Water-Quality Assessment of the White River Basin, Indiana: Analysis of Available Information on Pesticides, 1972-92

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS, ABBREVIATIONS, AND SYMBOLS

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
gallon per minute (gal/min)	0.06309	liter per second
million gallons per day (Mgal/d)	3.785	million liters per day
pound (lb)	0.4536	kilogram
pound per day (lb/d)	0.4536	kilogram per day
foot per day (ft/d)	0.3048	meter per day
square foot per day (ft^2/d)	0.09294	square meter per day

The following abbreviations are used in this report:

Abbreviation or Symbol	Description
IDEM	Indiana Department of Environmental Management
NAS	National Academy of Sciences
USEPA	U.S. Environmental Protection Agency
USFDA	U.S. Food and Drug Administration
USGS	U.S. Geological Survey
NAWQA	National Water-Quality Assessment
NWQL	National Water-Quality Laboratory
ANOVA	analysis of variance
ELISA	enzyme-linked immunosorbent assay
GC/MS	gas chromatographic mass spectrometry
MCL	Maximum Contaminant Level
<	less than
>	greater than
μg/kg	microgram per kilogram
μg/L	microgram per liter
μm	micrometer

Water-Quality Assessment of the White River Basin, Indiana: Analysis of Available Information on Pesticides, 1972–92

By Donna S. Carter, Michael J. Lydy, *and* Charles G. Crawford

ABSTRACT

A retrospective analysis of available pesticide data (1972–92) for the White River Basin was conducted as part of the U.S. Geological Survey National Water-Quality Assessment Program. Data on the occurrence of pesticides in streams, stream-bottom sediments, fish, and ground waters were obtained from the National Water Information System of the U.S. Geological Survey and from the Indiana Department of Environmental Management. The characteristics of the data sets used in this report are described, and results are interpreted with respect to factors that affect observed pesticide concentrations.

Currently used water-soluble herbicides, such as triazines and acid amides, were measured in surface waters near the mouth of the White River and at other locations over time to investigate the seasonal patterns of herbicide runoff. Herbicide concentrations reach a peak during the first major storm following application in agricultural areas and remain elevated for 1 to 2 months, commonly exceeding U.S. Environmental Protection Agency mandated drinking-water regulations. Herbicide concentrations are highest during late spring and early summer runoff. Most herbicide loadings to the river occur during this time, with about 1 percent of the applied herbicides (as the parent compounds) being transported out of the basin by the river.

Bottom sediments and fish were analyzed for historically used organochlorine insecticides and other lipophilic (fat-soluble) pesticides. Dieldrin, components of technical chlordane, and DDT-related compounds were the most frequently detected pesticides in sediments and in fish tissues. These pesticides exceeded U.S. Food and Drug Administration Action Levels for edible fish tissues at 5 to 13 percent of the sites sampled. Areas where pesticide concentrations in sediment were high also tended to have high concentrations in fish; this indicates that bottom sediments probably are the primary source of lipophilic pesticides to aquatic biota and that bottom-dwelling fish likely can be used to detect local contamination.

Ground-water/surface-water interaction and the occurrence of pesticides in ground waters throughout the White River Basin were examined by use of two data sets. (1) Atrazine concentrations during base-flow conditions in

small streams throughout the basin were used to study the potential for interaction between surface waters and nearby shallow aquifers. The bedrock karst region had significantly higher atrazine levels than the rest of the basin, indicating that the degree of interaction is high in this region and that the ground water is susceptible to contamination from surface sources and (or) recharge from contaminated surface waters. (2) A wide variety of water-soluble (hydrophilic) and lipophilic pesticides were measured in water from wells throughout the basin. Water from four wells had detectable concentrations of pesticides; water from three of the wells was contaminated with atrazine and its metabolites. The wells where pesticides were detected were located in karst or alluvial outwash, indicating that these highly permeable hydrogeomorphic units are highly susceptible to ground-water contamination.

INTRODUCTION

Background

The overall goal of the National Water-Quality Assessment (NAWQA) Program is to describe the status and trends in the quality of the ground-water and surface-water resources of the United States, and to link these trends with an understanding of the natural and human factors that affect the quality of these resources (Hirsch and others, 1988). The NAWQA Program integrates water-quality information at a range of scales from local to national. A major component of the program is the study-unit investigation, which includes 60 major hydrologic basins throughout the Nation. These investigations are the foundation upon which national-level-assessment activities are based. The White River, in south-central Indiana, is one of the 20 study units in which data-collection and analysis activities are underway as of 1994.

Study-unit investigations have four main components: (1) an analysis of existing data to gain insight into current and historical water-quality conditions and to aid in the design of NAWQA studies, (2) occurrence and distribution assessment to determine spatial characteristics of water quality, (3) long-term water-quality monitoring to determine temporal trends, and (4) case studies to examine the causes of water-quality degradation in local areas. Nationally consistent protocols for study design, data collection, and analysis are followed to facilitate interbasin comparison and data interpretation on a national scale.

Purpose and Scope

This report describes results of an analysis of pesticide data in the White River Basin for the period 1972–92. This report (1) describes the spatial and temporal coverage of available data on pesticides within the surface water, ground water, bottom sediment, and fish in the White River Basin; (2) presents a preliminary interpretation of the patterns of concentrations and loads in the basin with respect to seasonal, streamflow, and spatial effects; and (3) identifies data gaps and additional information that are needed to meet the goals of NAWQA.

The objectives of the White River NAWQA are linked to water-quality issues. Thus, the scope of this report is limited to the occurrence of pesticides in various compartments of the aquatic system including streams, stream-bottom sediments, fish, and ground water. Other planned reports will address the environmental setting of the White River Basin and the occurrence of nutrients in the basin. Seasonal and streamflow effects on currently used water-soluble herbicide concentrations in surface waters are investigated in 83 samples collected from the White River near Hazleton, Ind., and 19 samples collected at 8 locations throughout the basin by the U.S. Geological Survey (USGS); little information was available on currently used insecticides.

Streamflow effects on historically used lipophilic (fat-soluble) pesticide concentrations are examined in 83 surface-water samples collected by the Indiana Department of Environmental Management (IDEM) at 12 sites throughout the White River Basin and in 10 surface-water samples collected by the USGS at 4 sites in the Eagle Creek watershed. The occurrence of lipophilic pesticides in 104 stream-bottom sediments collected by the IDEM at 84 sites throughout the White River Basin and 15 sediments collected by the USGS at 11 sites in the Eagle Creek watershed are discussed. Pesticide levels at the 84 IDEM sediment sites are compared to levels in 266 fish samples collected at 80 nearby sites by the IDEM. Finally, spatial effects (of hydrogeomorphic strata and aquifer type) on currently used water-soluble pesticide concentrations are examined in 48 water samples collected at 48 small streams receiving discharge from nearby shallow aquifers and in 174 ground-water samples collected at 101 wells located throughout the basin.

