-storage analyses of the **West Fork** dam site (fig. 33, site 17, Qave = 14.1 mgd, DA = 20.7 sq. mi.) was similar to the analysis of the Middle Fork Reservoir. A series of monthly discharges for a period of 55 years was generated for the site based on records available for the Alpine Station from 1929 to 1984. Reservoir evaporation was assumed to be about 3.13 feet per year. A dead storage volume of 112 mg (343 acre-feet) was set aside for sediment accumulation in the next 50 years of life of the reservoir. This value was based on an average sedimentation rate of 0.11 mg/sq. mi./year (0.33 acre-feet/sq. mi./year) as observed in the past 25 years of operation of Middle Fork Reservoir.

Table 28 presents the storage capacities required for various drafts. The storage capacities include storage for evaporation and sediment. Fig. 35 shows the draft-storage relationship in graphical form. Installation of Tainter gates would be a less costly way of increasing supply to Richmond than constructing a new dam on the West Fork.

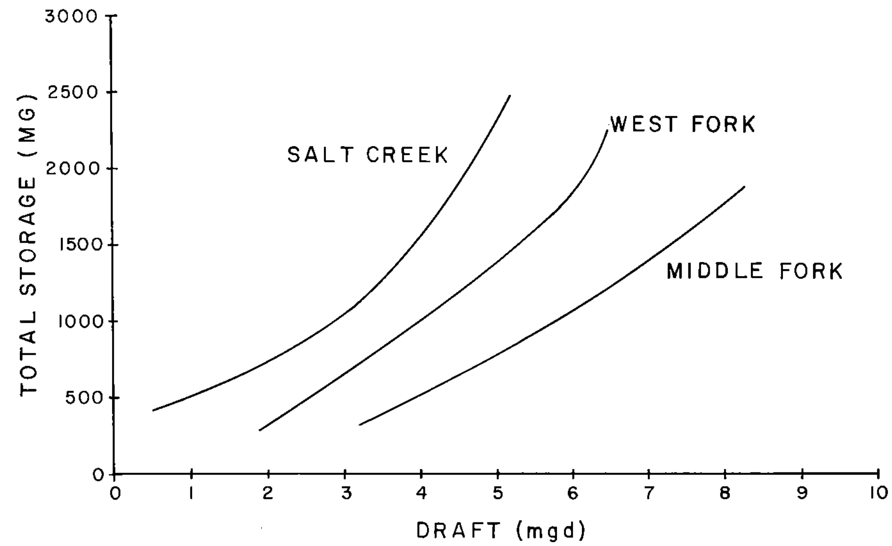


Figure 35. Draft — storage curves for significant sites

Batesville presently obtains its water supply from nearby reservoirs and therefore has facilities for the treatment of surface water. The **Salt Creek** site (see fig. 33, site 13, Qave = 24.4 mgd, DA = 34.4 sq. mi.) was chosen because the drainage area, excluding the drainage area of Lake Santee, is relatively large and is reasonably close to Batesville. The considered dam site is approximately 1.5 miles from the channel of Little Laughery Creek, which flows south past Batesville. To treat the water from Salt Creek, the water would have to be pumped from the reservoir over the Whitewater Basin divide and into Little Laughery Creek where it would then flow about 3 or 4 miles to Batesville. The water would have to be lifted approximately 165 feet from the reservoir to the basin divide.

Because there was no gaging station on Salt Creek, monthly discharges from Laughery Creek near Farmers Retreat were used in the YIELD program. Laughery Creek was selected because of its hydrologic similarity with Salt Creek. Unfortunately, the period of record for the Laughery Creek station was only 32 climatic years. Therefore, the storage capacities were adjusted to correspond to a dependability of 98 percent by using stream-flow data from a nearby station with a longer period of record.

Table 28. Draft-storage: West Fork of the East Fork Whitewater River

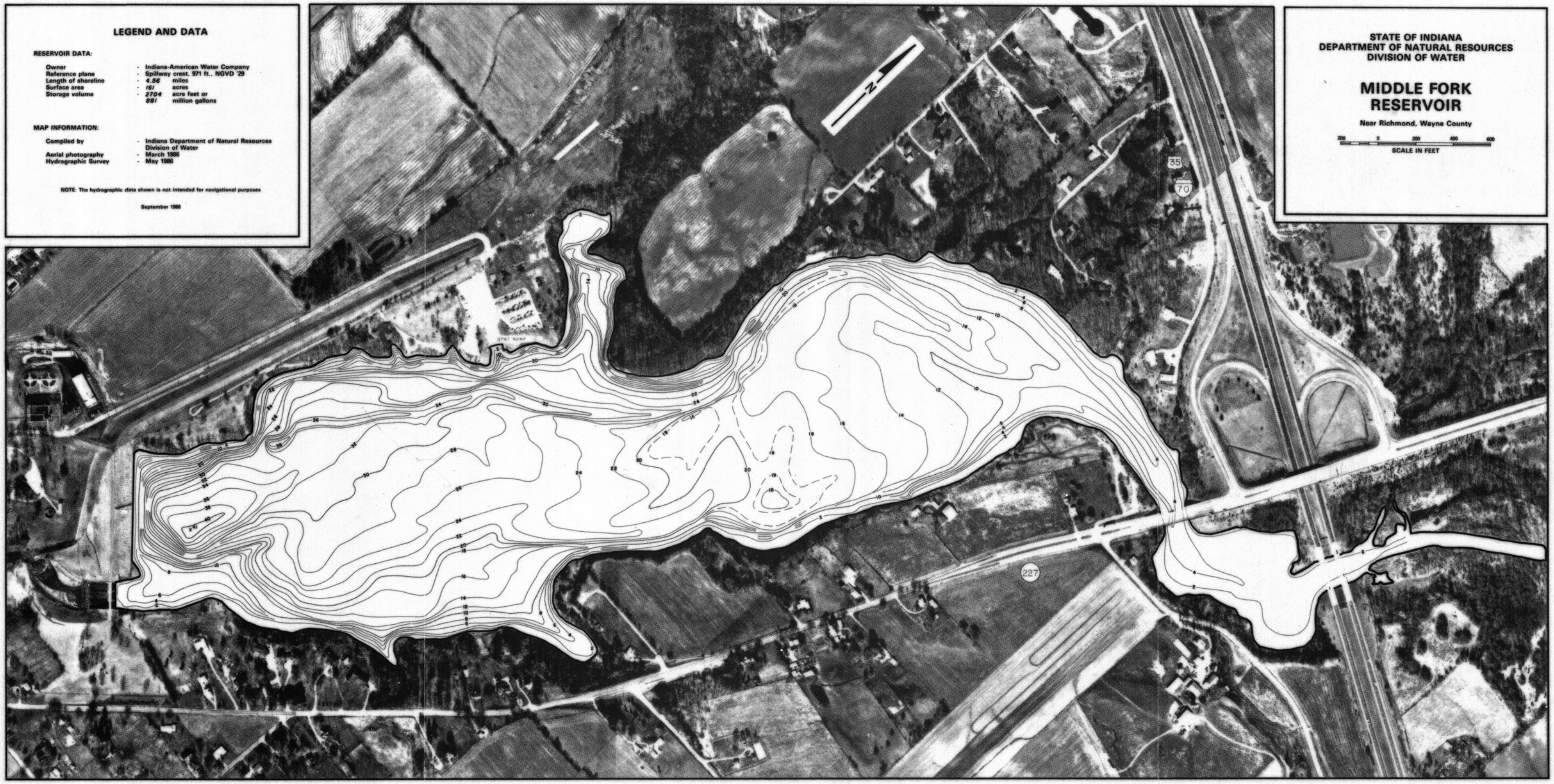
Draft		Storage	
cfs	mgd	ac-ft	mg
3	1.9	904	295
5	3.2	2163	705
7	4.5	3713	1210
9	5.8	5265	1715
10	6.5	6944	2262

Table 29 presents the draft-storage values for the Salt Creek dam site. The storage set aside for sedimentation was 1000 acre-feet (326 million gallons) and an evaporation rate of 3.13 feet per year was used. The sedimentation rate used was taken from a report on Brookville Lake (U.S. Army Corps of Engineers, 1978). The dead storage was rounded to 326 mg (1000 acre-feet).

Batesville has an existing water supply capacity of about 2.0 mgd. Although the projected demand for the year 2000 is only 1.5 mgd, the Salt Creek site could provide an additional supply for both Batesville and the surrounding area.

Fig. 36 shows the draft-storage curves for all three sites in non-dimensional form. These curves were developed by dividing active storage and drafts by the mean annual discharge (average discharge) for each site.

The curves for Middle Fork Reservoir and the West Fork site coincide because the inflows were derived



LEGEND AND DATA

RESERVOIR DATA:

Owner	- Indiana-American Water Company
Reference plane	- Spillway crest, 971 ft., NGVD '29
Length of shoreline	- *4.56* miles
Surface area	- *161* acres
Storage volume	- *2704* acre feet or *881* million gallons

MAP INFORMATION:

Compiled by	- Indiana Department of Natural Resources Division of Water
Aerial photography	- March 1986
Hydrographic Survey	- May 1986

NOTE: The hydrographic data shown is not intended for navigational purposes

September 1986

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

MIDDLE FORK RESERVOIR

Near Richmond, Wayne County

Figure 34. Depth contours of Middle Fork Reservoir

Table 29. Draft-storage: Salt Creek

Draft		Storage	
cfs	mgd	ac-ft	mg
1	0.7	1310	427
3	1.9	2179	710
5	3.2	3456	1126
6	3.9	4565	1487
7	4.5	5939	1935
8	5.2	7590	2473

from the same station. The Salt Creek site curve is above the other curve, indicating that the Salt Creek site requires more storage per average flow than the other two sites. Tributaries in the southern part of the basin have more variable flow than northern tributaries or the major northern rivers because of geologic and topographic differences.

The draft-storage curve for an ungaged site may be determined from a non-dimensional draft-storage curve of a hydrologically similar basin by multiplying selected pairs of values from the non-dimensional curve by the average discharge for the ungaged site.

The U.S. Army Corps of Engineers is responsible for the maintenance and operation of the **Brookville Lake** dam (site 25, Qave = 256 mgd, DA = 380 sq. mi.). The Corps has a computer model to simulate the operation of the reservoir. Using this computer model, the Corps has determined that Brookville Lake has a water supply capability of 90.5 mgd (140 cfs). This value is in addition to any required downstream releases. Again, this water supply capability corresponds to a dependability level of 98 percent (that is, no deficits allowed within a 50-year period of operation).

The Indiana Department of Natural Resources presently administers only one contract which involves the sale of water from Brookville Lake. This contract with the Franklin County Water Association is unique in that the water purchased is not withdrawn directly from the reservoir but rather from two wells located on the Fairfield causeway.

The wells are approximately 135 feet deep and utilize an outwash aquifer system which is artificially recharged by the reservoir. This situation results in a higher productive capacity for the system than would normally be anticipated. The contractual arrangement

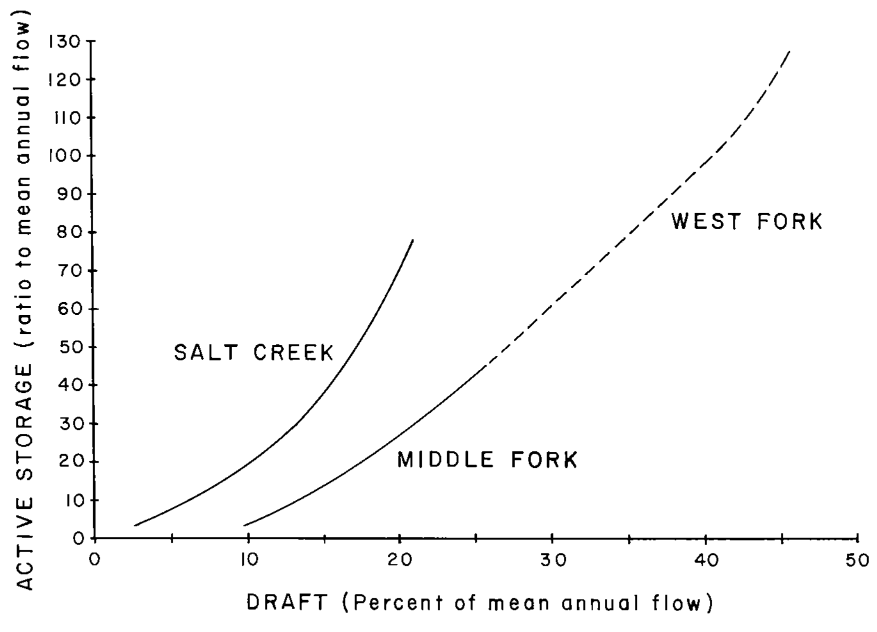


Figure 36. Non-dimensional draft — storage curves

was made based on the assumption that the wells can meet future water supply needs because of the reservoir's existence and the associated recharge of the underlying aquifer system by reservoir water.

Because the Division of Water's registration system for water withdrawal facilities only considers the type of withdrawal, water use by the Franklin County Water Association is registered and reported as a ground-water use. According to annual reports, the utility withdrew an average of 0.3 mgd in 1985 and 1986. The utility currently is allowed to purchase up to an annual average of 0.5 mgd.

In addition to the two Franklin County Water Association wells, four other public supply wells owned by the IDNR are located on or near the Fairfield and Dunlapsville causeways. Because no direct surface-water withdrawals are made for these public supply uses or other registered uses, Brookville Lake remains a largely underutilized source of water supply.

Streams

The dependability of a stream is the degree to which stream flow is sustained by base flow during dry periods. One measure of dependability is the 1-day, 30-year low flow (1Q30), because it is base flow and because the 30-year return interval represents a moderately dry period.

In order to compare stream-flow dependability throughout the Whitewater Basin, the 1Q30 per square mile of drainage area was computed for each of the stream gages in the basin. As can be seen from table 30, the 1Q30 per square mile of drainage area varies from gage to gage. This variation is due to the variation of base-flow rates along the length of each stream in the basin.

In general, the 1Q30 per square mile decreases going downstream on the Whitewater River and its east fork. The 1Q30 per square mile of the Whitewater River at Hagerstown, Alpine, and Brookville is 0.092, 0.067, and 0.055 cfs/sq. mi., respectively (table 30). The 1Q30 flow of the East Fork Whitewater River at Richmond (0.013 cfs/sq. mi.) is low because of flow regulation at Middle Fork Reservoir.

The 1Q30 per square mile flows of the major and minor tributaries are smaller than those of the main channels. Also, the 1Q30 per square mile flow is smaller the farther south the tributary enters one of the main channels. These differences are due to differences in hydrogeology throughout the basin. There is less outwash in the valleys of the minor tributaries. Also, these tributaries have developed on till or on bedrock in the southern part of the basin.

Stream flow is also more variable in the tributaries than in the main channels and even more variable in tributaries in the southern part of the basin. Streams which have much variability in their daily discharges have less sustained flow during dry periods and are less dependable.

Streams which have 7-day, 10-year low flows (7Q10) and 1Q30 low flows equal to zero are not dependable sources of water supply. The dashed line in fig. 33 was taken from Arihood and Glatfelter (1986). South of this line, 7Q10 and 1Q30 low flows are expected to be zero. However, as can be seen in table 30, there are also streams north of this line which have 7Q10 and 1Q30 equal to zero.

Because of the poorly sustained stream flow in the southern part of the basin, dependable sources of surface-water supply would have to come from reservoirs on tributaries or from the Whitewater River. The Whitewater River has previously been considered as a source of water supply in another study (Indiana Department of Natural Resources, 1983).

Wastewater Treatment Facilities

A wastewater treatment facility uses stream flow to dilute its effluent. The level of treatment that must be provided in order for the receiving stream to meet water quality standards downstream of the facility is determined in part by the magnitude of the 7-day, 10-year design flow at the point of wastewater discharge. Therefore, the 7Q10 represents an instream flow need for wastewater treatment facilities.

The wastewater treatment facilities are presented in table 31 (see fig. 33) along with the stream-flow parameters of the receiving streams. Significant withdrawals from streams above a wastewater plant could threaten stream quality below the plant if withdrawals are large during periods of low stream flow.

Presently, there are very few significant surface-water withdrawals in the basin. It is important, however, to monitor new withdrawals upstream of wastewater plants to determine potential effects on stream flow at the plant.

GROUND-WATER AVAILABILITY

Ground water in the Whitewater River Basin is available from unconsolidated materials and from bedrock. Water-bearing unconsolidated deposits are

Table 30. Surface-water availability based on stream-flow characteristics

Site[1]	Station number[2]	Station name	Total Drainage area (sq mi)	1-day, 30-year low flow			7-day, 10-year low flow		Average flow	
				cfs[3]	mgd	cfs/sq mi	cfs[3]	mgd	cfs[3]	mgd
1	03-274650	Whitewater River near Economy	10.4	0.30	1.90	0.029	0.36	0.23	10.8	7.0
3	03-274750	Whitewater River near Hagerstown	58.7	5.4	3.50	0.092	7.11	4.59	68.0	43.9
5	03-274800 L	Martindale Creek near Cambridge City	58.1	0.66[4]	0.43	0.011	1.20[5]	0.78	66.5[4]	43.0
7	03-274900 L	Greens Fork at Greens Fork	66.7	0.91[4]	0.59	0.014	1.60[5]	1.03	76.0[4]	49.1
10	03-274950	Little Williams Creek at Connersville	9.16	0.25	0.16	0.027	0.37	0.24	10.2	6.6
11	03-275000	Whitewater River near Alpine	522	35.0	22.6	0.067	45.5	29.4	552	357
15	03-275200 L	Salt Creek near Metamora	115	0.45[4]	0.29	0.004	0.90[5]	0.58	126[4]	81
18	03-275500	E.F. Whitewater River at Richmond	121	1.60[4]	1.03	0.013	4.20[5]	2.71	115	74
20	03-275576 L	Elkhorn Creek at Richmond	27.5	0[6]	0	0	0[5]	0	35.2[4]	22.8
21	03-275600	E.F. Whitewater River at Abington	200	13.7	8.9	0.069	18.9	12.2	229	148
22	03-275700 L	Silver Creek near Liberty	9.67	0[6]	0	0	0[5]	0	11.1[4]	7.2
24	03-275850 L	Hanna Creek near Roseburg	22.3	0.15[4]	0.10	0.007	0.30[5]	0.19	25.5[4]	16.5
26	03-276000	E.F. Whitewater River at Brookville	380	15.0[7]	9.7	0.040	20[7]	12.9	396	256
28	03-276500	Whitewater River at Brookville	1224	67.0[7]	43.3	0.055	89[7]	57.5	1273	823
29	03-276527 L	Big Cedar Creek at Cedar Grove	29.6	0[6]	0	0	0[5]	0	33.8[4]	21.8

[1] Site locations shown in figure 33.

[2] Low-flow partial-record station (L).

[3] From U.S. Geological Survey data through climatic year 1984 except as noted.

[4] Estimated with regression equation.

[5] From Stewart (1983); data through climatic year 1978.

[6] Assumed to be zero because 7-day, 10-year low flow is zero.

[7] Prior to construction of Brookville Lake.

mainly composed of glacially-derived tills, lacustrine clays, and outwash sands and gravels of pre-Wisconsinan to Wisconsinan age. Ground water from bedrock aquifers is primarily found in limestones and dolomites of Ordovician or Silurian age.

The development potential or potential yield of an aquifer depends on aquifer coefficients (transmissivity, hydraulic conductivity, and storage), aquifer thickness, areal extent, water levels, and recharge.

''Safe yield'' is a term frequently used to describe the amount of ground-water which can be withdrawn without exceeding a given criteria. For example, safe yield is often defined as an amount not exceeding average annual natural recharge. However, safe yield estimates based solely on natural recharge are conservative because they ignore the effects that ground-water development may have on the recharge capability of an aquifer. For example, pumping ground-water from an aquifer which is hydraulically connected to a river may induce recharge to the aquifer through the streambed. If the hydraulic connection is good, the pumped water will eventually be derived from stream flow reduction, in which case safe yield is limited by an allowable reduction in stream flow.

Safe yield is also defined in terms of the maximum pumpage which will avoid lowering water levels below some predetermined level. For example, it may be decided that for an unconfined aquifer, the maximum allowable reduction in saturated thickness is 50 percent. Analytical and numerical models can then be used to estimate the amounts of water which can be pumped at given locations without exceeding the 50 percent reduction criterion.

Minimum ground-water levels may be established by the Natural Resources Commission (IC 13-2-6.1). If established, the minimum level criteria may govern the safe yield of a given ground-water withdrawal facility.

Transmissivity Values

Transmissivity is a measure of the water-transmitting capability of an aquifer. Expressed as the rate at which water flows through a unit width of an aquifer, transmissivity is obtained by multiplying the aquifer's hydraulic conductivity by its saturated thickness.

Transmissivity values in this report were obtained by three methods. Aquifer test data yields the best estimates of transmissivity. Fairly good estimates can be obtained from specific capacity data (pumping rate divided by drawdown) which has been adjusted for the effects of dewatering and/or partial penetration of the aquifer. Specific capacity data with unadjusted drawdowns yields the least reliable estimates.

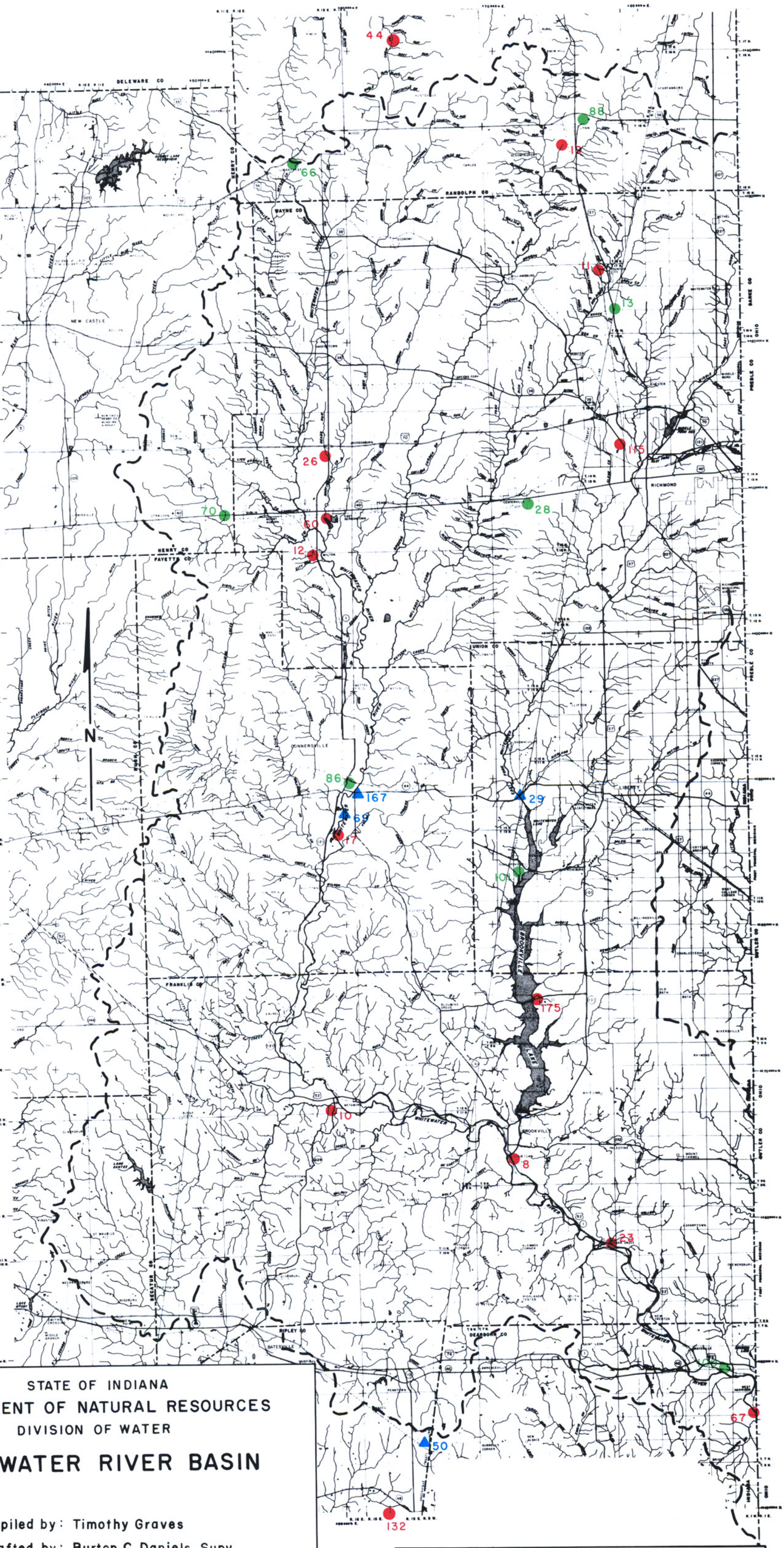
Fig. 37, which shows transmissivity values at various locations in the Whitewater River Basin, is color-coded to show which method was used to estimate each value. The wide range of values is due partly to variations in geologic materials and partly to the different methods used to estimate transmissivity.

For comparative purposes, it is best to examine transmissivity values of the same color category, thus

Table 31. Stream-flow characteristics at wastewater treatment facilities

Site[1]	Location	Stream	Area (sq mi)	1-day, 30-year low-flow		7-day, 10-year low-flow		Average flow	
				cfs	mgd	cfs	mgd	cfs	mgd
27	Brookville	E.F. Whitewater	382	15	9.7	20	12.9	396	256
4	Cambridge City	Whitewater	88.1	5.0	3.2	7.0	4.5	101	65.3
8	Centerville	Nolands Fork	61.7	0.99	0.64	1.7	1.1	70.5	45.6
9	Connersville	Whitewater	443	30	19	38	25	467	302
2	Hagerstown	Whitewater	29.6	1.6	1.0	2.3	1.5	33.8	21.8
12	Laurel	Whitewater	578	43	28	53	34	608	393
23	Liberty	UNT Silver Creek[3]	0.17	0	0	0	0	NA[2]	NA[2]
6	Lynn	Mudd Creek	13.4	0.19	0.12	0.36	0.23	15.3	9.9
14	Oldenburg	Harveys Branch	4.1	0	0	0	0	4.3	2.8
19	Richmond	E.F. Whitewater	121	1.6	1.0	4.2	2.7	115	74

[1] Site locations in figure 33.
[2] NA - not available.
[3] UNT - unnamed tributary.



STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

WHITEWATER RIVER BASIN

Compiled by: Timothy Graves
Drafted by: Burton C. Daniels, Supv.
Donald L. Spilmon
Connie K. Williams

SCALE AS SHOWN

5 0 5 10 MILES

5 0 5 10 KILOMETERS

DRAFTED 1987

EXPLANATION

Transmissivity Values x 10^3 (GPD/ft.)

▲ Transmissivity from Aquifer Test

● Transmissivity from Specific Capacity Data (with adjusted drawdown)

● Transmissivity from Specific Capacity Data (with unadjusted drawdown)

Figure 37. Transmissivity values

eliminating one of the sources of variation. The resulting comparison is based solely on differences in the thickness and permeability of the water-bearing formation.

Interpretation of a given transmissivity value is complicated by the fact that transmissivity is the product of hydraulic conductivity and saturated thickness. Therefore, a given transmissivity value could result from a thick sequence of relatively low-permeability materials or from a thin sequence of relatively high-permeability materials.

Recharge

Natural recharge rates for aquifer systems in the Whitewater Basin have been estimated based on aquifer geometry and hydrogeologic conditions. Applying these rates across an aquifer system yields an estimate of the total system recharge. Summing the totals for each system gives an estimate of the recharge to the entire basin. Using this method, the recharge to the Whitewater Basin is estimated to exceed 178 mgd (table 32).

As table 32 shows, the estimated recharge rate of 500,000 gpd/sq mi for the Whitewater Valley Aquifer System is several times greater than rates for other unconsolidated systems. The presence of well-drained, loamy soils and highly permeable sands and gravels in the major river valleys permits substantial percolation of rainfall-derived recharge. The hydraulic connection between the major rivers and the underlying outwash deposits also can permit temporary recharge from streams during storm events.

The recharge rate for the Wayne-Henry Aquifer System is about one-third that of the Whitewater System due to the lower permeability of till sequences overlying sand and gravel lenses. However, the Wayne-Henry System covers an area four times that of the Whitewater System. When the lower recharge rate is applied across a much larger area, a greater total recharge value is obtained (table 32).

Recharge rates for other unconsolidated systems are estimated to be 100,000 gpd/sq mi for the Fayette-Union System and 50,000 gpd/sq mi for the Dearborn System. Recharge to bedrock will be less than that of the overlying materials.

Development Potential

Sand and gravel outwash deposits of the Whitewater River valley and its major tributary valleys are the most productive and dependable source of ground-water supply in the Whitewater Basin. These deposits, designated as the Whitewater Valley Aquifer System, (pl. 3), have the highest recharge rate in the basin (table 32). The outwash sands and gravels are typically 25 to 75 feet thick and large-diameter wells can generally yield up to 500 gpm.

Although the Whitewater System underlies less than 8 percent of the basin's total area, about three-fourths of the registered municipal and industrial facilities utilize the system as a ground-water source. Approximately 11 mgd, or more than 90 percent of the ground-water used in the basin, was withdrawn from this system in 1986.

Because of the large amount of storage in and recharge to the Whitewater System, there is a significant potential for further ground-water development from this system. Much of the current ground-water development has occurred in the Richmond and Connersville vicinities. However, the development potential is also high to the south of Brookville, where the outwash is particularly thick.

Where outwash deposits of the Whitewater Valley Aquifer System are not present, intratill sand and gravel lenses are a major ground-water source. These lenses vary widely in depth and lateral extent, and are usually not traceable beyond small areas. However, intratill aquifers in the northern half of the basin are the source of ground-water supply for nearly one quarter of the basin's registered municipal and industrial facilities.

Although well yields up to 150 gpm have been reported in some northern areas of the basin, yields from intratill aquifers typically range from less than 15 gpm in Wayne County to less than 2 gpm in Franklin and Dearborn Counties. This decrease in yields from north to south is primarily due to the thinning and increased age of glacial deposits. Typical aquifer thickness ranges from about 10 feet in northern areas to less than 2 feet in the south.

The water-producing capability of the bedrock aquifer systems generally decreases from the western and northern basin margins, where Silurian bedrock predominates, toward the southern and central areas, where Ordovician bedrock is present (pl. 3). Bedrock of the less productive Ordovician Aquifer System contains more shale and has thinner-bedded strata with multiple shale and limestone layers. Well yields from bedrock also tend to decrease from north to south, probably due primarily to the thinning of unconsolidated materials, which may act as a recharge reservoir for the underlying bedrock.

Table 32. Estimates of aquifer system recharge

County	Randolph	Wayne	Henry	Fayette	Union	Rush	Decatur	Franklin	Ripley	Dearborn	System Totals
UNCONSOLIDATED AQUIFER SYSTEMS											
Wayne-Henry: Recharge rate = 150,000 gpd/ sq mi											
Area (sq mi)	80.0	306.0	42.5	16.5	2.5	—	—	—	—	—	447.5
Recharge (mgd)	12.0	45.9	6.4	2.5	0.4	—	—	—	—	—	67.2
Fayette-Union: Recharge rate = 100,000 gpd/sq mi											
Area (sq mi)	—	48.5	—	129.0	150.5[1]	—	—	34.0[1]	—	—	362.0[1]
Recharge (mgd)	—	4.9	—	12.9	15.1	—	—	3.4	—	—	36.3
Dearborn: Recharge rate =50,000 gpd/sq mi											
Area (sq mi)	—	—	—	34.0	2.0	14.0	33.0	322.0	21.0	37.5	463.5
Recharge (mgd)	—	—	—	1.7	0.1	0.7	1.7	16.1	1.1	1.9	23.3
Whitewater: Recharge rate =500,000 gpd/sq mi											
Area (sq mi)	4.0	47.5	—	17.5	7.5	—	—	22.0	—	4.5	103.0
Recharge (mgd)	2.0	23.8	—	8.8	3.8	—	—	11.0	—	2.3	51.7
COUNTY TOTALS											
Area (sq mi)	84	402	42.5	197	162.5[1]	14	33	378[1]	21	42	1376[1]
Recharge (mgd)	14.0	74.6	6.4	25.9	19.4	0.7	1.7	30.5	1.1	4.2	178.5
BEDROCK AQUIFER SYSTEMS[2]											
Silurian:											
Area (sq mi)	81.0	106.2	20.2	52.2	9.2[1]	14	28.8	30.0	0	0	341.6[1]
Recharge Rate (gpd/sq mi)	{ commonly <150,000 }			{ <100,000 }		{ commonly <50,000 }					
Ordovician:											
Area (sq mi)	3.0	295.8	22.3	144.8	153.3[1]	0	4.2	348.0[1]	21.0	42.0	1,034.4[1]
Recharge Rate	{ Ordovician bedrock is only marginally productive }										

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[1] Includes area of the county to the Ohio border outside the basin boundary.

[2] Recharge to the bedrock aquifer systems depends upon the recharge rate and water consumption in the overlying unconsolidated aquifer systems. Recharge to bedrock aquifers will generally be a fraction of the overlying unconsolidated system recharge rate.

SUMMARY AND REFERENCES

SUMMARY

In response to legislative directives contained in the 1983 Water Resource Management Act, the Indiana Department of Natural Resources, Division of Water published a report describing the availability, distribution, quality, and use of surface water and ground water in the Whitewater River Basin, Indiana. The second in a series of 12 regional investigations, this report provides hydrologic data and related information for planners, government officials, and others interested in the state's water resources.

The Whitewater River Basin drains 1329 square miles in southeast Indiana and 145 square miles in southwest Ohio. About 2 miles east of the Indiana-Ohio state line, the Whitewater River joins the Miami River, which empties into the Ohio River at the intersection of Indiana, Ohio, and Kentucky. The Whitewater River Basin in Indiana encompasses parts of 10 counties, but 82 percent of the land area lies within Wayne, Fayette, Union, and Franklin Counties.

POPULATION AND ECONOMY

More than half of the 1980 basin population of 145,500 resided in Wayne County, particularly in and near Richmond, the basin's largest city. Nearly a third of the basin population resided in Fayette and Franklin Counties.

The recent decrease in Wayne County's population is expected to continue through at least the year 2000 as Richmond's population continues to decline. Moderate increases in population are projected for Franklin and Union Counties. An increase in population is also projected for Fayette County; however, provisional estimates show a decline in population since 1980.

Manufacturing, wholesale-retail trade, services, and government constitute the Whitewater Basin's four largest non-farm employment classes and account for three-fourths of the total earnings. Farm employment exceeds non-farm employment in Union and Franklin Counties. Farm earnings in the basin are highest in Union County.

Cropland, the major land use in the Whitewater River Basin, is particularly widespread in Union and Wayne Counties. The largest tracts of forest land occur in southern Fayette and western Franklin Counties, where erosive soils and hilly terrain limit the availability of prime cropland. Residential and commercial development is primarily concentrated in and near the cities of Richmond and Connersville, which together comprise 40 percent of the basin's total population.