Acknowledgments

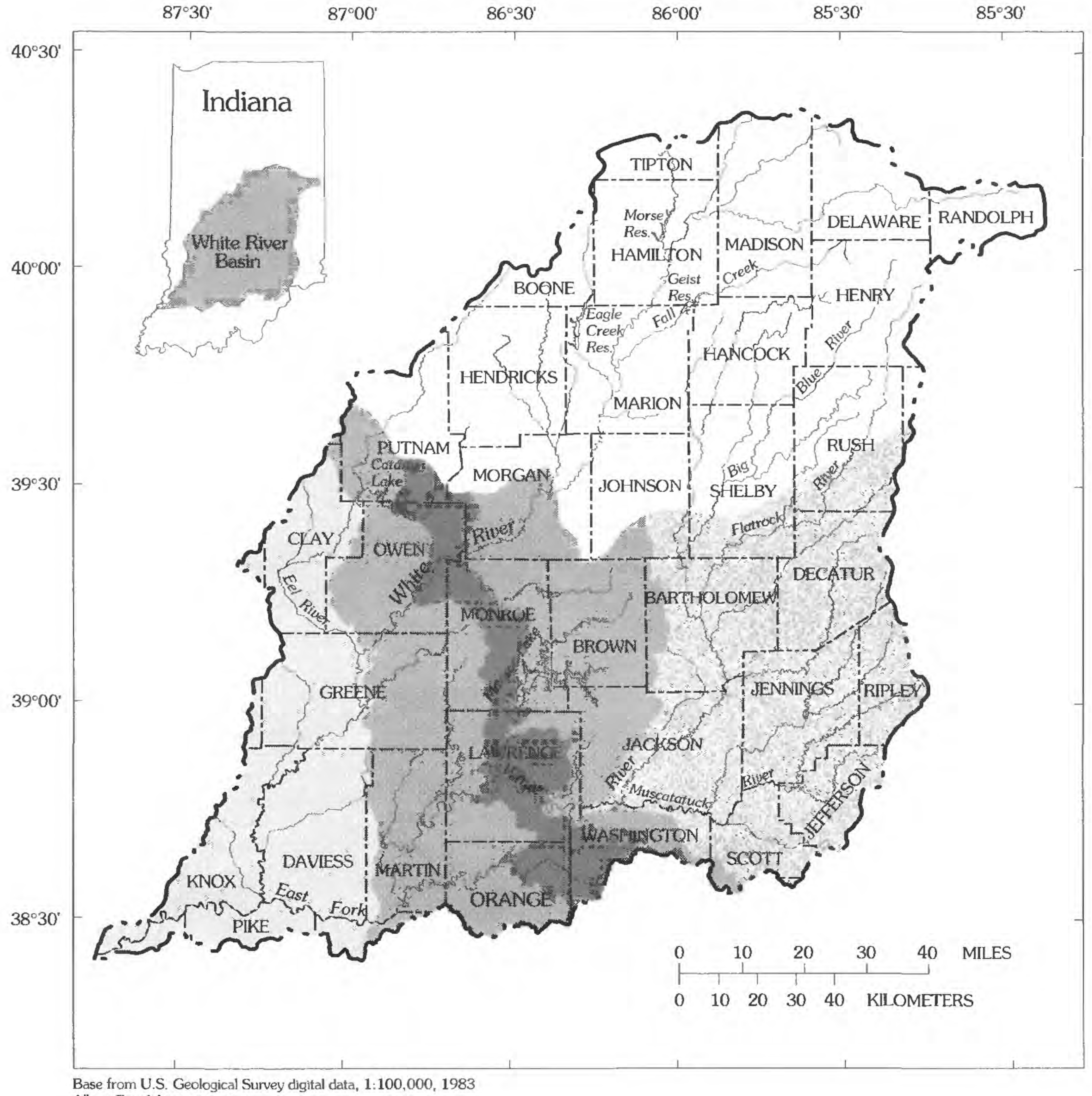
James Stahl and John Winters of the Indiana Department of Environmental Management assisted in obtaining and tabulating the bottom-sediment and fish-tissue data described in this report.

DESCRIPTION OF THE WHITE RIVER BASIN

Location and Physiography

The White River Basin in south-central Indiana has a total drainage area of 11,350 mi^2 that is divided into two nearly equal-sized subbasins. The eastern part comprises 5,746 mi^2 and is drained by the East Fork White River and its major tributaries, the Driftwood and Muscatatuck Rivers. The western part of the basin comprises 5,603 mi^2 and is drained by the main stem of the White River and its major tributary, the Eel River.

Five major hydrogeomorphic strata (fig. 1) and an additional stratum for ground-water assessments were designated for the White River Basin on the basis of hydrogeologic and geomorphologic characteristics, ecoregions, and the physiographic provinces originally defined by Malott (1922). Bedrock geology is the major factor affecting three strata—bedrock uplands, bedrock lowland and plain, and karst plain. Glaciation is the major factor affecting the other strata—till plain, glacial lowland, and fluvial deposits. The bedrock uplands are located in the south-central part of the basin and consist of relatively resistant siltstones, sandstones, limestones, and shales (Schneider, 1966). Differential erosion has produced the relatively high relief hill and valley landscape that characterizes the bedrock uplands strata. The bedrock lowland and plain stratum is located in the southeastern part of the basin. The entire extent of this stratum has been covered by pre-Wisconsin till and (or) lake deposits, and the northern third also has been covered by Wisconsin till. The eastern half of the stratum often has steep-sided valleys, whereas the western half is broad and gently undulating (Schneider, 1966). The karst plain stratum is located in the south-central part of the basin between the two units that comprise the bedrock upland stratum. The karst plain is an area of low relief that is formed from well fractured Mississippian limestones that have undergone extensive karst development (Palmer and Palmer, 1975). The karst plain contains numerous sinkhole and solution features and is characterized by discontinuous surface streams with subterranean drainage. The till-plain stratum, in the northern half of the basin, is the largest. The till plain is flat to gently rolling and consists of buried pre-Wisconsin till with overlying Wisconsin till at the surface. Lenses of sand and gravel occur in the loamy till and the drift ranges from 50- to 400-ft thick, though it is typically 100- to 200-ft thick (Malott, 1922). The southwestern part of the basin, the glacial lowland strata, was glaciated during Illinoian time. Much of the area has been extensively reworked by glaciofluvial processes. The entire stratum is covered by thick deposits of pre-Wisconsin drift composed of till, loess, sand dunes,



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Albers Equal Area projection
Standard parallels 29°30" and 45°30", central meridian -86°

EXPLANATION

HYDROGEOMORPHIC STRATA

- Till plain
- Bedrock upland
- Glacial lowland
- Bedrock lowland and plain
- Karst plain
- White River Basin boundary
- County boundary

Figure 1. Hydrogeomorphic strata of the White River Basin, Ind.

outwash, or lake deposits. The fluvial deposits stratum, used for ground-water assessments only, consists of permeable surficial deposits adjacent to major streams. This stratum is not shown in figure 1 because it is not restricted to a contiguous geographic area but is found along streams and rivers throughout the basin.