TOPOGRAPHY AND GEOLOGY

The northern third of the Whitewater River Basin lies within the Tipton Till Plain and has nearly flat to gently rolling topography characterized by morainal deposits of Wisconsinan age. The southern two-thirds of the basin lies within the Dearborn Upland and is dominated by dissected upland plains and narrow ridges. Near the basin's northeastern boundary, land surface elevation often exceeds 1,200 feet m.s.l. along the crest of the Knightstown Moraine. In the extreme southeastern part of the basin, land surface elevation is approximately 500 feet m.s.l. where the Whitewater River exits Indiana. Maximum local relief can exceed 400 feet where bedrock ridges border the lower Whitewater River valley.

The Wisconsinan glacial boundary, which extends through Franklin and southwest Fayette Counties, divides the Whitewater River Basin into two geologically distinct portions. North of this glacial boundary, bedrock is covered by variable but often thick layers of tills, lacustrine clays, and sands and gravels. The only bedrock exposures occur along some of the larger river valleys, particularly the East Fork Whitewater River. South of the Wisconsinan boundary, thin layers of residuum and/or pre-Wisconsinan tills overlie the bedrock surface, which is commonly exposed along valley sides. Outwash deposits within the valleys of the Whitewater River and its major tributaries are thicker south of the Wisconsinan glacial boundary, but are more laterally extensive to the north.

Limestones and dolomites of Silurian age underlie the western, northern, and northeastern portions of the Whitewater River Basin. Ordovician limestones and shales underlie the basin's central part. Bedrock elevation ranges from more than 1050 feet m.s.l. in the northeastern part of the basin to about 450 feet m.s.l. where the Whitewater River exits Indiana. A large buried bedrock valley in western Wayne County and eastern Henry County is filled with up to 300 feet of glacial sediment.

SURFACE-WATER HYDROLOGY

Normal annual temperatures within the Whitewater Basin range from 50^{o}F in northern areas to 52^{o}F in the south. Normal annual precipitation ranges from 38 inches in the north to 40 inches in the south. Evapotranspiration annually consumes from 27 to 28 inches of water. The amount of precipitation available on a monthly and seasonal basis is generally abundant, but extended periods of dry weather can sometimes occur.

Drainage in the Whitewater River Basin is well developed, particularly in southern areas where glacial deposits are older or absent. Principal streams are entrenched in glacial drift in northern parts of the basin, and are cut into bedrock in southern areas. Channel slopes of the Whitewater River and its east fork are among the highest for major Indiana rivers.

Low stream flows are moderately sustained along the principal streams, where ground-water discharge from outwash deposits accounts for about 55 percent of the total runoff. In general, the degree of groundwater contribution appears to be greatest in northern areas of the basin, particularly along the Whitewater River and its major tributaries in Wayne County, where outwash deposits are laterally extensive and occasionally quite thick.

In southern areas of the Whitewater River Basin, stream flow in the mainstem Whitewater River is well sustained by ground-water discharge from thick outwash sands and gravels. However, tributary streams generally cease flowing during dry periods because of minimal ground-water seepage from thin, clayey tills.

Middle Fork Reservoir, Lake Santee, and Whitewater Lake are the major manmade impoundments in the Whitewater River Basin used for recreation or for recreation and public water supply. Brookville Lake, the basin's largest reservoir, is used for flood control, recreation, and water supply. The reduction of flood peaks downstream of Brookville Lake has prevented more than $2.5 million in flood damages since 1974.

The operation of Brookville Lake dam significantly reduces downstream flood discharges and also modifies seasonal flows. Downstream flows in autumn are higher than normal during reservoir drawdown. In contrast, downstream flows in spring are lower than normal as the reservoir level is increased to summer pool. Daily stream flows will reflect scheduled as well as occasional operations at the dam, and hence can sometimes be excessively high or low.

Water quality is generally good in the Whitewater River and its east fork. At the stream quality gage on the Whitewater River downstream of Brookville, however, violations of the bacterial standard for recreational uses have frequently been recorded. Only occasional violations have been recorded along other reaches. A 28-mile segment of the Whitewater River in Franklin County has been recommended for inclusion in Indiana's Natural, Scenic, and Recreational Rivers System.

Middle Fork Reservoir and Brookville Lake are two moderately eutrophic lakes of good water quality. Iron and manganese concentrations are occasionally high, but nutrient levels are low and concentrations of toxic substances are negligible. Although Whitewater Lake has recently experienced an improvement in overall water quality, a siltation problem remains.

Because hydrologic data form a framework upon which management decisions are based, the adequacy of data networks for ongoing water management purposes was assessed. Based upon a Division of Water review, data collected from climatic stations and observation wells in the Whitewater River Basin are sufficient for water management needs. The establishment of stream gaging stations on either Greens Fork or Nolands Fork, Salt Creek or Pipe Creek, and the Middle Fork of the East Fork Whitewater River upstream of Middle Fork Reservoir should be considered, primarily to provide data for regional hydrology. In addition, reinstatement of the Richmond gage as a partial-record station could provide low-flow data for an urban river reach. Stations currently operating on Little Williams Creek at Connersville, Whitewater River near Economy, and Whitewater River near Hagerstown are recommended for discontinuation between 1988 and 1990 because of sufficient record.

GROUND-WATER HYDROLOGY

Ground water in the Whitewater River Basin is available from glacial deposits and from bedrock. Of the six aquifer systems identified in the basin, the Whitewater Valley System is by far the most productive. Well yields of 500 gpm can be expected throughout most of this system, which occupies the valleys of the Whitewater River and its major tributaries.

The sand and gravel outwash deposits comprising the Whitewater Aquifer System may reach 100 feet in thickness, but thicknesses of 25 to 75 feet are typical. These outwash sands and gravels contrast sharply with the clay-dominated or bedrock environments of surrounding aquifer systems.

The Wayne-Henry Aquifer System is the second most productive unconsolidated system. The principal aquifers are intratill sand and gravel lenses which are confined by clay or till sequences. Aquifer materials can reach 40 feet in thickness, but are generally 10 feet thick or less. Most wells in the Wayne-Henry System produce less than 15 gpm, but yields of 150 gpm have been reported.

West and southwest of Richmond, a fairly consistent intratill sand and gravel zone has been delineated within the Wayne-Henry Aquifer System. This zone is usually about 5 feet thick, and most wells produce at least 10 gpm.

Ground-water supplies are limited in the Fayette-Union and Dearborn Aquifer Systems, which are comprised of clay-rich till sequences of Wisconsinan and pre-Wisconsinan age, respectively. Intratill sand and gravel lenses are generally less than 4 feet thick in the Fayette-Union System, and less than 2 feet thick in the Dearborn System. Most wells in the two systems produce only 2 to 3 gpm; however, yields of 10 gpm can typically be expected in part of northeastern Union County, where sand and gravel zones are more abundant and slightly thicker. Dry holes are fairly common in the Dearborn System, which has the most limited ground-water resources of the unconsolidated aquifer systems in the Whitewater River Basin.

Silurian limestone and multiple layers of Ordovician limestone and shale are used as a ground-water source where glacial aquifers are absent. The best Silurian bedrock production is along the basin's northern boundary, where yields of 30 to 60 gpm are common. Farther south, well yields decrease to 10 gpm or less. Wells completed in Ordovician bedrock generally produce less than 8 gpm, and dry holes are fairly common.

Ground water throughout the Whitewater River Basin is characterized by high alkalinity, high hardness, and mostly basic pH. Ground water generally meets standards for public supply; however, iron concentrations commonly exceed the secondary drinking-water standard of 0.3 mg/l. Total dissolved solids concentrations exceeded the secondary limit of 500 mg/l in half of the wells sampled in the Ordovician Aquifer System. The primary drinking-water standard for nitrate (as nitrogen) of 10 mg/l was exceeded in three wells in the Whitewater Valley System and one well in the Ordovician System.

The Wayne-Henry, Fayette-Union, and Silurian Aquifer Systems have the three highest median iron values and the three lowest median nitrate values. The Dearborn System has the lowest median values of alkalinity, calcium, magnesium, hardness, and total dissolved solids, whereas the Ordovician System has the highest median values of these constituents. In addition, the Ordovician System has the highest median chloride and sodium values. The Dearborn System and Whitewater Valley System have the two lowest median iron values and the two highest median nitrate values. The Whitewater System also has the highest median value of sulfate.

Wayne County has been designated by the Indiana Department of Environmental Management as a geographic area where ground-water protection may be most needed. Detectable levels of at least one volatile organic compound were found by the U.S. Environmental Protection Agency in six public water supplies in the Whitewater River Basin.

WATER USE AND PROJECTIONS

The 44 high-capacity water withdrawal facilities registered in the Whitewater River Basin reported a total average use of nearly 12 mgd of ground water and nearly 5 mgd of surface water in 1986. Public supply utilities accounted for about 85 percent of the water withdrawn, and self-supplied industries accounted for approximately 15 percent. Total estimated water withdrawals from small-capacity, non-registered facilities averaged about 4 mgd for domestic self-supplied uses, and 2 mgd for livestock uses.

More than three-fourths of the basin's water usage for public supply occurs in Richmond and Connersville. Withdrawals for public water supply are projected to increase in all basin counties except Fayette, where a two percent decrease is projected from 1985 to the year 2000.

Ground water is the source of all public supply withdrawals in the Whitewater River Basin except in eastern Wayne County, where Middle Fork Reservoir provides about 60 percent of Richmond's water supply needs. In a unique situation involving water supply at Brookville Lake, water used by the Franklin County Water Association is derived from two wells located on the Fairfield causeway; hence, the utility's water withdrawals are categorized as ground-water withdrawals. A water supply contract with the Indiana Department of Natural Resources, however, considers this use to be met by surface water from Brookville Lake.

About 60 percent of the water withdrawn by industries is derived from ground water. Three-fourths of the registered industrial water usage occurs in Wayne County, primarily in and near Richmond. Although sand and gravel operations within the basin account for more than half of the water withdrawn by industries, the greatest percentage increase in water use is projected for primary metal production.

Only one agricultural irrigator is registered in the Whitewater River Basin. The potential for increased agricultural irrigation is limited in most of the basin by moderate to steep slopes, unsuitable soils, and variability of water supply; however, some areas in the major stream valleys may be suitable for irrigation development.

WATER AVAILABILITY AND DEVELOPMENT

The most dependable water supplies for current and future development are available in the valleys of the Whitewater River and its major tributaries. Outwash sand and gravel deposits underlying these valleys serve as a ground-water source for about three-fourths of the registered withdrawal facilities and comprise about 90 percent (11 mgd) of reported ground-water use. The permeable sand and gravel deposits designated as the Whitewater Valley Aquifer System have an estimated recharge rate several times that of the intratill aquifer systems.

Most registered facilities with surface intakes withdraw water from excavations near the major streams. The Whitewater River or reservoirs on its tributaries could supply additional surface water for future development.

Middle Fork Reservoir's dependable yield of 5.3 mgd corresponding to its present total storage capacity exceeds the demand of 3.8 mgd projected for Richmond's surface-water needs in the year 2000. If additional surface-water supply were to be required, the installation of Tainter gates could increase the reservoir yield to 8.3 mgd. The construction of a reservoir on the West Fork of the East Fork Whitewater River, although more costly, could also provide an additional supply of surface water for the Richmond vicinity.

Although Batesville's present water supply capacity of approximately 2 mgd exceeds the projected demand of 1.5 mgd for the year 2000, the construction of a reservoir on Salt Creek could provide an additional supply for Batesville and nearby areas. Batesville, which lies outside the Whitewater River Basin boundary, currently supplies water to Oldenburg, which lies just inside the boundary.

Brookville Lake is by far the largest but least used reservoir supply in the basin. The U.S. Army Corps of Engineers estimates the water supply capability of Brookville Lake to be 90.5 mgd. Although six registered wells utilized for public supply are located on or near the Fairfield and Dunlapsville causeways, no registered facilities currently withdraw water directly from the lake. Brookville Lake therefore remains a largely underutilized source of water supply.

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APPENDICES

Appendix 1.

GLOSSARY

Alluvial—describes deposits of clay, silt, sand, gravel, or other particulate rock material in a streambed, on a flood plain, or on a delta

Aquifer—a saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients

Bank storage—the water absorbed into the banks of a stream channel when the stage rises above the water table in bank formations, then returns to the channel as effluent seepage when the stage falls below the water table

Base flow—the portion of stream flow derived largely or entirely from ground-water seepage

Bucket-rig well—a large-diameter well typically utilized in areas of low ground-water yields

Buried valley—depression in an ancient land surface or in bedrock now covered by younger deposits; especially a preglacial valley filled with glacial drift

Channel slope—the slope of the streambed between points that are 10 and 85 percent of the distance from the location on the stream to the basin divide, as determined from topographic maps; expressed in feet per mile

Climatic year—the 12-month period, April 1 to March 31, designated by the calendar year in which it begins; for example, climatic year 1984 is from April 1, 1984 to March 31, 1985; climatic year is designed to encompass the annual summer-fall low-flow period

Colluvium—loose rock debris at the foot of a slope or cliff deposited by rock falls, landslides, and slumpage

Combined sewer overflow—a discharge composed of untreated or partially treated sewage mixed with stormwater

Confined—describes an aquifer in which ground water is isolated from the atmosphere by impermeable formations; confined ground-water is generally subject to pressure greater than atmospheric

Contaminant (drinking water)—as defined by the U.S. Environmental Protection Agency, any physical, chemical, biological , or radiological substance in water, including constituents which may or may not be harmful

Continuous-record station—a site on a stream or lake where continuous, systematic observations of stage and/or discharge are obtained by recording and nonrecording instruments and periodic measurements of flow

Cyclonic—describes a roughly circular area of low atmospheric pressure in which the winds blow counterclockwise in the northern hemisphere

Direct runoff—water entering a stream channel promptly after a precipitation event; it is presumed to consist of surface runoff and a substantial portion of the interflow.

Dissected—cut by erosion into hills and valleys or into flat upland areas separated by valleys

Diurnal—having a daily cycle

Drainage density—ratio of total length of all channels within a drainage basin to the area of that basin

Drawdown (ground water)—difference between the water level in a well before and during pumping

Appendix 1. Continued

Drawdown (surface water)—artificial lowering of the water level of a lake or reservoir

Drift—unconsolidated sediment and rock debris transported and deposited by glaciers or glacial streams

Dry hole—a well that produces little or no water

End moraine—see moraine

Epilimnetic—describes the upper layer of a thermally stratified lake in which the water is nearly uniformly warm, circulating, and fairly turbulent

Estimate (population)—a number based on events that have already occurred

Eutrophic—describes a body of water which has become enriched with plant nutrients, most commonly phosphorus and nitrogen

Evapotranspiration—collective-term that includes water discharged to the atmosphere as a result of evaporation from the soil and surface water bodies and by plant transpiration

Fecal coliform—bacteria that occur naturally in the intestines of humans and animals; bacterial counts in waterways are used as indicators of pollution from human and animal wastes

First-order stream—a channel reach which has no tributaries

Flood, 100-year—a statistically-derived flood discharge having an average frequency of occurrence of once in 100 years, or a one percent chance of being equaled or exceeded in any given year

Flowing well—a well deriving its water from a confined aquifer and in which the water level stands above the ground surface

Fragipan—a loamy, brittle subsurface soil horizon which is low in porosity, low or moderate in clay, but high in silt or very fine sand; a fragipan appears cemented and restricts plant roots and the percolation of water

Frequency analysis—a statistical method for attaining the probability that a given hydrologic event will be equaled or exceeded

Grab sample—water collected at a single location and at a single time as opposed to a sample composited over space or time

Growing season—the average number of days between the last spring and first autumn temperature of 32°F

Ground moraine—rock and soil material deposited from a glacier on the ground surface over which the glacier has moved; it is bordered by lateral and/or end moraines.

Ground-water discharge—in this usage, the part of total runoff which has passed into the ground and has subsequently been discharged into a stream channel

Hummock—a mound, knoll, or hillock

Hydraulic conductivity—a constant describing the rate at which water moves through a permeable medium; often expressed in gallons per day per square foot

Hydrograph—graph showing stage, flow, velocity, or other properties of water with respect to time

Appendix 1. Continued

Hypolimnion—the lower layer of a thermally stratified lake in which the water is nearly uniformly cool and relatively quiescent

Igneous—describes rocks that solidified from molten or partly molten material

Intercalated—interstratified; inserted among other layers

Interflow—the part of precipitation which infiltrates the surface soil, and moves laterally toward streams as perched ground water

Intratill—describes geologic materials contained within a single till unit

Lacustrine—pertaining to, produced by, or formed in a lake or lakes

Loamy—describes a soil composed of a mixture of clay, silt, sand, and organic matter

Loess—a homogeneous, fine-grained deposit consisting predominantly of silt, and chiefly deposited by wind

Macrophytes—macroscopic forms of aquatic vegetation

Maximum contaminant level—the maximum permissible level of a contaminant in water which is delivered to the free-flowing outlet of the user of a public water system

Median—the middle value of a set of observations arranged in order of magnitude

Metamorphic—describes rocks that have formed in the solid state in response to pronounced changes of temperature, pressure, and chemical environment

Moraine—a mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift deposited chiefly by the direct action of glacial ice

Normal (climatic)—average (or mean) value for a particular parameter over a designated period, usually the most recent 30-year period ending every decade (1941-70, 1951-80, for example)

Outwash—sand and gravel deposited by meltwater streams in front or beyond the margin of active glacial ice

Overland flow—the part of runoff which passes over the land surface to the nearest stream channel

Paleosol—an ancient, buried soil

Partial-body contact—any contact with water up to but not including complete submergence

Partial-record station—a site where limited stream-flow and/or water quality data are collected systematically over a period of years

Per capita income—total money income of the residents of a given area divided by the resident population of that area; represents the amount of income received before deductions for personal income taxes, social security, bond purchases, etc.; receipts not counted include ''lump sums'' payments such as capital gains or inheritances

Phytoplankton—an assemblage of microscopic aquatic plants having no or very limited powers of locomotion

Physiography—the origin and evolution of landforms

Appendix 1. Continued

Piezometric surface—an imaginary surface representing the level to which water from a given aquifer will rise under its own head

Polychlorinated biphenyls (PCBs)—a family of chlorinated hydrocarbons toxic to animals and humans

Projection (population)—a number based on trends and patterns of the past

Recharge (ground water)—process of entry of water into the zone of saturation

Recurrence interval—the average time interval, in years, within which the magnitude of a given event, such as a flood, storm, or low-flow event will be equaled or exceeded

Regression analysis—a statistical method for determining linear dependence, and, where significant correlation exists, in making predictions

Regulation (stream)—artifical manipulation of the flow of a stream

Residuum—rock material remaining essentially in place after all but the least soluble constituents have been removed

Runoff (total)—the part of precipitation that appears in surface-water bodies; it is the same as stream flow unaffected by artificial manipulation; runoff expressed in inches shows the depth to which the drainage area would be covered if all the runoff for a given period were uniformly distributed

Second-order stream—a channel reach which receives flow from two or more first-order streams

Static water level—the level of water in a well that is not being affected by withdrawal of ground water

Stratigraphy—geological study of the formation, composition, sequence, and correlation of unconsolidated or rock layers

Surface runoff—water which passes over the land surface to the nearest stream channel (overland flow) plus precipitation falling directly on the stream

Tailwater—water in a channel or pool immediately downstream of a structure such as a bridge, culvert, or dam

Terminal moraine—a moraine formed across the front edge of a glacier marking its farthest advance

Terrace—a bench or discontinuous segments of a bench, in a valley at some height above the modern floodplain, and which is part of an abandoned floodplain

Till—unsorted, unstratified drift deposited directly by a glacier without subsequent reworking by meltwater; it consists of a heterogeneous mixture of clay, silt, sand, and gravel ranging widely in size and shape

Topography—the relief and contour of a surface, especially land surface

Toxic—describes materials which are or may become harmful to plants or animals when present in sufficient concentrations

Transmissivity—rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient

Unconfined—describes an aquifer whose upper surface is a water table free to fluctuate under atmospheric pressure

Unit discharge—a general term used to describe a streamflow parameter uniformly distributed over the drainage basin during a specified unit of time

Appendix 1. Continued

Valley train—a long, narrow body of outwash confined within a valley

Water year—the 12-month period, October 1 to September 30, designated by the calendar year in which it ends; for example, water year 1984 is from October 1, 1983 to September 30, 1984; water year is designed to encompass the annual winter-spring high-flow period

Weathering—the decay of earth materials through a complex interaction of physical, chemical, and biological processes

Whole-body contact—direct contact with water to the point of complete submergence

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Glossary is partially adapted from Langbein and Iseri, 1960; U.S. Geological Survey, 1984; and the American Geological Institute, 1976.

Appendix 2. Historic and projected county population

Upper figures: Division of Water estimates, in-basin portion only.
Lower figures: U.S. Census Bureau, total county (1900-1980); Indiana State Board of Health (1983), total county (1985-2000).

County	1900	1910	1920	1930	1940	1950	1960	1970	1980	1985	1990	1995	2000
Dearborn	3036	2927	2741	2880	3154	3439	3923	4026	4691	4966	5239	5472	5677
	22194	21396	20033	21056	23053	25141	28674	29430	34291	36300	38300	40000	41500
Decatur	1727	1663	1576	1532	1568	1612	1772	2012	2110	2124	2151	2177	2204
	19518	18793	17813	17308	17722	18218	20019	22738	23841	24000	24300	24600	24900
Fayette	12365	13208	15707	17632	17786	21433	22407	24022	25906	26389	26939	27489	27856
	13495	14415	17142	19243	19411	23391	24454	26216	28272	28800	29400	30000	30400
Franklin	15537	14539	14038	13746	13664	15202	16132	16064	18594	19436	20289	21237	21996
	16388	15335	14806	14498	14412	16034	17015	16943	19612	20500	21400	22400	23200
Henry	2732	3241	3777	3837	4379	4955	5325	5728	5808	5739	5695	5663	5641
	25088	29758	34682	35238	40208	45505	48899	52063	53336	52700	52300	52000	51800
Randolph	5301	5367	4900	4599	4950	5021	5260	5349	5549	5550	5606	5661	5716
	28653	29013	26484	24859	26755	27141	28434	28915	29997	30000	30300	30600	30900
Ripley	934	914	879	850	888	882	970	993	1147	1199	1246	1293	1335
	19881	19452	18694	18078	18898	18763	20641	21138	24398	25500	26500	27500	28400
Rush	691	664	660	666	649	679	699	698	672	641	621	611	604
	20148	19349	19241	19412	18927	19799	20393	20352	19604	18700	18100	17800	17600
Union	5299	4916	4728	4618	4725	5035	5071	5169	5387	5497	5497	5576	5654
	6748	6260	6021	5880	6017	6412	6457	6582	6860	7000	7000	7100	7200
Wayne	38775	43538	47895	54535	57938	68223	73669	78713	75678	73530	72237	71242	70545
	38970	43757	48136	54809	58229	68566	74039	79109	76058	73900	72600	71600	70900
Total	86397	90977	96901	104895	109701	126481	135228	142774	145542	145071	145520	146421	147228
	211083	217528	223052	230381	244643	268970	289025	304026	316269	317400	320200	323600	326800

Appendix 3. General Soil Map

AGRICULTURAL EXPERIMENT STATION AND COOPERATIVE
EXTENSION SERVICE, PURDUE UNIVERSITY: AND THE SOIL
CONSERVATION SERVICE, U.S. DEPARTMENT OF AGRICULTURE (1971)

Note: This map is intended for general planning. Each delineation contains soils different from those shown in the legend. For operational planning, use detailed soil maps that may be available in published or unpublished form at the local Soil and Water Conservation District Office.

SOIL ASSOCIATIONS

3. *Wakeland-Stendal-Haymond-Bartle:* Nearly level, somewhat poorly drained, silty Wakeland and Stendal and well drained, silty Haymond in alluvial deposits, and somewhat poorly drained, silty Bartle with fragipans in acid alluvial deposits.

4. *Genesee-Shoals-Eel:* Nearly level, well drained, loamy Genesee, moderately well drained, loamy Eel, and somewhat poorly drained, loamy Shoals in alluvial deposits.

18. *Fox-Martinsville-Alluvial soils:* Sloping and nearly level, well drained, loamy Fox on outwash sand and gravel, and loamy Martinsville on outwash sand and silt and associated soils in alluvial deposits.

19. *Fox-Nineveh-Ockley:* Nearly level, well drained, loamy soils on outwash sand and gravel.

62. *Blount-Pewamo:* Nearly level, somewhat poorly drained, clayey Blount and very poorly drained, clayey Pewamo in glacial till.

64. *Crosby-Brookston:* Nearly level, somewhat poorly drained, clayey Crosby and very poorly drained, loamy Brookston in glacial till.

66. *Fincastle-Ragsdale-Brookston:* Nearly level, somewhat poorly drained, silty Fincastle in wind-blown silts and glacial till, very poorly drained, silty Ragsdale in wind-blown silts and loamy Brookston in glacial till.

72. *Reesville-Ragsdale:* Nearly level, somewhat poorly drained, silty Reesville and very poorly drained, silty Ragsdale in wind-blown silts.

81. *Miami-Russell-Fincastle:* Sloping, well drained, loamy Miami in glacial till and silty Russell in wind-blown silts and glacial till and nearly level somewhat poorly drained, silty Fincastle in wind-blown silts and glacial till.

83. *Miami-Crosby:* Sloping, well drained, loamy Miami and nearly level, somewhat poorly drained, clayey Crosby in glacial till.

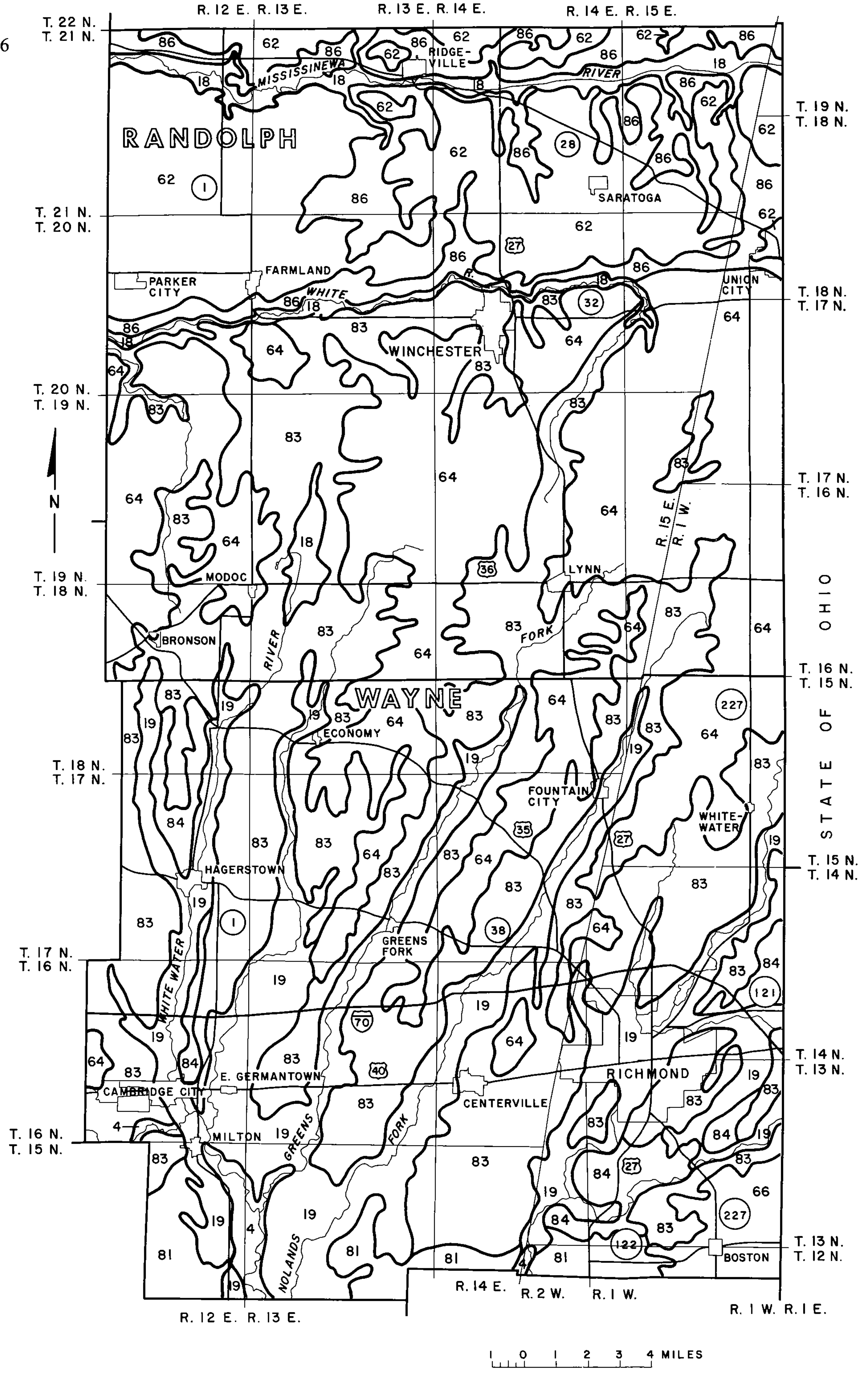
84. *Miami-Hennepin:* Sloping, well drained, loamy Miami and steep, well drained, shallow, loamy Hennepin in glacial till.

86. *Morley-Blount:* Sloping, well drained, clayey Morley and nearly level, somewhat poorly drained, clayey Blount in glacial till.

91. *Avonburg-Clermont:* Nearly level, somewhat poorly drained, silty Avonburg and poorly drained, silty Clermont, both with fragipans, in wind-blown silts and weathered glacial till.

93. *Cincinnati-Rossmoyne-Hickory:* Sloping, well drained, silty Cincinnati and moderately well drained, silty Rossmoyne, both with fragipans, in wind-blown silts and weathered glacial till, and steep, well drained, loamy Hickory in weathered till.

101. *Fairmount-Switzerland:* Steep, well drained, shallow, clayey Fairmount and deep, clayey Switzerland in weathered shale and limestone.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VILLE
SARATOGA
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CITY
FARMLAND
WHITE
R.
UNION
CITY
WINCHESTER
MODOC
BRONSON
RIVER
LYNN
FORK
R. 15 E.
R. 1 W.
STATE OF OHIO
ECONOMY
FOUNTAIN
CITY
WHITE-
WATER
HAGERSTOWN
GREENS
FORK
WHITE WATER
E. GERMANTOWN
CAMBRIDGE CITY
CENTERVILLE
RICHMOND
MILTON
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FORK
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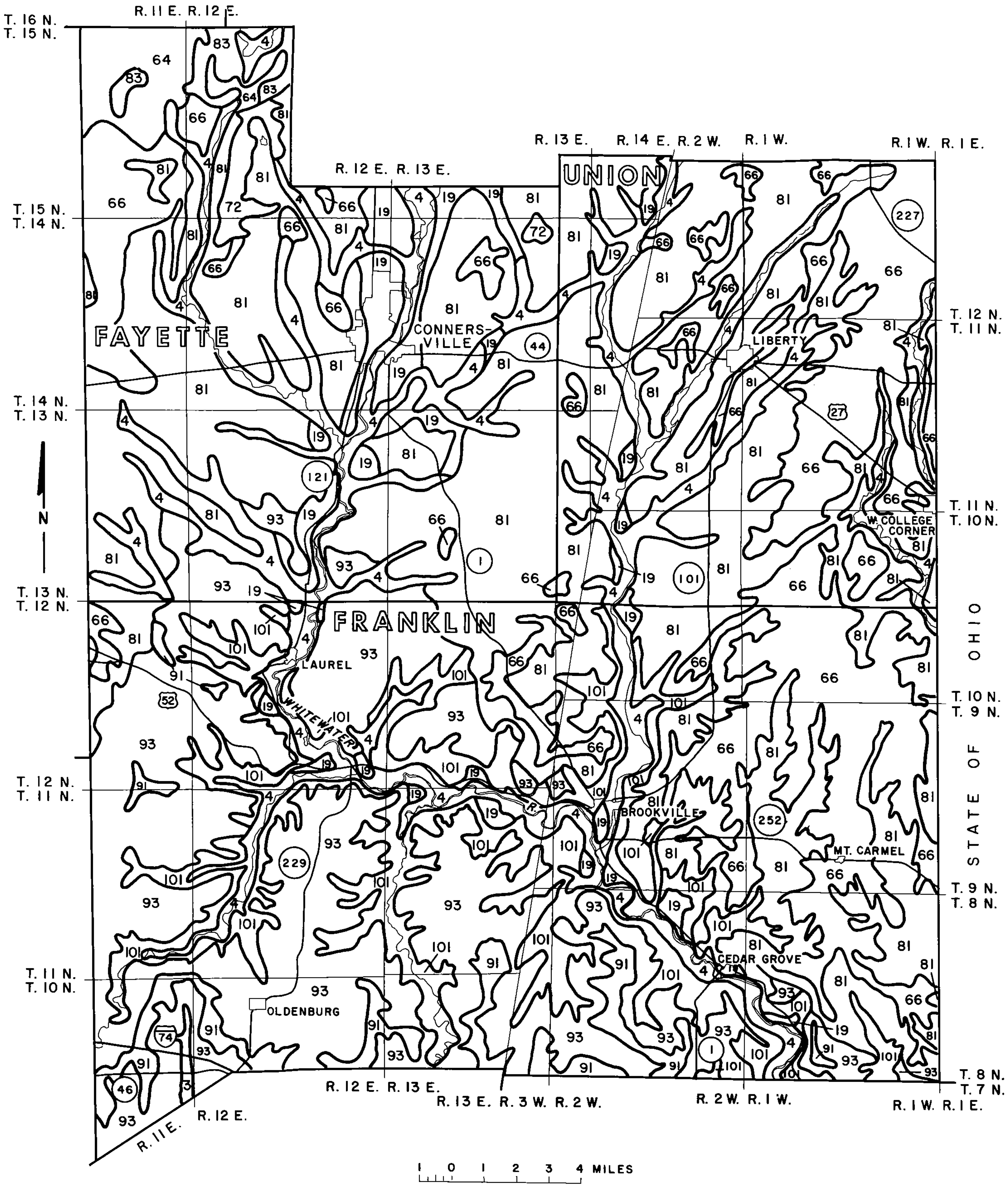
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FAYETTE
CONNERS-
VILLE
LIBERTY
T. 14 N.
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W. COLLEGE
CORNER
T. 13 N.
T. 12 N.
FRANKLIN
LAUREL
WHITEWATER
T. 10 N.
T. 9 N.
STATE OF OHIO
T. 12 N.
T. 11 N.
BROOKVILLE
MT. CARMEL
T. 9 N.
T. 8 N.
CEDAR GROVE
T. 11 N.
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OLDENBURG
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T. 7 N.
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R. 13 E. R. 3 W. R. 2 W.
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R. 1 W. R. 1 E.
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252
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Appendix 4. Discussion of exposed stratigraphic units

The Kope Formation consists dominantly of bluish- to brownish-gray clay shale, but about five percent is thin discontinuous beds of fossiliferous limestone that occur mostly in the upper one-half to one-third of the formation. These beds are more prevalent southward, so that a considerable part the of the formation exposed in the southeastern extremity of the basin consists of limestone.

Approximately 100 feet of the upper Kope Formation is exposed in the Whitewater River Basin, although the formation ranges in thickness from about 250 feet in Dearborn County to more than 550 feet at the northern limit of the basin. The lower Kope Formation grades laterally southward through a progressive facies change into the Lexington Limestone, which otherwise underlies the Kope.