Hydrogeologic Setting

Ground-water quality and quantity vary across the different strata of the White River Basin and depend on geologic setting, type of aquifer, and depth of the aquifer. The two major aquifer types in the basin are unconsolidated aquifers associated with glacial deposits which occur primarily in the northern and southwestern parts of the basin, and consolidated bedrock aquifers in the south-central and southeastern parts of the basin. The two aquifer types can be divided further into four main aquifers: outwash and alluvial deposits, sand lenses in Wisconsin till, Mississippian carbonate rocks, and Silurian-Devonian carbonate rocks.

Outwash (materials associated with valley trains from glacial melting) and alluvium (recent materials associated with stream systems), can be present in any of the hydrogeomorphic strata previously discussed; however, most of these materials are found in the fluvial-deposits stratum. The outwash and alluvial aquifer type is the most productive in the State and can yield up to 2,000 gal/min. These aquifers are 20- to 80-ft thick and are predominantly homogeneous sand and gravel (Gray, 1983). Infiltration and transmissivity rates are high because of the permeability of this material; these characteristics make outwash and alluvial aquifers some of the most easily contaminated types of aquifers in the basin. The Wisconsin till aquifers consist of sand and gravel deposits that are commonly laterally discontinuous and are enclosed by silty clay and clay till.

The glacial drift is up to 400-ft thick in places (Gray, 1983). The thickness of sand and gravel units interbedded in the till averages 15 ft. These units can coalesce vertically, but generally the discontinuous nature of the clays in the tills causes the clays to act as semipermeable confining units. Ground-water flow is usually from the till aquifers into the aquifers of the fluvial deposits stratum (Lapham, 1981). The high clay content in the till slows recharge and may act as a barrier for migration of pesticides. Almost all Silurian-Devonian carbonate-rock aquifers are confined; they are fractured and yield water through a 500- to 600-ft-thick section. The Devonian bedrock is more shaley than the Silurian, which can contain porous reef structures. Mississippian carbonate-rock aquifers are found in the karst plain of the White River Basin and are characterized by numerous fractures and joints that have been widened by dissolution. Ground-water flow in many of the caverns and solution channels can approach that of surface-water streams. Recharge to the aquifers is derived locally from precipitation, and ground-water flow in the carbonate rocks responds rapidly to rain, as is typical of karst terrain. Thus, pesticides applied to overlying soils could be transported to the ground water in a short period of time. Transmissivity ranges from 10^{-5} ft^2/d in unfractured parts of the aquifer to 10^3 ft^2/d in solution-enhanced parts. Infiltrating pesticides could move rapidly into and throughout the aquifers. This rapid infiltration makes entire aquifers susceptible to contamination.

Surface-Water Hydrology

Much of the drainage for the main fork of the White River is from glacial or fluvial sediments, whereas the East Fork White River flows across bedrock-dominated sections of the basin for about one-third of its length. The main fork of the river is bordered by well developed flood-plain deposits because it flows through areas consisting mainly of unconsolidated glacial material; the deposits are not as extensive along the east fork. The two forks of the White River converge near Petersburg, Ind., forming a main channel that flows westward for about 50 mi where it joins the Wabash River at the Indiana-Illinois State line. Long-term average flow within the main channel at Petersburg is 11,800 ft^3/s. The average unit streamflows (mean annual divided by drainage area) for all streams in the White River Basin are comparable, ranging from 0.96 to 1.43 $(ft^3/s)/mi^2$. Variations in streamflow generally are moderate and follow seasonal fluctuations. Discharges usually peak in April or May when precipitation is the highest (Martin and Crawford, 1987). Seasonal median streamflows are highest in the winter and spring. Peak flows generally are much higher in streams originating in bedrock than in those originating in glacial deposits; the storage capacity of the glacial material tends to dampen the extremes in surface runoff. During drought, flows in streams originating in bedrock typically are zero, whereas streams originating in glaciated deposits tend to have a sustained base flow. Rapid runoff occurs after storms in high-relief areas where bedrock is exposed, whereas runoff in the glaciated areas is less rapid.

Land and Water Use

The primary land use within the White River Basin is row-crop agriculture. Other major land uses and land covers include urban, forest, coal mines and limestone quarries, and wetlands (fig. 2). Agriculture comprises nearly 64 percent of the basin; corn and soybeans are the predominant crops. The effect of agricultural activities on pesticide concentrations may have a significant impact on the quality of water within the basin. The U.S. Department of Agriculture has termed Indiana "the state with potentially the most threatened water supply in the country" (Taylor, 1989). The bedrock uplands contain less row-crop-agriculture cover (31 percent) than other areas in the basin because of steep topography and thin soil. The till plain has the most (81 percent) row-crop cover (Mitchell and others, 1977).

A total of 11.6 million acres were planted with Indiana's top 10 crops in 1991. These crops included corn (5,700,000 acres), soybeans (4,450,000 acres), winter wheat (720,000 acres), hay (675,000 acres), oats (45,000 acres), peppermint (21,000 acres), tobacco (8,800 acres), spearmint (7,500 acres), potatoes (4,100 acres), and rye (4,000 acres) (Gann and Danekas, 1992). Apples and peaches also were grown; the land area covered by orchards is not known. Herbicides were applied to 97 percent of the corn (18,136,000 lb used) and to 95 percent of the soybeans (6,522,000 lb used) in Indiana in 1991. Insecticides were applied to 33 percent of the corn (1,863,000 lb used), and negligible amounts were used on soybeans in Indiana. Atrazine was the most common herbicide (6,332,000 lb applied) used on corn, with 89 percent of corn acres in Indiana treated. Alachlor was used on 39 percent of corn acres with 4,704,000 lb applied; metolachlor was used on 28 percent of the acres with 2,714,000 lb applied (Gann and Danekas, 1992). On soybeans, alachlor was the most used herbicide (by mass) in Indiana with 20 percent of the acres treated and 1,711,000 lb applied in 1991. Metolachlor followed with 19 percent of soybean acres treated and 1,611,000 lb applied. Overall, alachlor was the most heavily used herbicide in Indiana, followed by atrazine (Gann and Danekas, 1992). Table 1 summarizes major pesticide usage in Indiana. A variety of factors affect the amount of pesticides that leave cropped areas; some of these factors include the chemical and physical properties of the pesticides, physical properties of the soils, amount and timing of rainfall, amount and type of pesticide applied, method and timing of application, and tillage practices (U.S. Environmental Protection Agency, 1988b).