The Dillsboro Formation conformably and gradationally overlies the Kope and is about 300 feet thick in much of the Whitewater drainage area. The Dillsboro is a sequence of alternating, mostly thin-bedded, fossiliferous limestone and calcareous shale. The limestones tend to be better exposed than the shale, but comprise only about 30 percent of the Dillsboro and are less prominent northward.

The Whitewater Formation overlies the Dillsboro and encompasses the youngest Ordovician rocks in Indiana. The formation was named for exposures along the Whitewater River at Richmond, Indiana. Throughout most of the basin the lower part of the formation is recognized as the Saluda Dolomite Member, a unit that makes a relatively sharp, but conformable boundary with the underlying Dillsboro. The Saluda is mostly varicolored, fine-grained dolomite but includes a zone rich in the corals **Columnaria** and **Tetradium.** The Saluda thins to the north and is less than 10 feet thick in Wayne County. The remaining part of the Whitewater Formation is mostly argillaceous, fossiliferous limestone interbedded with calcareous shale.

Although there is more limestone in the Whitewater Formation than in the underlying Dillsboro and Kope Formations, the upper part of the Whitewater Formation in Wayne County consists mostly of shale. The Whitewater is about 90 feet thick in Wayne County and maintains nearly the same thickness to the south because the part of the formation above the Saluda thins to the south in compensation for the thickening of the Saluda.

The Brassfield Limestone of Silurian age unconformably overlies the Dillsboro in the Whitewater River Basin. The Brassfield is generally a medium- to coarse-grained fossiliferous limestone with numerous irregular blebs and stringers of shale. The formation is commonly yellowish-brown to salmon pink, but near Richmond the basal part is nearly white, and the overlying limestone is dark gray. Maximum thickness at the north end of the drainage basin is about 15 feet, but a thickness of less than 4 feet is common.

The Salamonie Dolomite unconformably overlies the Brassfield Limestone. In the southeastern part of the basin, the Salamonie includes some shale and very argillaceous limestone in its lower part, which is normally less than 40 feet thick. This lithology is transitional to the north into a more pure dolomite. The upper part of the Salamonie, though absent from the Whitewater Basin, commonly is cherty.

Appendix 5. Characteristics of subsurface stratigraphic units

	Group	Rock unit	Thickness (ft)	Description
Ordovician Series		Lexington Limestone	0-225	Gray fossiliferous limestone with lesser amounts of shale
	Black River	Plattin Formation	195-210	Tan, fine-grained to very fine-grained argillaceous and dolomitic limestone
		Pecatonica Formation	75-90	Gray and brown lithographic to fine-grained limestone and dolomite; commonly argillaceous or silty near base
	Ancell	Joachim Dolomite	105-180	Varicolored fine-grained dolomite and limestone; middle part more pure; black shale interbeds in upper part
		Dutchtown Formation	10-55	Light-gray and brown argillaceous dolomite; some thin green shale interbeds
	Prairie du Chien	Shakopee Dolomite	0-280	Light-gray to brown fine-grained to very fine-grained dolomite with interbedded shale, siltstone, and sandstone
		Oncota Dolomite	250-310	Gray and brown, mostly medium- to fine-grained cherty dolomite
Cambrian System		Potosi Dolomite	700-1125	Gray and brown fine- to medium-grained dolomite and a few thin zones of shale or siltstone
	Munising	Davis Formation	75-95	Mixed gray dolomite, siltstone, shale, and limestone
		Eau Claire Formation	440-510	Variable oolitic limestone, shale, siltstone, sandstone, and dolomite
		Mt. Simon Sandstone	375-625	White to gray, poorly sorted, poorly consolidated sandstone; includes several gray and maroon shale beds
Precambrian rocks				

Appendix 6. Example of hydrograph separation for East Fork Whitewater River at Abington

While the peaks of an annual stream hydrograph represent overland and subsurface flow and sometimes ground water flow, base flow is a slow response to long-term changes in the regional ground-water flow (see Freeze and Cherry, 1979, p. 225). The base-flow hydrograph therefore will be much smoother than the stream hydrograph. A good first approximation to the base-flow hydrograph could be obtained by simply cutting off the peaks of the stream hydrograph. However, it is quite possible to have base-flow hydrograph peaks (see Linsley and others, 1982, pp. 210-213).

An ideal base-flow recession is a straight line on semi-logarithmic graph paper. Hence, one can assume that when the falling limb (recession limb) of the stream hydrograph becomes a straight line, the hydrograph is essentially all base flow. However, if a precipitation event occurs before overland and subsurface flows cease, the recession limb of the stream hydrograph will not be a straight line. If the second precipitation event and any following precipitation events produce successively smaller peaks, there will be a recession trend. It may be possible to glean from the trend an estimated base-flow recession segment. This segment may be sketched in below the stream hydrograph (see accompanying figure).

To help detect the slope of the recession segments of multiple precipitation events, it is useful to inspect the entire yearly stream hydrograph. The slope of the base-flow recession for single precipitation events can be used to help determine the base-flow recession segments for multiple precipitation events. Although the slope of base-recession will vary throughout the year, the general trend of the recession can be estimated from single precipitation events.

The next problem is to determine when the base-flow peaks occur, and when to begin each rising limb. The methods for constructing this portion of the base-flow hydrograph are arbitrary. However, it is reasonable to believe that a base-flow hydrograph peak should not occur before the stream hydrograph peak. The base-flow rising limb will probably be steeper than the base-flow recession limb.

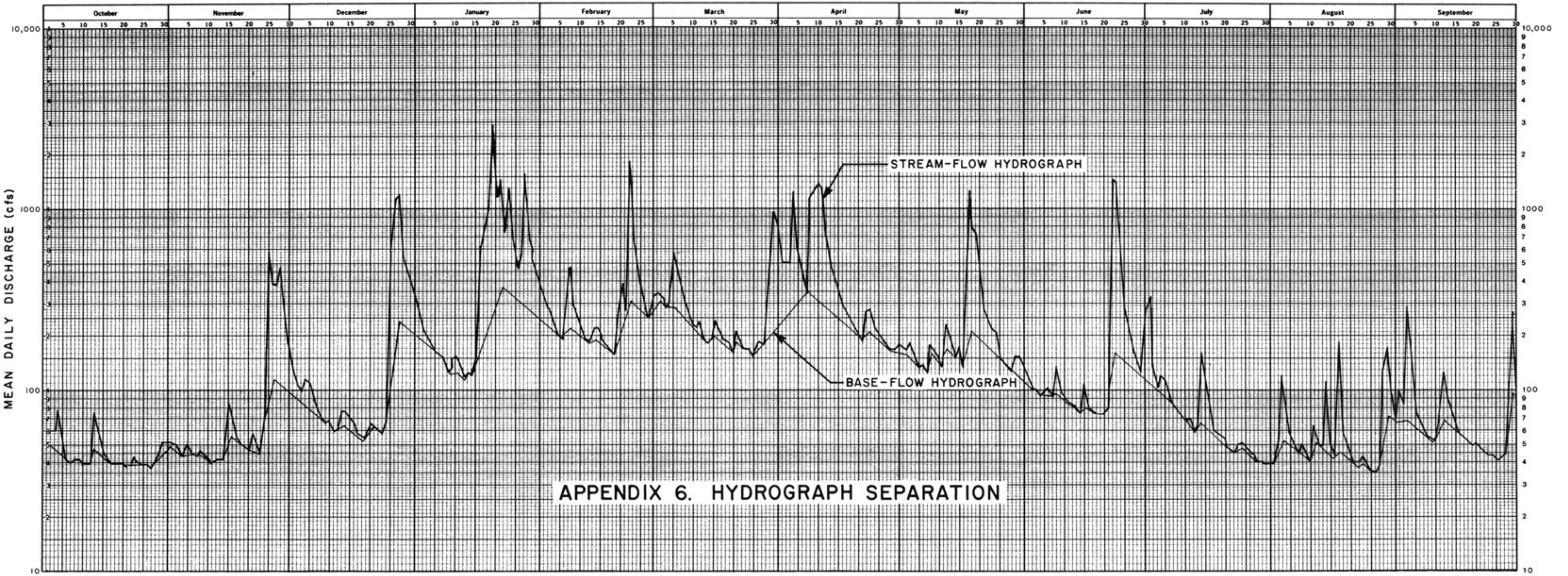
UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY (WATER RESOURCES DIVISION)
SEMI-LOG PLOT OF DAILY VALUES

Form 9-285 (9-77)

Station Name EAST FORK WHITEWATER RIVER AT ABINGTON, IN

Station Number 03275600

Year W.Y. 1974



APPENDIX 6. HYDROGRAPH SEPARATION

Appendix 7. Maximum contaminant levels for selected inorganic chemicals

{All values except pH are in milligrams per liter; if multiple uses have been designated, the most protective standard applies; dash indicates no available criterion. References to standards are current as of early 1987.}

Aquatic life: Values for all constituents except iron, pH, selenium, and silver are for one-hour averages; selenium and silver are not to be exceeded at any time; trace metals where applicable - at a hardness of 250 milligrams per liter.

Public supply: Maximum permissable level of a contaminant in water at the tap; national secondary regulations (reference e) are not enforceable; both national primary regulations and state regulations are enforceable (references b,c and f).

Irrigation and livestock: All values from National Academy of Sciences, 1974.

Constituent	Aquatic life		Public supply		Irrigation	Livestock
	Value	Reference	Value	Reference		
Arsenic (trivalent)	0.360	a	0.05	b,c	0.1	0.2
Barium	—	—	1.0	b,c	—	—
Cadmium	0.011	a	0.01	b,c	0.1	0.5
Chloride	0.019	a	250	d,e	—	—
Chromium (hexavalent)	0.016	a	0.05	b,c	0.10	1.0
Copper	0.042	a	1.0	e	0.2	0.5
Fluoride	—	—	4.0 prim 2.0 sec	b,f f	1.0	2.0
Iron	1.00	d	0.3	e	5.0	—
Lead	0.264	a	0.05	b,c	5.0	0.1
Manganese	—	—	0.05	e	0.2	—
Mercury	0.002	a	0.002	b,c	—	0.01
Nitrate (as nitrogen)	—	—	10.0	b,c	—	10.0
pH (standard unit)	6.0-9.0	d	6.5—8.5	e	4.5—9.0	—
Selenium	0.260	g	0.01	b,c	0.02	0.05
Silver	0.020	g	0.05	b,c	—	—
Sulfate	—	—	250	d,e	—	—
Total dissolved solids	—	—	500	e	500—1000	3000
Zinc	0.254	h	5.0	e	2.0	25.0

[a] U.S. Environmental Protection Agency, 1985a
[b] Indiana Environmental Management Board, 1979
[c] U.S. Environmental Protection Agency, 1986c
[d] Indiana Stream Pollution Control Board, 1985
[e] U.S. Environmental Protection Agency, 1979
[f] ________1986a
[g] ________1980
[h] ________1987

Appendix 8. Summary of selected stream quality constituents collected by the Indiana Department of Environmental Management, 1976-85

{All values in milligrams per liter except as indicated; dash indicates no data.}

Station 1: East Fork Whitewater River near Abington.
Station 2: Mainstem Whitewater River at Brookville.

Constituent	Station	Mean	Range	Constituent	Station	Mean	Range
Temperature (°C)	1	13	1—28	Nitrogen (TKN)	1	0.7	0.2—2.3
	2	13	1—27		2	—	——
Specific conductance (micromhos/cm)	1	659	420—960	Nitrate-Nitrite, total as N	1	3.7	0.6—10.8
	2	544	310—780		2	3.3	0.6—11.0
pH (field; std unit)	1	7.7	6.7—8.2	Phosphorus, total as P	1	0.17	0.03—0.4
	2	7.8	6.5—8.1		2	0.12	0.03—1.3
Dissolved oxygen	1	10.3	4.8—14.7	Chloride	1	37	19—78
	2	10.2	4.9—14.6		2	19	11—33
Biochemical oxygen demand (5-day)	1	2.0	1.0—9.4	Sulfate	1	57	37—100
	2	1.9	1.0—5.7		2	41	25—59
Chemical oxygen demand	1	14	5—31	Cyanide (µg/l)	1	5	1—14
	2	—	——		2	—	——
Alkalinity as $CaCO_3$	1	227	140—264	Nickel (µg/l)	1	16	10—60
	2	—	——		2	—	——
Hardness as $CaCO_3$	1	307	182—352	Zinc (µg/l)	1	20	10—60
	2	—	——		2	—	——
Organic carbon, total as C	1	4.9	2.6—9.8	Suspended solids	1	30	1—152
	2	6.1	2.5—15.3		2	81	1—1260
Ammonia, total as N	1	0.2	0.1—2.1	Fecal coliform (col/100 ml)	1	4040	10—90,000
	2	0.1	0.1—0.8		2	4690	10—110,000

Appendix 9. Concentrations of common stream quality constituents and selected metals collected by the U.S. Geological Survey, 1974-81

{Excerpted from Smith and Alexander, 1983; data for Whitewater River at Brookville; all values in milligrams per liter except as indicated.}

Constituent	Number of samples	Mean
Temperature (degrees C)	77	12.6
Turbidity (JTU)	38	25.2
Specific conductivity (micromhos/cm)	74	522.9
pH (std unit)	75	8.0
Dissolved oxygen	59	11.3
Alkalinity as $CaCO_3$	64	211.7
Dissolved solids	75	296.4
Organic carbon, total as C	33	4.4
Ammonia, total as N	41	0.1
Nitrate-Nitrite, total as N	74	2.1
Phosphorus, total as P	74	0.1
Calcium	75	66.8
Magnesium	74	24.4
Sodium	75	9.5
Potassium	75	2.5
Chloride	75	17.9
Sulfate as SO_4	74	39.9
Silica	75	4.3
Fecal coliform (col/100 ml)	6	7148.0
Fecal streptococci (col/100 ml)	40	2074.0
Phytoplankton (cells/ml)	53	13370.0

Metals (total)	Number of samples	Median
Arsenic (µg/l)	24	1.0
Barium (µg/l)	13	100.0
Iron (µg/l)	24	220.0
Manganese (µg/l)	24	40.0
Zinc (µg/l)	23	20.0

Appendix 10. Summary of selected stream quality constituents collected by the U.S. Army Corps of Engineers, 1972-86

{All values in milligrams per liter except as indicated.}
Station 1: East Fork Whitewater River near Liberty.
Station 2: East Fork Whitewater River below Brookville Lake dam.
Station 3: Silver Creek below Whitewater Lake.

Constituent	Station	No. of samples	Mean (mg/l)	Range (mg/l)	Constituent	Station	No. of samples	Mean (mg/l)	Range (mg/l)
Temperature	1	88	16.8	1.1—27.2	Nitrate-nitrite,	1	82	3.0	0.1—9.0
(degrees C)	2	89	15.3	0.6—27.8	total as N	2	72	2.0	0.1—5.7
	3	82	16.9	2.8—29.7		3	63	2.1	0.1—8.0
Turbidity (NTU)	1	66	20.2	0.2—247.0	Phosphorus,	1	85	245.3	10.0—1060.0
	2	65	6.7	0.5—150.0	total as P	2	72	129.8	10.0—670.0
	3	60	9.5	0.6—78.0	(µg/l)	3	66	86.5	10.0—750.0
Specific	1	85	626	210—930	Calcium	1	42	86.2	13.0—127.6
conductance	2	87	496	60—720	(as Ca)	2	42	66.4	10.0—219.0
(micromhos/cm)	3	79	478	20—740		3	40	64.0	6.0—119.0
pH (field;	1	81	8.0	6.9—8.7	Magnesium	1	42	17.3	0.7—38.3
std unit)	2	83	7.8	6.0—8.5		2	42	12.5	0.4—23.0
	3	77	8.0	6.4—8.8		3	40	13.6	0.3—27.0
Dissolved oxygen	1	91	9.8	4.8—16.4	Sodium	1	17	16.0	6.0—39.0
	2	92	10.0	6.1—16.8		2	17	6.9	4.0—9.0
	3	85	9.1	2.1—16.0		3	18	9.4	3.0—27.0
Biochemical	1	36	2.9	0.2—6.4	Potassium	1	17	2.3	1.0—5.0
oxygen demand	2	36	2.8	0.1—6.3		2	17	2.2	1.0—6.0
(5-day)	3	34	3.4	0.2—7.7		3	17	3.0	2.0—7.0
Alkalinity	1	60	247	116—400	Chloride	1	48	35.4	2.0—73.0
as $CaCO_3$	2	59	193	111—289		2	49	19.6	9.1—33.0
	3	57	195	51—380		3	49	24.5	13.1—60.0
Hardness	1	83	312	170—842	Sulfate	1	48	58.4	5.0—123.0
as $CaCO_3$	2	84	248	95—526		2	49	43.2	18.5—73.0
	3	78	240	105—347		3	49	35.7	10.9—100.0

Appendix 10. Continued

Constituent	Station	No. of samples	Mean (mg/l)	Range (mg/l)	Constituent	Station	No. of samples	Mean (mg/l)	Range (mg/l)
Total dissolved solids	1	58	450	222—723	Aluminum (µg/l)	1	21	1197.1	130.0—9940.0
	2	62	343	198—756		2	19	328.2	50.0—2296.0
	3	58	325	150—553		3	19	539.0	70.0—2970.0
Organic carbon, total as C	1	18	5.9	1.0—20.0	Barium (µg/l)	1	18	78.2	50.0—113.0
	2	18	4.5	1.0—9.0		2	16	55.5	20.0—122.0
	3	18	5.9	1.0—10.0		3	19	47.6	10.0—95.0
Ammonia, total as N	1	82	0.14	0.05—1.4	Iron (µg/l)	1	80	1444.6	100.0—13650.0
	2	71	0.14	0.05—1.0		2	80	786.7	100.0—9250.0
	3	66	0.27	0.05—1.8		3	61	603.1	100.0—3000.0
Nitrogen (TKN)	1	84	0.9	0.1—4.4	Manganese	1	80	75.4	10.0—690.0
	2	73	0.8	0.1—7.0		2	81	111.6	10.0—1090.0
	3	67	1.0	0.1—4.3		3	61	79.6	10.0—400.0

Appendix 11. Concentrations of selected water quality constituents collected by the U.S. Army Corps of Engineers at Brookville Lake, 1974-86

{Data from U.S. Army Corps of Engineers; all values in milligrams per liter except as indicated; dash indicates no data.}

Station 1: near Dunlapsville causeway.
Station 2: at Fairfield causeway.
Station 3: near dam.