Farming practices in Indiana vary somewhat depending on the type of crop grown and the location farmed but, in general, the preparation of fields begins in spring after the ground has thawed.

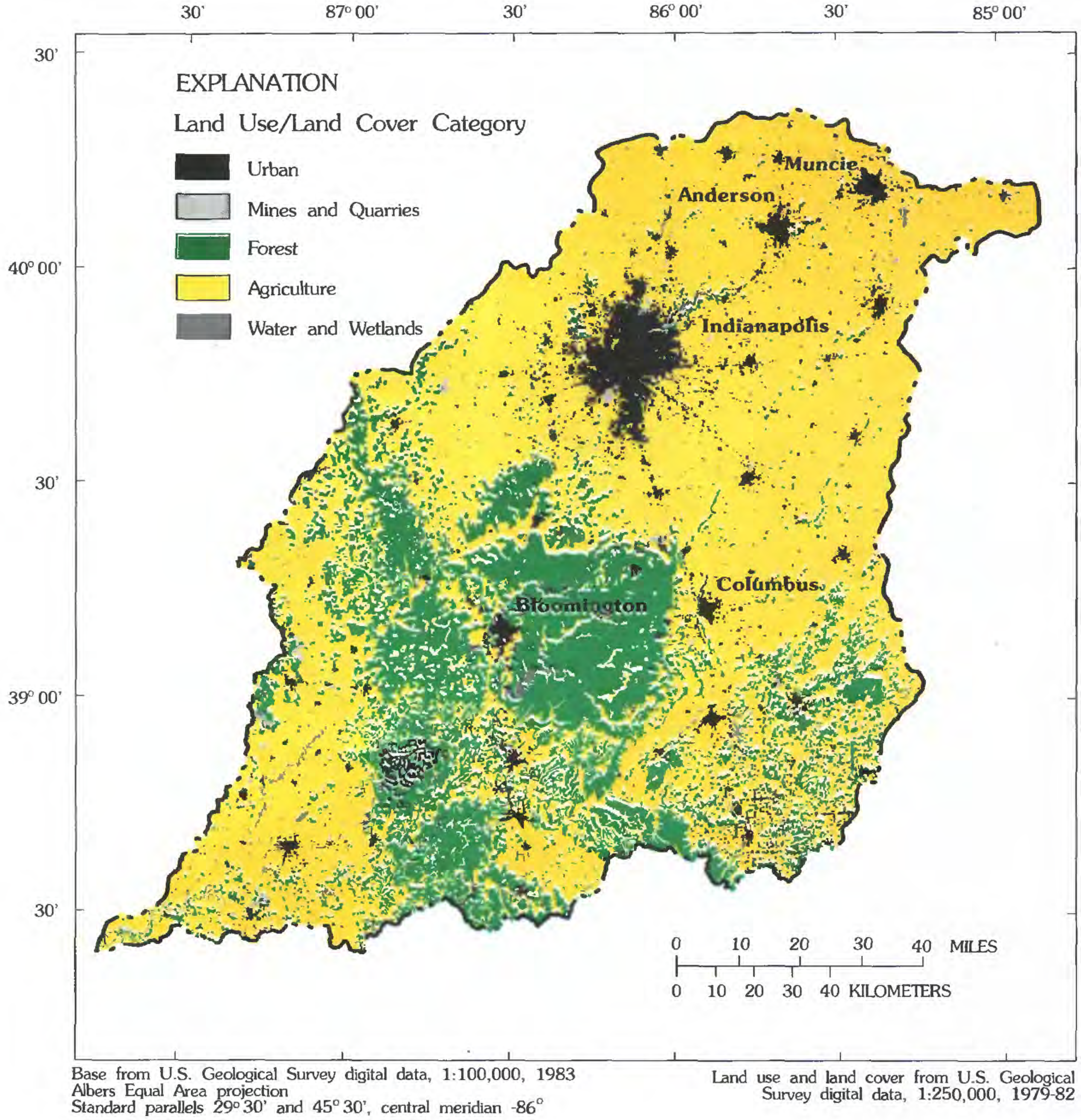


Figure 2. Major land use and land cover categories, in the White River Basin, Indiana.

Table 1. Common pesticides currently used on corn and soybeans in Indiana
[CAS number, Chemical Abstract Service registry number]

Pesticide	Chemical class	CAS number	Tons used in 1991[1]	Use
Alachlor	Chloracetamide	15972-60-8	3,208	Pre-emergence herbicide
Atrazine	Triazine	1912-24-9	3,166	Selective herbicide
Metolachlor	Chloracetamide	51218-45-2	2,163	Pre-emergence herbicide
Butylate	Thiocarbamate	2008-41-5	818	Selective herbicide
Cyanazine	Triazine	21725-46-2	753	Selective herbicide
Trifluralin	Dinitroanaline	1582-09-8	321	Selective pre-emergence herbicide
Pendimethalin	Dinitroanaline	40487-42-1	291	Selective herbicide
Chlorpyrifos	Organophosphate	2921-88-2	266	Insecticide
Terbufos	Organophosphate	013071-79-9	246	Systemic insecticide, nematicide
Metribuzin	Triazine	21087-64-9	188	Herbicide
Bentazon	Unclassified	25057-89-0	169	Selective post-emergence herbicide
Carbofuran	Carbamate	1563-66-2	163	Insecticide, nematicide, miticide
Clomazone	Unclassified	81777-89-1	126	Broad spectrum herbicide
Dicamba	Benzoic acid	1918-00-9	125	Herbicide
Fonofos	Organophosphate	944-22-9	123	Soil insecticide
Linuron	Substituted urea	330-55-2	81	Herbicide
2,4-D	Chlorinated phenoxy	1702-17-6	75	Selective herbicide
Imazaquin	Imidazolinone	81335-37-7	43	Selective herbicide
Chlorimuron-ethyl	Sulfonylurea	90982-32-4	32	Selective post-emergence herbicide
Acifluorfen	Diphenyl ether	62476-59-9	29	Selective post-emergence herbicide
Aethoxydim	Diphenoxy	74051-80-2	26	Systemic post-emergence herbicide
Imazethapyr	Imidazolinone	81335-77-5	25	Herbicide

[1]Indiana Agricultural Statistics Service, 1992.

Fields are plowed and disked to loosen the soil and prepare a seed bed. Plowing for spring-planted crops takes place from the end of March through May. During 1986–90, 61 percent of the land was plowed by March 30, and 97 percent was plowed by May 20. A short time before planting or during planting, pre-emergence herbicides are applied to the soil. Corn typically is planted from the end of April to mid-June. During 1986–90, 63 percent of the corn crop was planted by May 10, and 89 percent was planted by May 30 (Indiana Agricultural Statistics Service, 1992). Soybeans typically are planted from the beginning of May to the end of June. By May 30, 61 percent of soybeans were planted and, by June 20, 92 percent were planted. Weed growth during the growing season may require application of post-emergent herbicides. Corn and soybeans are harvested in Indiana from mid-September to the end of November. During 1986–90, 47 percent of the corn and 63 percent of the soybeans were harvested by October 20, and 94 percent of the corn and 98 percent of the soybeans were harvested by November 20. After harvest, crop residues typically are incorporated into the soil by disking. This usually is done in November in Indiana (Indiana Agricultural Statistics Service, 1992). The soil then is allowed to sit through the winter accumulating moisture until the following spring when the cycle is repeated.

Industrialization is more prominent within the northern part of the basin—which includes the cities of Indianapolis, Muncie, and Anderson—than it is in the southern part. Urban land use covers approximately 8 percent of the White River Basin (Mitchell and others, 1977). Indianapolis is the largest metropolitan area in the basin. Indianapolis and its suburbs have a population of about 1.5 million people (approximately three-quarters of the total population in the basin). Small urban areas with 50,000 to 100,000 people include Anderson, Bloomington, Columbus, and Muncie. The effect of urban areas on pesticide concentrations in the White River Basin has not been studied extensively, but it seems likely that most of the pesticides in urban areas would originate from lawn, garden, and home products, and from products used on public lands, such as golf courses, parks, and roadsides.

Much of the area covered by forest in the White River Basin is in the bedrock-upland stratum. Approximately 28 percent of the basin is forested (Mitchell and others, 1977), although the forested areas are not contiguous in large blocks but are intermixed with agricultural and pasture land. Virgin stands of timber are rare, and most of the forests are second or third growth. Forested areas commonly are on top of ridges and on steep (10–50 percent) slopes.

The southwestern part of the White River Basin has coal deposits that are mined extensively. Numerous limestone quarries are located in the south-central part of the basin. Strip mining and quarries account for less than 0.55 percent of the total land use within the basin, and their effect on pesticide levels probably is negligible.

Most of the water withdrawn from the White River Basin is from surface-water sources (88.5 percent or 966 Mgal/d), whereas 11.5 percent (126 Mgal/d) is from ground-water sources. Most ground-water withdrawals are for public-supply systems and domestic use (Indiana Department of Natural Resources, 1990). Streamflow is variable in the southern part of the basin, and ground-water supplies there are not reliable. Reservoirs have been constructed to help provide a reliable source of water. In many rural areas, public supply systems have been developed. The largest water withdrawals (ground water and surface water combined) in the basin are for noncontact cooling water in powerplants (64 percent) and public-water supply (23 percent), with commercial, industrial, and irrigation water accounting for the remaining 13 percent. Marion County (where Indianapolis is located) makes the largest withdrawals of surface water and ground water in the basin.

SOLUBILITY PROPERTIES OF PESTICIDES

The transport and fate of pesticides in the aquatic environment strongly depend on the water solubility of the pesticides. The pesticides discussed in this report are divided into two categories: water-soluble and lipophilic. In this report, pesticides with water solubilities greater than a few parts per million are considered water soluble. Most pesticides currently used in the United States are water soluble by the definition above. Water-soluble pesticides applied to soil tend to be more mobile than nonsoluble types (Swann and others, 1983) and can enter aquatic systems in the dissolved state. Because they are dissolved, the distributions of water-soluble pesticides in an aquatic system is determined by water movement.

Lipophilic compounds have a strong affinity for fats and other lipids. These compounds tend to have a lack of affinity for water; thus, the terms lipophilic and hydrophobic often are used synonymously although there are subtle differences between the two terms that are not considered here. Lipophilic compounds do not dissolve in water to an appreciable degree; thus, their environmental fate differs from that of water-soluble compounds. Lipophilic pesticides generally are not found in surface waters at high concentrations because of their low solubility in the aqueous phase (although high suspended or dissolved organic carbon in the water can lead to increased solubility) (Chiou and others, 1986).

Lipophilic pesticides are very soluble in the organic matter and lipids associated with sediments and aquatic organisms. These pesticides partition out of water into the organic material associated with sediments or into lipids in biota. Sediments and aquatic organisms are the major reservoirs for lipophilic contaminants in the aquatic environment. By contaminant mass, sediments are the largest environmental sink for lipophilic contaminants. Lipophilic contaminants adsorb to the organic coating on sediment particles; thus, the fate of lipophilic pesticides is linked to sediment movement rather than water movement. Because bottom sediments are not as mobile as stream waters, sediment-bound lipophilic pesticides tend to accumulate over relatively long periods of time and are not as susceptible to rapid changes in concentration as are pesticides in the aqueous phase. Because of their chemical structure, many lipophilic pesticides tend to be more stable in the environment than water-soluble pesticides and can persist in aquatic systems for many decades, creating potential pollution problems long after they are no longer being introduced into the environment.

Biota are an important environmental sink for lipophilic contaminants because of the tendency of these compounds to accumulate to potentially dangerous concentrations in the lipids of organisms. Lipophilic pesticides bioaccumulate in organisms and tend to biomagnify through food chains (Metcalf and others, 1973; Veith and others, 1980). Bioaccumulation is the concentration of lipophilic compounds from the environment into organisms and involves uptake from sediment, food, or water. Biomagnification is a more specific term describing the concentration of lipophilic compounds in predator species that results from ingestion of food species that contain these compounds. The higher an organism is in a food chain, the more it could be affected by biomagnification. The tendency of lipophilic contaminants to accumulate in organisms to concentrations many orders of magnitude higher than in the surrounding environment makes these compounds potentially dangerous to all animals, including humans.