Constituent	Station	No. of samples	Mean	Range	Constituent	Station	No. of samples	Mean	Range
Temperature (degrees C)	1	358	20.2	4.7—30.0	Nitrate-nitrite, total as N	1	—	—	——
	2	998	17.4	4.5—29.7		2	77	1.3	0.1—4.7
	3	1523	14.9	0.6—29.1		3	262	2.1	0.1—21.7
Turbidity (NTU)	1	106	12.1	2.0—140.0	Phosphorus, total as as P (µg/l)	1	—	—	——
	2	138	4.5	0.1—33.0		2	86	42.0	10.0—165.0
	3	261	4.5	0.0—175.0		3	253	43.0	10.0—480.0
Secchi (inches)	1	44	31	18—84	Calcium (as Ca)	1	64	76.2	48.8—113.0
	2	56	48	24—120		2	78	73.7	46.5—199.0
	3	64	59	24—144		3	170	58.5	6.0—101.0
Specific conductance (micromhos/cm)	1	252	470	300—750	Magnesium	1	64	7.6	0.0—18.5
	2	662	474	315—785		2	79	8.6	0.0—22.4
	3	1103	470	320—780		3	173	12.8	0.4—27.0
pH (field; std unit)	1	239	7.9	6.8—8.8	Chloride	1	46	21.2	11.2—50.4
	2	600	7.8	——		2	92	19.7	9.2—50.8
	3	981	7.7	6.3—9.7		3	189	19.8	2.0—47.3
Dissolved oxygen	1	299	7.7	0.0—17.6	Sulfate	1	47	41.3	34.2—58.7
	2	680	5.4	0.0—15.8		2	92	38.6	2.7—69.8
	3	1104	4.8	0.0—15.0		3	188	40.7	5.0—100.0
Biochemical oxygen demand (5-day)	1	—	—	——	Iron (µg/l)	1	—	—	——
	2	—	—	——		2	101	304.8	100.0—925.0
	3	161	2.6	0.1—7.7		3	246	527.0	100.0—32400.0
Alkalinity as $CaCO_3$	1	57	182	115—300	Manganese (µg/l)	1	—	—	——
	2	111	108	108—314		2	104	296.7	17.0—3000.0
	3	219	176	——		3	249	176.6	10.0—3560.0
Hardness as $CaCO_3$	1	109	226	162—332	Chlorophyll a (µg/l)	1	76	22.0	1.2—50.0
	2	169	224	126—321		2	87	9.7	0.0—27.2
	3	272	226	52—672		3	100	8.1	0.5—31.0

Appendix 11. Continued

Constituent	Station	No. of samples	Mean	Range	Constituent	Station	No. of samples	Mean	Range
Total dissolved solids	1	46	311	206—577	Station 3				
	2	92	294	68—402					
	3	192	312	27—866	Total organic carbon		73	4.6	1.0—26.0
Ammonia, total as N	1	—	—	——	Sodium		74	6.7	1.0—10.0
	2	82	0.3	0.0—2.4	Potassium		74	2.4	1.0—6.0
	3	257	0.2	0.0—2.9	Aluminum (µg/l)		82	660.3	50.0—22640.0
Nitrogen (TKN) as N	1	—	—	——	Barium (µg/l)		70	47.0	20.0—197.0
	2	82	0.8	0.1—5.9	Chromium (µg/l)		29	8.7	1.0—85.0
	3	261	0.7	0.1—4.2	Copper (µg/l)		29	19.7	5.0—169.0
					Lead (µg/l)		25	5.0	2.0—29.0
					Mercury (µg/l)		33	31.5	1.0—260.0
					Thallium (µg/l)		30	397.0	174.0—1000.0

Appendix 12. Results of chemical analysis from selected water wells (in mg/l except as indicated)

Location number: *, analysis of softened water; —, anomalous analysis (EMP balance error >5%); +, bucket rig well; #, bucket rig well with six inch casing.
Well owner: DNR, Department of Natural Resources; N, north; OBS, observation well; PW, pumping well; S, south; T, test well.
Township: N, north.
Range: E, east; W, west.
Aquifer system: DB, Dearborn; FU, Fayette-Union; O, Ordovician; S, Silurian; WH, Wayne-Henry; WO, Whitewater Valley Outwash.
Date sampled: month and year.
[1]Results in standard pH units; [2]Laboratory analysis; [3]TDS values are the calculated sum of major constituents in a ground-water sample; [4]TDS values are the calculated sum of major constituents expected in an anhydrous residue of a ground-water sample with bicarbonate converted to carbonate in the solid phase.

Location No.	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissloved Solids[3]	Total Dissolved Solids[4]
1*	P Pierson	18N	13E	2	157	WH	10/85	7.5	2	0.2	0.3	161.9	0.1	<0.10	<0.10	343.2	1.4	17.5	1.2	<0.02	609	396
2	L McCormic	19N	14E	28	181	S	10/85	7.2	339	82.9	32.0	19.8	1.3	1.50	<.10	361.4	3.5	23.2	1.0	<.02	618	394
3	E Bruns	17N	12E	21	105	WH	10/85	6.9	394	99.5	35.4	4.7	.7	.90	<.10	320.8	16.5	62.6	.2	<.02	618	419
4	P Monger	17N	12E	24	144	WH	10/85	7.1	367	93.0	32.8	4.5	.7	1.50	<.10	347.2	5.8	38.7	.3	<.02	609	394
5	H Bolen	18N	13E	30	247	WH	10/85	7.4	285	58.4	33.9	50.8	1.0	.30	.20	298.1	18.9	94.2	1.0	<.02	630	445
6	L Litton	17N	13E	4	139	WH	10/85	7.4	268	64.7	25.9	25.4	1.0	1.00	<.10	326.4	1.3	9.5	1.3	<.02	543	341
7	R Doerstler	17N	13E	20	64	WH	10/85	7.0	379	91.7	36.5	6.1	.8	<.10	.10	355.7	2.2	38.3	.5	<.02	619	398
8	W Evans	17N	11E	22	120	WH	10/85	7.2	312	72.4	32.1	8.2	.6	1.30	<.10	311.4	2.5	30.2	1.0	<.02	539	346
9	N Wright	18N	12E	2	156	WH	10/85	7.1	359	86.3	34.9	16.8	.9	1.30	<.10	401.0	1.8	21.4	.9	<.02	667	418
10	Peoples Bank	18N	13E	6	205	S	10/85	7.2	264	59.5	28.2	22.9	.8	1.30	<.10	298.1	4.9	21.5	.7	<.02	510	325
11	R Cates	19N	13E	32	86	WO	10/85	6.9	381	93.7	35.7	5.2	.7	2.10	<.10	347.7	4.0	50.0	.5	<.02	624	408
12	R Davis	18N	13E	10	200	S	10/85	7.1	310	70.8	32.4	27.3	.9	1.40	<.10	353.3	6.2	23.2	.8	<.02	601	382
13	Hillside Nurs	16N	11E	25	50	WH	10/85	7.2	253	62.0	23.8	26.8	.9	1.10	<.10	304.9	1.7	0.8	1.2	<.02	500	311
14	P Suttles	16N	12E	18	94	WH	10/85	7.1	287	72.6	25.6	13.0	.8	1.20	<.10	327.7	3.4	<0.1	.7	<.02	527	324
15	E Miller	16N	12E	2	57	WO	10/85	7.0	352	87.8	32.4	4.6	.9	.90	<.10	313.2	6.0	45.9	.4	<.02	568	374
16	C Litton	18N	12E	33	131	WH	10/85	7.1	317	80.3	28.3	10.3	.8	1.90	<.10	342.7	1.2	5.6	.7	<.02	559	347
17	A Tarr	18N	12E	35	31	WO	10/85	6.9	385	98.3	34.0	8.2	1.3	<.10	<.10	320.4	23.6	36.0	.2	3.30	613	403
18	Hagerstown 3	17N	12E	23	112	WO	07/78	7.1	373	94.0	33.0	8.0	2.0	<.10	<.02	307.0	19.0	43.0	1.2	3.20	577	387
	Hagerstown 4	17N	12E	23	112	WO	10/85	6.9	368	94.3	32.3	7.9	1.4	<.10	<.10	297.1	18.0	44.2	1.4	3.60	583	386
19	G Crull	17N	13E	7	122	WH	10/85	7.3	347	84.8	32.9	11.2	.9	.20	<.10	363.0	1.2	5.0	.3	<.02	590	365
20	D Scammahorn	18N	13E	31	38	WH	10/85	6.9	453	118.4	38.2	3.5	1.0	<.10	<.10	363.5	8.7	66.9	.1	4.40	705	465
21	D Lewis	17N	14E	7	26	WO	10/85	7.5	354	88.1	32.6	4.4	1.6	<.10	<.10	240.7	45.8	29.3	.1	16.50	573	366

Appendix 12. Continued

Location No.	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissloved Solids[3]	Total Dissolved Solids[4]
22	D Bushman	17N	14E	31	63	WH	10/85	7.0	374	94.4	33.6	6.4	1.2	0.90	0.10	300.7	21.2	64.5	0.1	<0.02	593	407
23	S Hubell	17N	14E	11	168	WH	10/85	7.3	317	78.3	29.5	12.5	1.1	.40	.40	290.4	3.2	23.5	.8	<.02	518	338
24	R Manning	18N	14E	12	217	S	10/85	7.3	309	80.2	26.6	37.0	1.0	1.20	<.10	323.5	5.1	34.1	.6	<.02	590	389
25*	K Norton	18N	14E	14	43	WH	10/85	7.1	64	15.2	6.4	166.3	.5	<.10	<.10	319.9	22.2	80.5	.6	<.02	688	489
26	D Anderson	18N	14E	17	99	WH	10/85	7.4	262	64.9	24.3	36.7	1.0	1.60	<.10	310.6	3.3	29.4	1.3	<.02	556	364
27	J Burke	16N	14E	28	46	WH	10/85	7.2	385	95.3	35.9	6.4	.3	<.10	<.10	312.2	28.6	53.9	.3	1.70	619	421
28	E Jenkins	15N	14E	6	35	WH	10/85	7.5	430	99.2	44.5	8.0	.6	1.80	.40	398.3	20.9	48.2	.8	<.02	721	474
29	D Walther	16N	13E	36	30	WO	10/85	7.1	411	103.9	37.0	5.9	.8	<.10	<.10	297.1	26.5	34.6	.1	14.60	641	406
30	H Gwinnup	15N	12E	16	132	FU	10/85	7.7	340	84.6	31.5	17.6	.6	1.00	<.10	357.5	12.8	5.6	.2	<.02	599	378
31	Bentonville Farm Supply	15N	12E	19	46	WH	10/85	7.3	315	83.7	25.9	3.8	.4	1.40	<.10	256.8	9.6	62.8	.1	<.02	507	347
32	M Geise	14N	12E	6	35	FU	10/85	7.1	414	105.3	36.8	4.5	.5	<.10	<.10	317.2	14.4	77.5	.1	2.80	644	437
33	N Jeffers	17N	13E	22	83	WH	10/85	7.2	361	86.9	35.0	6.2	.5	1.60	<.10	348.9	11.1	27.4	.6	<.02	605	389
34	R Moyer	16N	13E	6	49	WH	10/85	7.9	300	72.6	29.0	14.7	.6	.40	<.10	312.2	16.5	19.5	.8	.50	547	352
35*	H Hall	16N	11E	2	190	WH	10/85	7.3	125	32.7	10.5	196.0	.5	1.10	<.10	400.8	44.8	108.7	.4	<.02	893	645
36	H Foulke	17N	11E	1	91	WH	10/85	7.4	369	92.7	33.5	5.4	.4	2.10	<.10	307.6	9.9	62.0	.8	<.02	591	400
37	C Retz	17N	11E	33	42	WH	10/85	7.4	351	84.3	34.2	7.0	.4	2.90	<.10	321.7	8.1	43.1	1.0	<.02	582	383
38	P Wesseler	16N	12E	16	130	WH	10/85	7.6	286	70.8	26.6	21.2	.4	1.00	<.10	312.2	20.3	1.0	.6	<.02	532	339
39	H Brockman	16N	13E	30	132	WH	10/85	7.1	364	93.6	31.8	4.6	.4	<.10	<.10	340.4	3.9	18.1	.3	2.70	588	367
40	Richmond 11	13N	1W	5	62	WO	10/85	—	369	93.0	33.3	17.9	1.3	<.10	<.10	295.2	33.7	67.4	1.4	.30	614	429
41	L Bourne	12N	1W	28	91	FU	10/85	7.5	249	58.0	25.4	46.0	.7	1.60	<.10	355.0	2.5	<.1	.3	<.02	576	356
42	J Andrews	18N	14E	35	195	WH	10/85	7.4	321	79.3	29.9	25.9	.7	5.00	.10	379.9	5.3	9.8	.2	<.02	634	399
43	R Swallow	16N	13E	28	45	WO	10/85	6.1	447	112.3	40.6	38.3	.9	<.10	<.10	339.8	105.0	64.5	.9	6.90	816	580
44	C Sanders	15N	13E	36	84	WH	10/85	7.2	358	91.9	31.3	5.0	.4	1.30	<.10	351.2	2.6	20.4	.3	<.02	592	374
45	C Upchurch	15N	14E	9	230	0	10/85	7.0	425	103.1	40.8	7.8	.6	.50	<.10	389.7	15.7	40.9	.3	<.02	695	453
46	A Gates	14N	1W	14	101	WH	10/85	7.1	295	70.4	29.0	21.9	.9	.60	.10	306.6	14.8	16.4	1.3	<.02	537	339
47	J Smith	14N	1W	11	100	S	10/85	7.3	286	66.3	29.3	28.1	1.2	.70	.10	347.4	25.3	16.7	.5	<.02	612	397
48	Tomlinson	15N	1W	23	50	WH	10/85	7.1	396	98.8	36.5	3.8	.4	.70	.10	320.8	19.1	61.9	.9	<.02	622	423
49	R Warvel	15N	1W	1	202	S	10/85	7.4	250	63.4	22.4	20.7	.5	1.70	<.10	293.6	15.4	5.7	.3	<.02	498	315
50*	P Hacker	15N	12E	25	102	WO	10/85	7.5	0	0.1	0.1	181.6	.2	<.10	<.10	295.3	44.5	34.2	.6	7.60	660	450

Appendix 12. Continued

Location No.	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissloved Solids[3]	Total Dissolved Solids[4]
51	T Ryckman	14N	12E	30	83	S	10/85	7.4	350	86.7	32.5	10.0	0.5	2.20	<0.10	356.8	20.6	9.4	0.2	<0.02	607	386
52	D Lane	14N	11E	13	45	FU	10/85	7.1	426	112.9	35.0	5.9	.6	2.50	.20	344.4	21.1	66.8	.9	<.02	674	460
53	C Conley	13N	11E	15	90	DB	10/85	7.7	312	75.8	29.9	13.5	.4	3.10	<.10	346.8	18.7	.9	.3	<.02	577	362
54	A Bertsch	16N	12E	36	86	WO	10/85	7.7	306	74.7	29.0	6.1	.4	5.90	.10	294.3	13.8	31.2	.8	<.02	529	347
55	F Rogers	13N	1W	34	105	FU	10/85	7.4	260	66.5	22.9	26.4	.8	.90	<.10	329.1	15.7	1.2	.4	<.02	546	342
56	B Druly	13N	1W	23	53	FU	10/85	7.3	360	92.6	31.4	7.3	.5	2.30	<.10	313.9	19.8	67.8	.8	<.02	613	419
57	M Sittloh	13N	1W	23	155	S	10/85	7.3	269	61.9	27.8	32.5	2.5	<.10	<.10	340.1	24.9	<.1	.4	<.02	572	361
58	J Fuller	13N	1W	11	78	FU	10/85	7.3	378	98.7	32.0	2.9	.7	1.80	<.10	317.2	29.3	56.8	.2	<.02	615	419
59—	D Delk	14N	1W	36	56	WH	10/85	7.0	441	114.9	37.5	96.6	2.3	.90	.20	396.9	208.0	64.2	.2	<.02	1015	769
60	R Young	15N	13E	32	28	WH	10/85	7.2	349	96.5	26.3	4.5	.9	<.10	<.10	284.8	20.5	42.4	.1	9.40	585	375
61	R McDaniel	14N	13E	9	115	FU	10/85	7.7	375	95.3	33.4	8.8	.4	1.60	<.10	401.6	.9	6.1	.2	<.02	647	398
62	D Wampler	15N	13E	17	40	WO	10/85	7.4	389	95.8	36.4	3.8	.9	<.10	<.10	269.5	17.6	30.9	.2	22.00	618	374
63	L Walker	15N	13E	4	100	WH	10/85	6.5	374	93.2	34.3	4.4	.4	1.20	.10	372.5	1.3	16.0	.2	<.02	615	384
64	C Paul	16N	14E	19	111	WH	10/85	7.1	328	82.9	29.4	3.7	.4	1.20	<.10	309.1	2.6	30.0	.2	<.02	535	343
65	B Barker	14N	12E	11	65	0	11/85	6.8	433	115.5	35.1	20.4	1.5	<.10	<.10	353.4	40.8	61.6	.4	5.40	736	498
66	Union Church	14N	12E	15	161	FU	11/85	7.5	274	66.4	26.2	58.8	.8	1.00	<.10	369.7	21.6	<.1	.4	<.02	634	406
67+	D Maxie	13N	12E	34	35	WO	11/85	7.1	319	83.2	27.1	3.6	.9	<.10	<.10	273.9	10.1	27.0	.1	6.40	521	329
68+	G Gettinger	13N	13E	14	38	FU	11/85	7.0	331	86.8	27.9	3.6	.6	<.10	<.10	269.0	6.7	57.4	.1	3.10	530	353
69	G Wilson	12N	13E	8	50	DB	11/85	6.9	367	91.8	33.4	9.6	.3	<.10	<.10	339.8	9.5	28.5	.1	2.80	610	389
70	D Platt	14N	1W	21	134	WH	11/85	7.4	256	60.8	25.3	35.0	.9	1.50	<.10	315.8	16.0	8.1	.9	<.02	546	350
71	O Allen	14N	2W	25	77	WH	11/85	7.4	339	74.7	37.2	8.1	.6	2.60	<.10	341.4	6.3	24.4	.8	<.02	584	372
72	W Elliott	16N	14E	5	37	WO	11/85	7.3	373	93.8	33.7	4.4	.6	.30	<.10	326.7	19.8	50.3	.2	.60	609	404
73	J Richardson	16N	13E	13	88	WH	11/85	7.1	362	93.2	31.4	4.4	.4	.10	<.10	331.1	19.9	30.5	.2	1.30	597	387
74	J Legg	15N	13E	23	62	WH	11/85	7.0	420	107.5	36.9	15.0	.6	.60	.10	360.4	15.7	82.9	.2	<.02	706	483
75	L Rose	14N	13E	3	50	FU	11/85	7.0	382	99.5	32.5	3.9	.4	<.10	.10	308.2	19.6	65.3	.1	<.02	604	413
76	C Eggleston	13N	12E	2	85	FU	11/85	6.6	315	83.9	25.6	12.0	.5	<.10	.50	318.0	16.8	14.0	.1	1.00	554	353
77	C Hurst	11N	2W	27	50	WO	11/85	7.0	350	91.3	29.7	5.5	.5	<.10	<.10	321.8	8.0	37.0	.1	2.80	583	374
78	T Cornett	13N	2W	35	43	WO	11/85	6.7	323	87.1	25.7	9.5	1.0	<.10	<.10	275.5	24.7	44.1	.1	2.30	542	367
79	G Fagan	16N	12E	12	59	WH	11/85	6.6	309	76.7	28.5	3.1	.4	.80	<.10	287.4	8.2	42.8	.2	<.02	517	339
80	J Bane	17N	13E	26	29	WO	11/85	6.9	345	87.6	30.7	4.4	.6	<.10	<.10	291.5	14.1	50.3	.1	4.30	566	371