SOURCES AND ANALYSIS OF DATA

Sources and Characteristics of Data

The sources of data used in this report are summarized in table 2; no other major data sources were located. Few long-term studies of pesticides in the White River Basin are available. In most of the studies, single or very few samples were collected at each site and were of a reconnaissance nature. The multiple-sample stations for the studies discussed in this report are shown in figure 3; names and locations of the sites are listed in table 3 (at back of report). The only high-sampling frequency, perennial study of pesticides is the Hazleton herbicide study (Goolsby and others, 1991a; unpublished data on file in the Kansas District Office of the U.S. Geological Survey). All of the samples for this study were collected from an abandoned bridge near Hazleton, Ind., about 30 mi downstream from the confluence of the east and main forks of the White River, and 20 mi upstream from the mouth of the river. Depth-integrated, equal-width increment water samples were collected by use of a USGS D-77 sampler equipped with Teflon collection bottle and nozzle. The Hazleton herbicide-study samples discussed in this report were collected under a wide variety of streamflow and seasonal conditions during May 1991–September 1992. The temporal and flow characteristics of herbicide occurrence in the White River Basin were characterized. The results of the Hazleton herbicide study are the only data set discussed in this report that is amenable to load estimation. The samples were analyzed by the USGS National Water-Quality Laboratory (NWQL) in Denver, Colo., for organonitrogen herbicides by USGS method 1379 (Sandstrom and others, 1992).

The White River herbicide reconnaissance was a seasonal study in which surface-water samples were collected at eight locations in March (prior to herbicide application) during low flow, in May (just after herbicide application) during high flow, and in October (harvest) 1989 during low flow to examine seasonal differences in herbicide

Table 2. Sources of data used in this report

[USGS, U.S. Geological Survey; IDEM, Indiana Department of Environmental Management; IGS, Indiana Geological Survey]

Agency	Data-collection progrsm	Sample type	Anslytes	Sampling frequency	Number of samples	Number of sites	Period of record
USGS	Hazleton herbicide study	Surface water	Water soluble herbicides	Semi-weekly to biweekly	83	1	5/1/91–8/26/92
USGS	White River herbicide reconnaissance	Surface water	Water soluble herbicides	2 to 3 times	19	8	3/24/89 – 11/1/89
USGS	White River atrazine synoptic	Surface water	Atrazine	1 time	48	48	3/9/92 – 3/16/92
IDEM	Surface-water monitoring	Surface water	Lipophilic pesticides	Quarterly	83	12	3/13/89 – 12/11/90
USGS	Eagle Creek watershed	Surface water and sediment	Lipophilic pesticides	1 to 3 times	10 water 15 sediment	4 water 11 sediment	8/25/80 – 4/13/83
USGS, IGS, IDEM	Pesticides in ground water	Ground water	Various pesticides	1 to 5 times	174	101	8/25/87 – 8/6/91
IDEM	Sediment and fish monitoring	Sediment and fish	Lipophilic pesticides	1 to 12 times	104 sediment 266 fish	84 sediment 80 fish	8/18/83 – 11/16/90

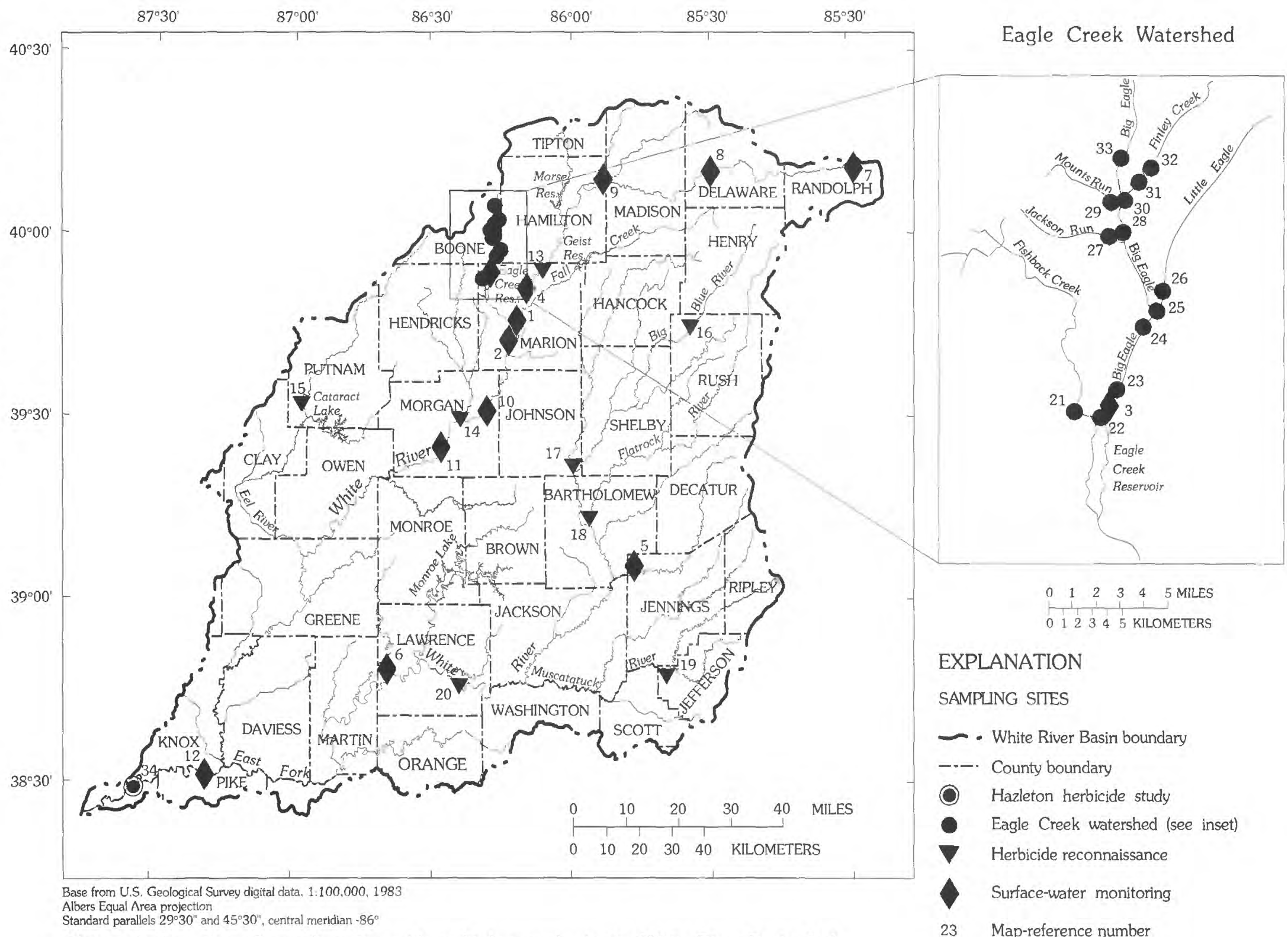


Figure 3. Location of sampling sites with multiple samples in the White River Basin, Ind.