Appendix 12. Continued

Location No.	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissloved Solids[3]	Total Dissolved Solids[4]
81	J Belcher	18N	13E	25	142	WH	11/85	6.8	364	74.9	43.2	8.9	0.7	1.90	<0.10	379.1	4.6	44.0	1.1	<0.02	655	420
82	J Thornton	17N	14E	4	37	WH	11/85	6.9	421	105.7	38.2	5.4	.6	.80	<.10	339.4	15.0	66.9	.4	<.02	655	444
83	D Stults	15N	1W	33	89	WH	11/85	7.2	290	73.8	25.8	21.7	.9	1.30	.10	348.1	1.9	20.5	1.4	<.02	597	381
84	L Berry	15N	1W	27	176	S	11/85	7.2	302	72.3	29.5	20.6	.8	.90	<.10	347.0	8.9	12.0	.8	<.02	579	364
85	J Logue	11N	1W	21	208	0	11/85	7.3	259	58.6	27.5	365.4	5.1	1.90	<.10	211.8	640.0	<.1	.4	<.02	1372	1241
86	S Felton	11N	1W	15	40	FU	11/85	6.9	327	87.2	26.5	11.3	3.3	<.10	<.10	288.1	15.1	37.1	.4	2.90	552	363
87+	U Charles	14N	13E	1	32	FU	11/85	7.0	347	94.0	27.4	6.5	.7	<.10	<.10	305.1	17.1	38.2	.2	3.20	578	377
88	J Bowman	14N	13E	14	31	FU	11/85	6.8	351	93.0	28.9	3.8	.4	2.00	.10	322.1	8.5	47.7	.3	<.02	585	385
89	C Ripberger	13N	13E	5	183	FU	11/85	6.9	265	68.5	22.7	110.4	2.3	2.70	<.10	312.5	161.0	<.1	.1	<.02	761	567
90	M Grey	11N	12E	23	40	DB	11/85	6.8	308	85.1	23.2	12.8	.3	<.10	<.10	283.5	18.0	45.3	.3	2.10	552	369
91+	C Allen	11N	13E	2	42	WO	11/85	7.0	348	116.2	13.9	5.6	.7	<.10	<.10	341.9	5.1	20.6	.2	3.50	600	376
92	Sperry Rubber	8N	2W	3	134	WO	11/85	7.1	360	97.1	28.7	7.7	.8	<.10	<.10	282.6	12.6	55.4	.2	2.70	565	380
93+	C Shell	11N	13E	20	34	DB	11/85	7.0	307	74.8	29.3	20.1	.4	<.10	<.10	273.4	31.1	32.2	.3	1.80	540	364
94	K Reineking	11N	13E	31	100	O	11/85	6.8	768	214.7	56.3	565.9	23.8	1.20	<.10	312.0	1160	148.0	.2	.80	2573	2377
95	Wolf & Dresser	7N	1W	13	45	WO	11/85	6.4	394	117.7	24.3	16.5	2.0	<.10	<.10	290.4	22.8	83.8	.2	2.70	639	449
96+	D Laker	11N	11E	34	52	DB	11/85	6.7	256	67.4	21.5	16.0	.3	<.10	<.10	247.7	7.3	21.7	.3	3.70	461	295
97	C Jackson	11N	11E	17	105	S	11/85	7.3	381	94.2	35.4	28.8	.7	2.50	<.10	437.0	15.4	5.3	.5	<.02	722	452
98	J Carter	13N	12E	8	55	S	11/85	6.8	356	85.6	34.6	5.2	.6	3.40	<.10	345.2	5.1	23.5	.4	<.02	587	373
99	W Gronning	13N	13E	9	82	FU	11/85	7.1	392	97.4	36.3	8.9	.5	.80	.20	434.3	3.3	5.4	.5	<.02	694	425
100	S Locke	13N	13E	4	50	FU	11/85	7.3	351	89.5	31.1	11.4	.5	3.20	<.10	325.3	9.8	39.6	.4	<.02	590	388
101	DNR Metamora	12N	12E	36	106	WO	11/85	7.5	280	78.5	20.5	3.7	.8	<.10	<.10	233.8	8.2	37.4	.2	1.90	447	295
102	D Snyder	12N	2W	24	79	FU	11/85	6.3	290	69.4	28.5	6.8	.5	1.70	<.10	325.3	1.4	3.7	.5	<.02	518	316
103	S Felton	11N	1W	15	96	FU	11/85	7.3	304	68.0	32.8	38.4	1.0	.90	<.10	406.1	1.9	<.1	.7	<.02	649	397
104+	J Jenkins	11N	1W	31	30	FU	11/85	7.2	404	101.0	36.8	6.2	.7	<.10	<.10	325.9	16.4	61.4	.5	<.02	629	427
105	M Radar	10N	1W	30	80	FU	11/85	7.3	353	92.4	29.8	47.3	1.4	.70	.20	379.5	33.5	4.0	.4	3.60	696	449
106+	J Dickman	10N	12E	15	42	DB	11/85	7.1	203	52.9	17.4	9.9	.6	<.10	<.10	170.4	9.8	20.5	.4	2.00	337	224
107+	D Eckerle	10N	13E	10	42	DB	11/85	7.3	190	47.3	17.5	19.1	.6	<.10	<.10	210.8	10.1	25.2	.5	.90	393	259
108	D Bruns	9N	13E	21	41	DB	11/85	7.0	215	61.8	14.7	8.0	.5	<.10	<.10	195.3	8.6	23.1	.2	.90	366	242
109	K Galey	7N	1W	36	75	0	11/85	7.0	446	109.9	41.8	34.3	1.3	<.10	<.10	359.6	21.0	154.1	.4	2.30	817	586
110	LTM Water T-1	18N	12E	10	140	WH	9/78	7.4	428	96.0	46.0	12.0	2.0	—	—	425.0	3.0	14.0	1.2	.10	693	429

Appendix 12. Continued

Location No.	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissloved Solids[3]	Total Dissolved Solids[4]
111#	S Stirn	11N	12E	9	42	DB	11/85	7.0	436	141.3	20.1	15.1	1.9	<0.10	0.70	346.9	33.2	66.1	0.1	3.60	724	496
112—	W Rose	13N	13E	9	290	0	11/85	7.0	450	116.5	38.6	324.0	5.8	1.70	.10	401.1	656.0	.7	.3	<.02	1641	1392
113	W Cook	12N	11E	6	124	S	11/85	7.9	280	71.3	24.8	16.4	.5	1.30	<.10	323.1	1.7	<.1	1.1	<.02	516	316
114#	J Kennedy	12N	11E	11	40	DB	11/85	8.5	263	73.4	19.5	5.2	.6	<.10	<.10	239.6	4.2	24.8	.3	2.50	437	280
115	H Thompson	9N	1W	35	70	O	11/85	7.3	312	87.0	23.1	4.8	4.6	<.10	<.10	232.4	21.3	44.0	.1	13.80	535	343
116	Lynn 2	19N	14E	34	210	S	3/66	7.2	355	77.0	40.0	19.0	2.0	1.60	.00	368.0	4.0	21.0	1.2	—	615	387
117	Lynn 3	19N	14E	34	200	S	7/76	7.5	360	80.0	39.0	19.0	2.0	1.10	<.02	365.0	2.0	21.0	1.5	<0.10	611	385
118	Lynn 4	19N	14E	35	91	WH	7/76	7.4	400	94.0	40.0	10.0	1.0	2.30	.03	372.0	2.0	32.0	1.1	—	636	406
120	Hagerstown 2	17N	12E	23	70	WO	1/75	7.7	376	95.0	34.0	5.0	2.0	—	—	300.0	13.0	62.0	.2	—	577	391
121	Perfect Circle	17N	12E	23	62	WO	10/64	7.6	340	92.8	26.3	—	—	—	.00	324.0	16.0	80.0	—	—	—	—
122	Camb. City 3	16N	12E	26	57	WO	1/75	7.7	346	87.0	31.0	6.0	2.0	<.10	<.02	284.0	13.0	47.0	.2	1.30	534	358
	Camb. City 1	16N	12E	26	57	WO	1/75	7.6	372	96.0	32.0	11.0	3.0	.50	.02	304.0	20.0	53.0	.2	1.90	588	400
	Camb. City 2	16N	12E	26	63	WO	1/75	7.6	370	95.0	32.0	10.0	3.0	.10	.02	298.0	20.0	53.0	.2	1.70	578	394
123	Milton 2	15N	12E	2	100	WO	8/86	8.3	262	72.0	20.0	39.0	1.7	.90	.00	286.0	39.0	8.0	.6	—	566	353
	Milton 1	15N	12E	2	100	WO	8/86	8.1	286	73.0	25.0	39.0	1.6	.91	.03	310.0	40.0	8.0	.6	—	530	374
124	USGS Wayne 6	15N	12E	24	49	WO	7/66	7.4	318	83.0	27.0	5.5	.9	.77	.50	256.0	9.0	38.0	.1	6.78	507	348
125	I-70 E RestPark	16N	13E	12	134	WH	3/83	8.1	350	93.0	28.0	8.0	1.3	<.05	<.02	358.0	<5.0	6.0	.3	.20	574	352
126	Fountain City 2	17N	14E	2	96	WH	12/70	7.5	360	78.0	40.0	17.0	2.0	1.20	.02	362.0	4.0	24.0	1.3	.40	610	385
	Fountain City 1	17N	14E	2	97	WH	7/74	7.6	338	76.0	36.0	18.0	2.0	2.60	.03	328.0	4.0	26.0	1.2	.20	566	363
127	Centerville 2	16N	14E	29	52	WH	4/75	7.6	352	90.0	31.0	3.0	1.0	<.10	.05	274.0	22.0	52.0	.2	<.10	534	364
	Centerville 1	16N	14E	29	50	WH	4/75	7.6	364	90.0	34.0	4.0	1.0	1.80	.07	282.0	21.0	54.0	.2	<.10	550	375
128	Centerville 3	16N	14E	20	52	WH	12/70	7.6	334	73.0	37.0	4.0	1.0	1.50	.10	252.0	14.0	60.0	.2	2.10	500	344
129	Richmond St. Hospital	14N	1W	31	130	WH	11/58	7.5	390	96.0	36.0	29.0	2.0	3.20	.05	305.0	27.0	94.0	.6	.30	660	471
130	Dublin 1	16N	12E	30	89	WH	10/58	7.6	392	96.0	37.0	9.0	1.0	.40	.10	326.0	13.0	62.0	.1	—	618	414
131	Abbattoir T-PW	14N	12E	36	49	WO	8/63	7.1	380	100.0	37.4	—	—	.42	.00	—	16.0	95.0	—	—	—	—
132	Everton 1	13N	12E	1	78	WO	2/67	7.3	300	75.0	27.0	4.0	2.0	.40	.09	254.0	7.0	51.0	.2	—	477	319
133	Connersville 5	14N	13E	18	97	WO	6/75	7.5	346	89.0	30.0	5.0	2.0	1.70	.08	272.0	10.0	61.0	.2	<.10	531	362
	Connersville 4	14N	13E	18	95	WO	6/75	7.5	374	96.0	33.0	5.0	2.0	1.90	.10	292.0	12.0	65.0	.2	.10	572	390
	Connersville 3	14N	13E	18	95	WO	6/75	7.8	306	78.0	27.0	5.0	2.0	<.10	.03	242.0	18.0	42.0	.2	2.20	462	320

Appendix 12. Continued

Location No.	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH^1	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$^{2}	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissloved Solids^3	Total Dissolved Solids^4
133	Connersville 2	14N	13E	18	81	WO	6/75	7.8	300	75.0	27.0	5.0	2.0	<0.10	<0.02	238.0	10.0	42.0	0.2	2.40	454	306
	Connersville 1	14N	13E	18	95	WO	6/75	7.2	320	82.0	28.0	5.0	2.0	<.10	<.02	252.0	12.0	44.0	.2	2.40	483	327
135	Liberty 1	14N	14E	29	42	WO	6/69	7.5	306	77.0	28.0	10.0	2.0	.20	.03	241.0	13.0	46.0	4.7	3.00	478	329
136	Brookville Res	14N	14E	29	55	WO	11/78	7.2	402	115.0	28.0	3.0	2.0	.20	.02	344.0	16.0	28.0	.2	5.80	618	405
137	USGS Union 6	11N	2W	14	65	O	7/67	7.6	294	75.0	26.0	88.0	6.0	.66	.10	357.0	74.0	12.0	.5	.10	718	497
138	Dunlapsvlle T-N	11N	2W	21	39	WO	6/75	7.4	314	80.0	28.0	4.0	2.0	<.10	<.02	266.0	5.0	38.0	.2	.50	482	317
139	Dunlapsvlle T-S	11N	2W	28	60	WO	5/75	7.7	282	72.0	25.0	4.0	5.0	<.10	<.02	236.0	8.0	32.0	.2	4.10	438	292
140	Liberty 1 Old	11N	1W	6	56	FU	4/58	7.8	408	104.0	36.0	9.0	1.0	1.20	.20	356.0	10.0	54.0	.2	.10	651	430
141	Laurel 2	12N	12E	10	57	WO	8/74	7.6	456	129.0	33.0	29.0	5.0	—	—	352.0	47.0	57.0	.1	8.60	738	520
142	Franklin Co 2	10N	2W	28	152	WO	5/80	7.6	368	99.0	29.0	11.0	1.7	.55	.11	324.0	20.0	39.0	.4	.10	596	395
	Franklin Co 2	10N	2W	28	134	WO	5/80	7.5	320	82.0	28.0	24.0	1.6	2.25	.03	308.0	30.0	26.0	.5	—	570	379
143	Brookville 1	9N	2W	20	91	WO	5/80	7.4	430	114.0	35.0	28.0	3.3	<.05	<.02	358.0	55.0	52.0	.2	2.60	727	505
	Brookville 3	9N	2W	20	150	WO	5/80	7.9	388	106.0	30.0	24.0	4.3	.08	.03	308.0	52.0	50.0	.2	2.10	644	454

Appendix 13. Discussion of Reservoir Yield Dependability

The dependability of the yield of a reservoir at a particular site depends upon the level of demand and the storage capacity of the reservoir. The YIELD computer program (Biek, 1986) determines various reservoir capacities needed to maintain a given draft with various levels of dependability.

Dependability is the fraction of time that demand is met (McMahon and Mein, 1986). The time increment for calculating dependability is one year. Years in which demand is not met are called deficit years. In the YIELD program, the deficit years are controlled deficits.

Controlled deficits occur when, during one or more of the dry years on record, controlled cutbacks in demand are made. For example, if it is anticipated that farmers may be able to tolerate a cutback to 80 percent of their allotted supply during the months of irrigation for the two severest dry years of record, then there will be two years of controlled deficit. If users of the reservoir can tolerate some shortages during these few dry years, then a smaller reservoir can be constructed.

The YIELD program computes the reliability or dependability of the yield for each number-of-years deficit. The dependability may be defined by the equation:

$$R = m/(n+1) = (n-d)/(n+1)$$

where

m = number of years demand is met,

n = the period of record of stream flow data,

d = number of years of deficit in which supply is cut back.

For example, suppose we have 50 years of stream data and one year of deficit will be acceptable. The dependability of the yield is:

$$R = (50-1)/(50+1) = 0.96$$

There is a 96 percent probability that the demand will be met in any given year.

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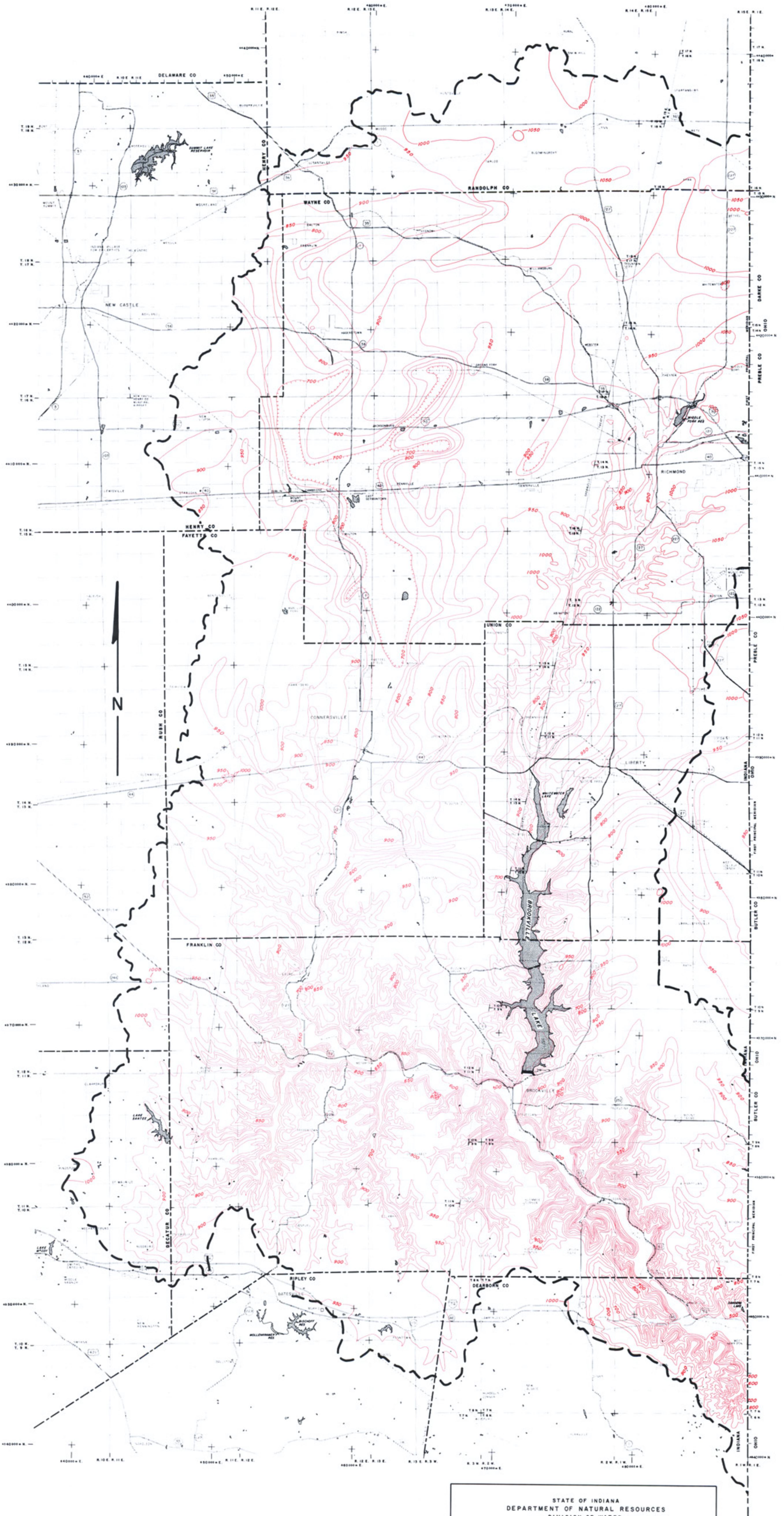
JAMES M. RIDENOUR, DIRECTOR

DIVISION OF WATER

RESOURCE ASSESSMENT 88-2 PLATE I



Explanation

—750— Elevation in feet above mean sea level (msl)
Contour interval = 50 feet

STATE OF INDIANA
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WHITEWATER RIVER BASIN

Compiled by : John C. Clark
Carole S. Porambo
Drafted by : Burton C. Daniels, Supv.
Donald L. Spilman
Connie K. Williams
Abbie George

1 0 1 2 3 4 MILES
5000 0 5000 10000 15000 20000 FEET
1 0 1 2 3 4 5 6 KILOMETERS

BEDROCK TOPOGRAPHY

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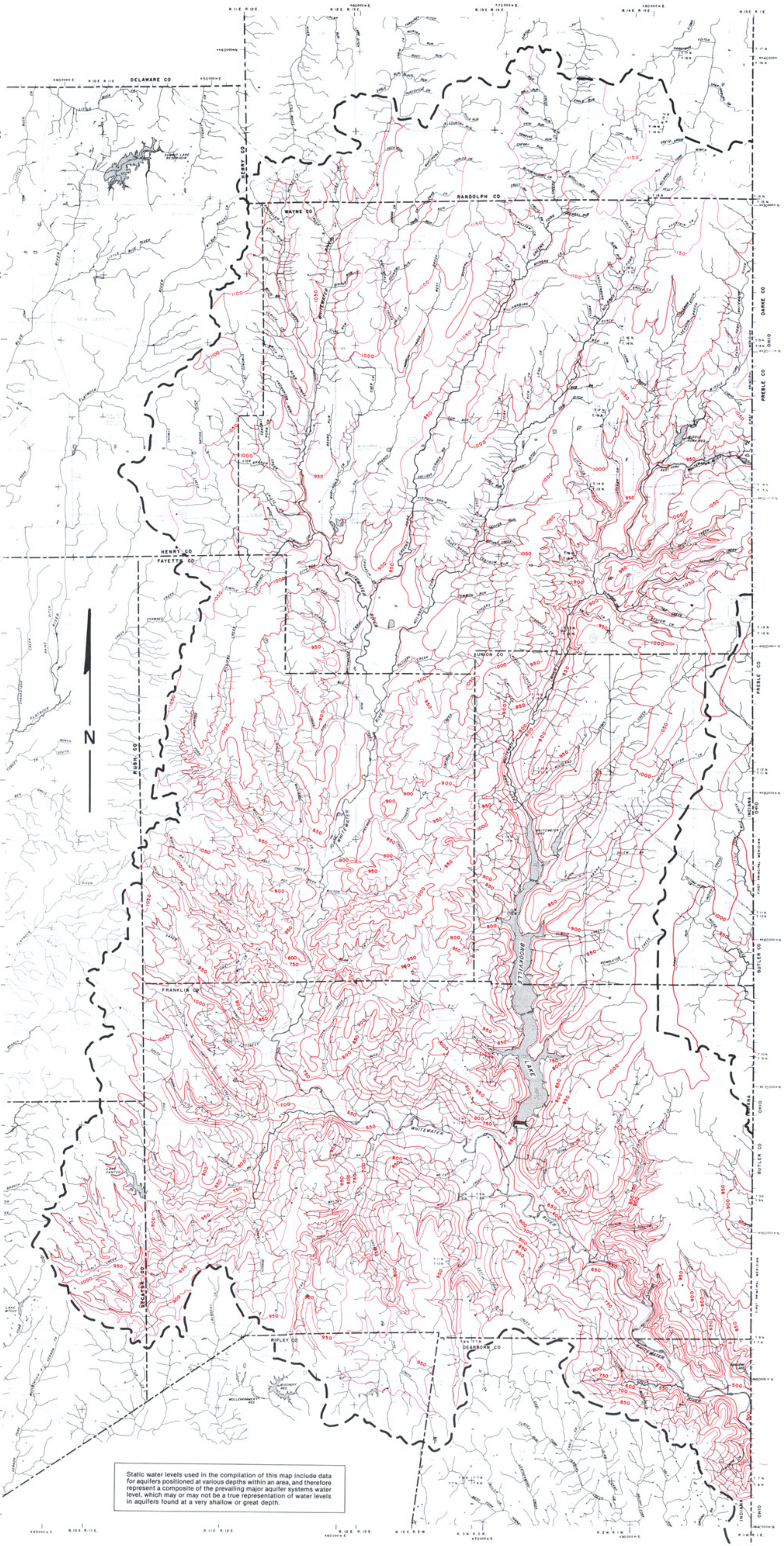
DEPARTMENT OF NATURAL RESOURCES
JAMES M. RIDENOUR, DIRECTOR



Static water levels used in the compilation of this map include data for aquifers positioned at various depths within an area, and therefore represent a composite of the prevailing major aquifer systems water level, which may or may not be a true representation of water levels in aquifers found at a very shallow or great depth.

Explanation

750 Elevation in feet above mean sea level (msl)
Contour interval = 50 feet

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
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WHITEWATER RIVER BASIN

Compiled by: John C. Clark
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Abbie G. George

1 0 1 2 3 4 MILES
5000 0 5000 10000 15000 20000 FEET
1 0 1 2 3 4 5 6 KILOMETERS

COMPOSITE PIEZOMETRIC SURFACE MAP FOR UNCONSOLIDATED AQUIFERS

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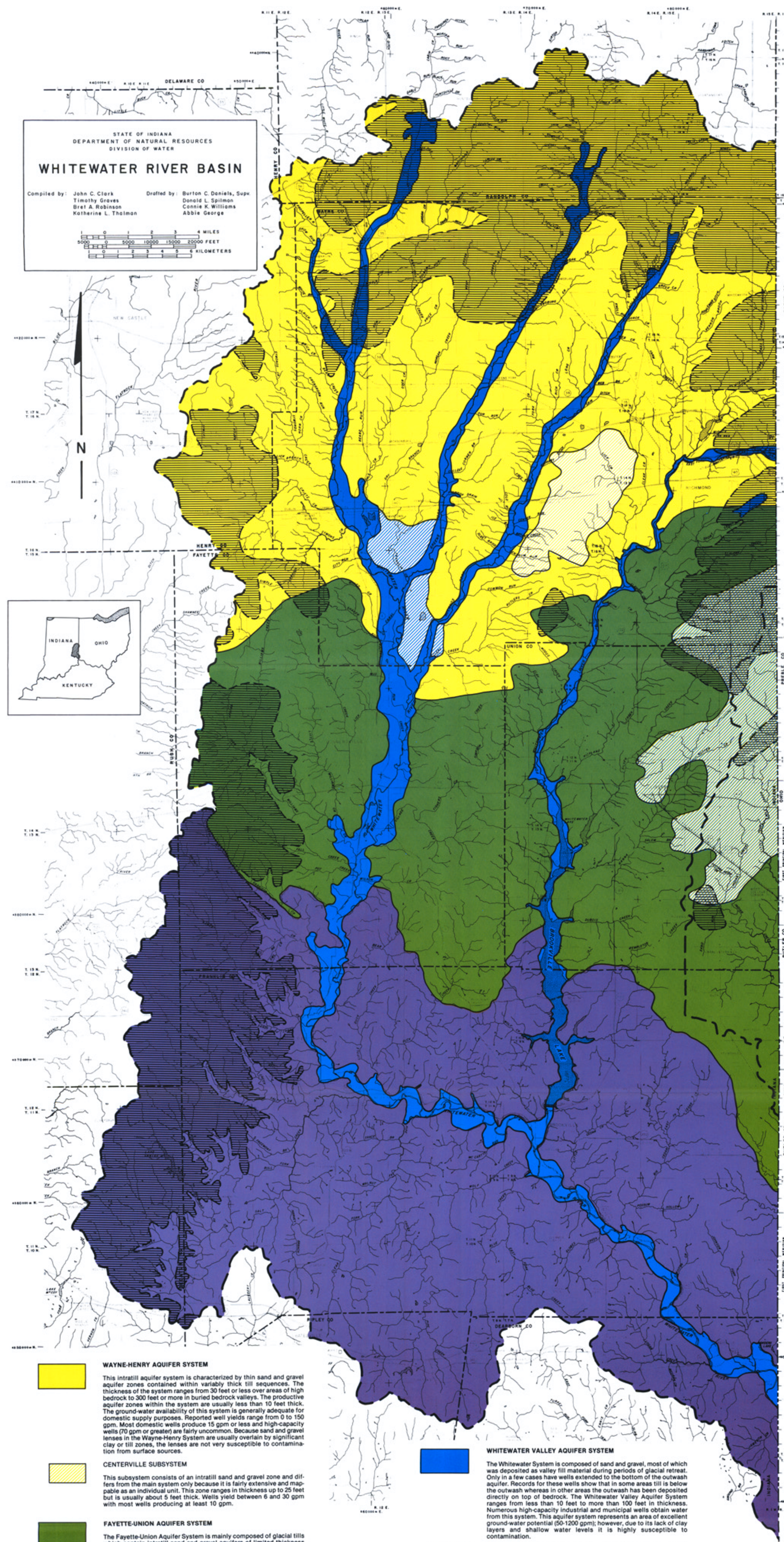
DEPARTMENT OF NATURAL RESOURCES
JAMES M. RIDENOUR, DIRECTOR



STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

WHITEWATER RIVER BASIN

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Donald L. Spilman
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Abbie George

🟨 **WAYNE-HENRY AQUIFER SYSTEM**

This intratill aquifer system is characterized by thin sand and gravel aquifer zones contained within variably thick till sequences. The thickness of the system ranges from 30 feet or less over areas of high bedrock to 300 feet or more in buried bedrock valleys. The productive aquifer zones within the system are usually less than 10 feet thick. The ground-water availability of this system is generally adequate for domestic supply purposes. Reported well yields range from 0 to 150 gpm. Most domestic wells produce 15 gpm or less and high-capacity wells (70 gpm or greater) are fairly uncommon. Because sand and gravel lenses in the Wayne-Henry System are usually overlain by significant clay or till zones, the lenses are not very susceptible to contamination from surface sources.

▨ CENTERVILLE SUBSYSTEM

This subsystem consists of an intratill sand and gravel zone and differs from the main system only because it is fairly extensive and mappable as an individual unit. This zone ranges in thickness up to 25 feet but is usually about 5 feet thick. Wells yield between 6 and 30 gpm with most wells producing at least 10 gpm.

🟩 **FAYETTE-UNION AQUIFER SYSTEM**

The Fayette-Union Aquifer System is mainly composed of glacial tills which contain intratill sand and gravel aquifers of limited thickness and extent. Intratill sand and gravel lenses average about 2 to 4 feet in thickness; however, in many areas these lenses are absent. Wells drilled in this system produce from 0 to 60 gpm; however, most wells average only 2 to 3 gpm. Bucket-rig wells, which draw water from thin sand zones or from seepage from fractures within the till, are frequently used. The aquifer system is only slightly susceptible to ground-water contamination because most buried sand and gravel lenses are overlain by significant thicknesses of clay.

▨ LIBERTY SUBSYSTEM

This subsystem of the Fayette-Union Aquifer System was identified because of the more frequent occurrence of significant sand and gravel aquifers. Sand and gravel lenses average about 4 feet in thickness and drilled wells usually yield about 10 gpm. Bucket-rig wells are less common than in the main Fayette-Union System due to the presence of thicker, more productive sand and gravel layers.

🟪 **DEARBORN AQUIFER SYSTEM**

This system consists of thin, eroded residuum and predominantly pre-Wisconsinan till overlying bedrock in southern portions of the basin. Significant sand and gravel zones are usually absent but thicknesses up to 15 feet have been reported. Water availability is generally poor although bucket-rig wells may produce water from thin sand or gravel units. Reported well yields range from 0 to 20 gpm but most wells produce only a few gpm and dry holes are fairly common. Because of the low permeability of the surface materials, this system is not very susceptible to contamination from surface sources.

🟦 **WHITEWATER VALLEY AQUIFER SYSTEM**

The Whitewater System is composed of sand and gravel, most of which was deposited as valley fill material during periods of glacial retreat. Only in a few cases have wells extended to the bottom of the outwash aquifer. Records for these wells show that in some areas till is below the outwash whereas in other areas the outwash has been deposited directly on top of bedrock. The Whitewater Valley Aquifer System ranges from less than 10 feet to more than 100 feet in thickness. Numerous high-capacity industrial and municipal wells obtain water from this system. This aquifer system represents an area of excellent ground-water potential (50-1200 gpm); however, due to its lack of clay layers and shallow water levels it is highly susceptible to contamination.

▨ In these areas of the Whitewater Valley Aquifer System, the outwash sands and gravels have been covered by a layer of clay or till. Sand and gravel zones of 20 to 30 feet are common with reported well yields ranging from 10 to 140 gpm. Aquifer zones in these areas are less susceptible to contamination from surface sources than other areas of the Whitewater Valley Aquifer System.

☐ **ORDOVICIAN BEDROCK AQUIFER SYSTEM**

This system is characterized by multiple layers of Ordovician-age limestone and shale. Wells developed in this system penetrate from 10 to 100 feet into bedrock. The productivity of wells in this system does not appear to be significantly correlated with the amount of bedrock penetration, however. Ground-water availability in this system is generally poor. Well yields of 0 to 50 gpm have been reported. Many wells yield between 2 and 8 gpm; however, dry holes are fairly common.

▤ **SILURIAN BEDROCK AQUIFER SYSTEM**

This system consists primarily of Silurian-age limestone with minor amounts of shale. Most wells producing from this system penetrate 30 feet or less into bedrock. Ground-water potential in this system is generally marginal with reported well yields of 0 to 60 gpm. Potential yields from this system are greatest to the north, commonly 30 gpm or greater, and decrease to the south. Yields also decrease near the Silurian-Ordovician boundary where yields are usually 10 gpm or less and dry holes are occasionally reported.

UNCONSOLIDATED AND BEDROCK AQUIFER SYSTEMS