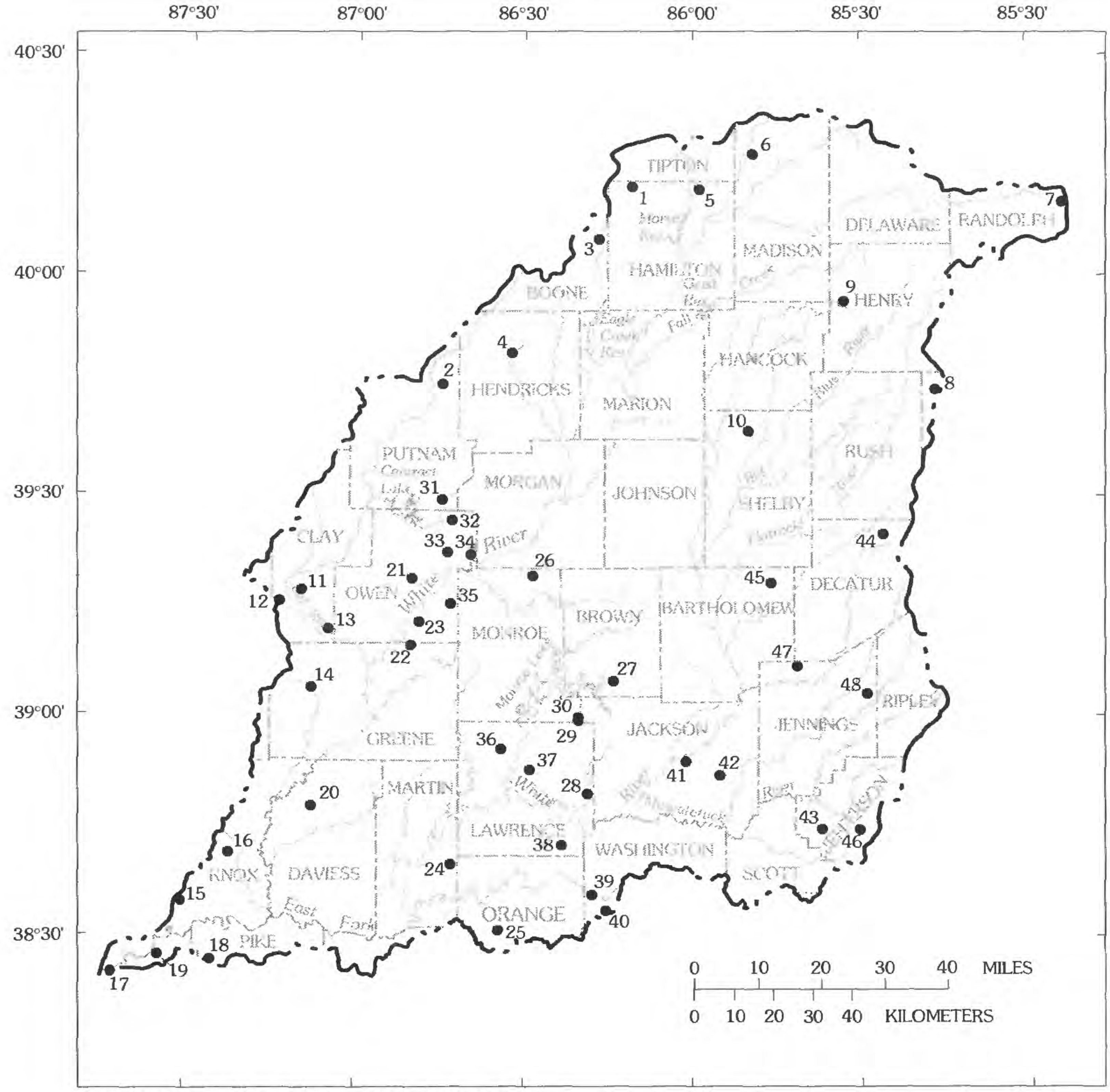
levels (Goolsby and others, 1991b). Eight sites—three on the main fork White River and tributaries and five on the east fork and tributaries—were sampled with depth-integrating techniques at three to five locations across the stream. The samples were filtered through glass fiber filters (1µm nominal pore size) and sent to the Kansas District of the U.S. Geological Survey for analysis of herbicides by solid-phase extraction followed by gas chromatography/mass spectrometry (GC/MS).

The IDEM surface-water-monitoring study (Indiana Department of Environmental Management, 1986) is a continuing program investigating the occurrence of historically used lipophilic pesticides in surface waters throughout the White River, especially the main fork. Some of the objectives of the program are to determine water quality during changing conditions, indicate sources and effects of contamination, and obtain baseline data to detect changes in contaminant concentrations. Many of the stations are placed to facilitate assessment of the effects of discharges in urban areas or to determine the quality of water that is withdrawn for public supplies. The samples discussed in this report are whole-water samples collected quarterly during March 1989–December 1990 under a variety of flow conditions. Samples usually were collected from bridges from the center of flow with a Kemmerer sampler or plastic bucket (Indiana Department of Environmental Management, 1986). Samples were collected from just under the water surface without touching the stream bottom and were analyzed by the Indiana State Board of Health.

The Eagle Creek watershed study (Wangsness, 1983) was a reconnaissance designed to define the general water quality of the upper Eagle Creek watershed near Indianapolis. For the lipophilic-pesticide phase of this study, surface-water samples were collected during low flow in October 1982 and during high flow in December 1982 and April 1983 by dipping the sample bottle from surface to bottom at several points in the stream. Bottom sediments were collected in August 1980 and October 1982 by compositing grab samples collected at several points per site. The sediments were wet sieved to <63 µm with stainless-steel sieves, and the water and sediments were sent to the USGS laboratory in Doraville, Ga., for analysis.

The White River atrazine synoptic study was a one-time study in which water samples from small streams (fig. 4) throughout the basin were collected during base flow in March 1992 to examine ground-water/surface-water interactions. Names and locations of the sites in figure 4 are listed in table 4 (at back of report). Grab samples of whole surface water were collected at the center of flow with pre-cleaned glass jars. The samples were analyzed for atrazine in the Indiana District of the U.S. Geological Survey by enzyme-linked immunosorbent assay (Rubio and others, 1991).

Available data on pesticides in ground water were compiled from data from various government agencies. Most of the sites in the data set (fig. 5) were sampled only once, independent of season. Locations of the sites in figure 5 are listed in table 5 (at back of report). The data were collected at different types of wells (private, municipal, and observation) throughout the White River Basin and the rest of Indiana. Samples collected from private or municipal wells were collected at the tap before any treatment and after plumbing had been flushed for at least 15 minutes. Samples from observation wells were collected with a peristaltic pump or a submersible, positive-displacement pump. Wells were purged until field measurements of temperature, pH, and specific conductance stabilized. Each well was analyzed for a different set of chemical constituents. The reason for compiling these data in the USGS National Water Information System was to examine the frequency of pesticide occurrence in Indiana (Indiana Department of Environmental Management, 1989). This report discusses only samples collected within the White River Basin.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Albers Equal Area projection
Standard parallels 29°30" and 45°30", central meridian -86°

EXPLANATION

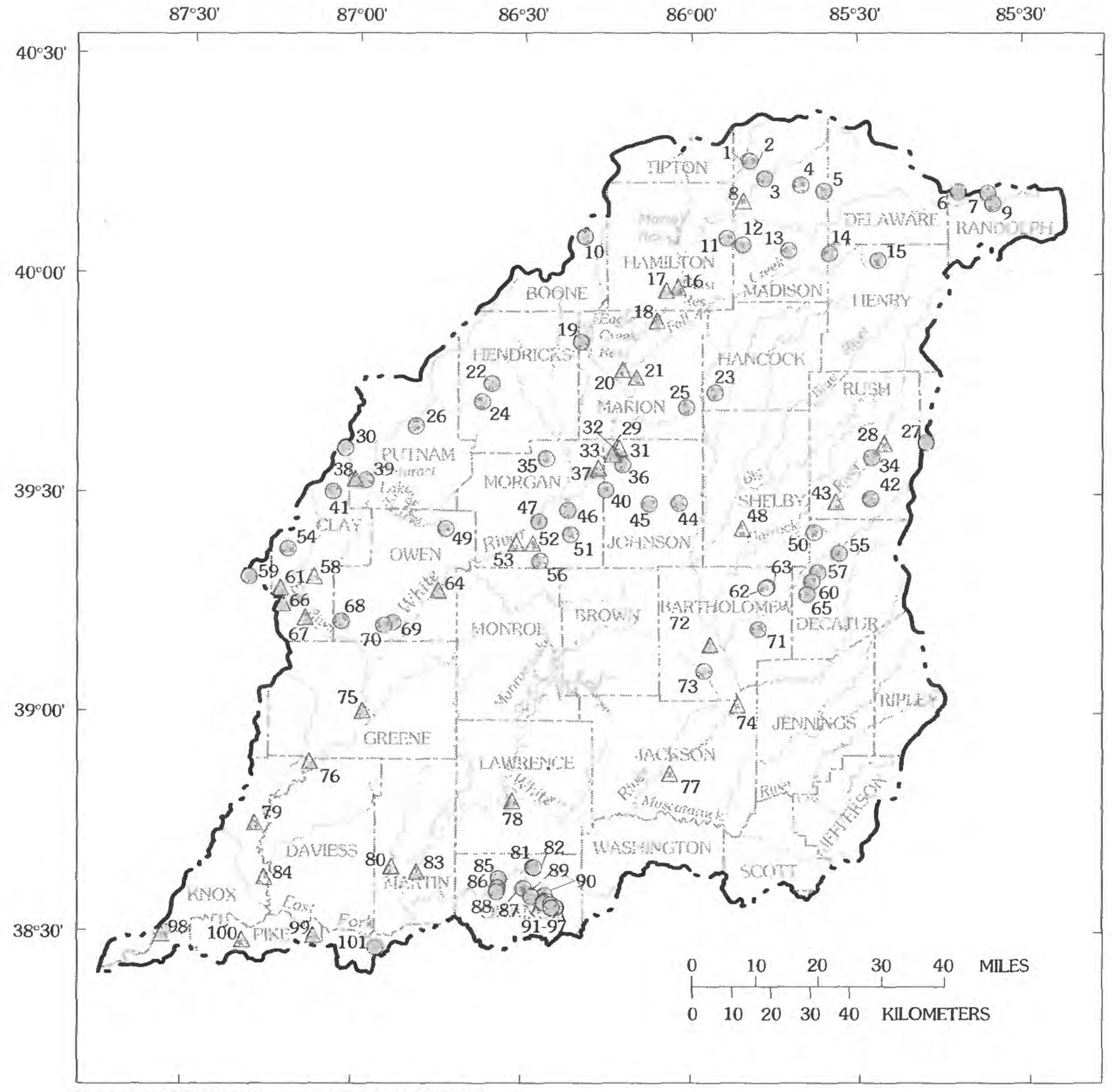
SAMPLING SITES

White River Basin boundary

County boundary

38 Atrazine sampling site and reference number

Figure 4. Surface-water sampling sites for atrazine synoptic study in the White River Basin, Ind.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Albers Equal Area projection
Standard parallels 29°30" and 45°30", central meridian -86°

EXPLANATION

SAMPLING SITES

White River Basin boundary
County boundary
Well
Well located in fluvial deposits stratum
84 Map reference number

Figure 5. Location of ground-water-sampling sites in the White River Basin, Ind.

The IDEM sediment- and fish-monitoring program is a long-term study investigating the concentrations of lipophilic pesticides present in streams in Indiana (Indiana Department of Environmental Management, 1990). For the data set discussed in this report, various fish species were collected by electroshocking during different times of the year from August 1983 through November 1990 at the sites shown in figure 6; names and locations of the sites are listed in table 6 (at back of report). Some fish were left whole, whereas others were filleted; the skin was removed from some fillets. Grab samples of bulk sediments were collected at several areas within a site and were composited. The samples were not sieved. All samples were analyzed by the Indiana State Board of Health laboratory in Indianapolis, Ind., or by Hazleton Laboratories of America, using standard analytical methods (U.S. Department of Health, Education and Welfare, 1982; U.S. Environmental Protection Agency, 1982).

Quantitative Data-Analysis Techniques

Several quantitative data analysis techniques were used in this report; a brief discussion of the methods follows. The log-percent difference, as proposed by Törnqvist and others (1985), was used to compute the percent difference between two replicate data sets. The log-percent difference between two variables, x and y, is defined as $100 \ln(y/x)$. This measure of relative change has the advantage of being both symmetric and additive. Kendall's tau, a nonparametric correlation coefficient (Conover, 1980), was used to measure the association between the concentrations of chlordane and dieldrin in sediments of the Eagle Creek watershed.

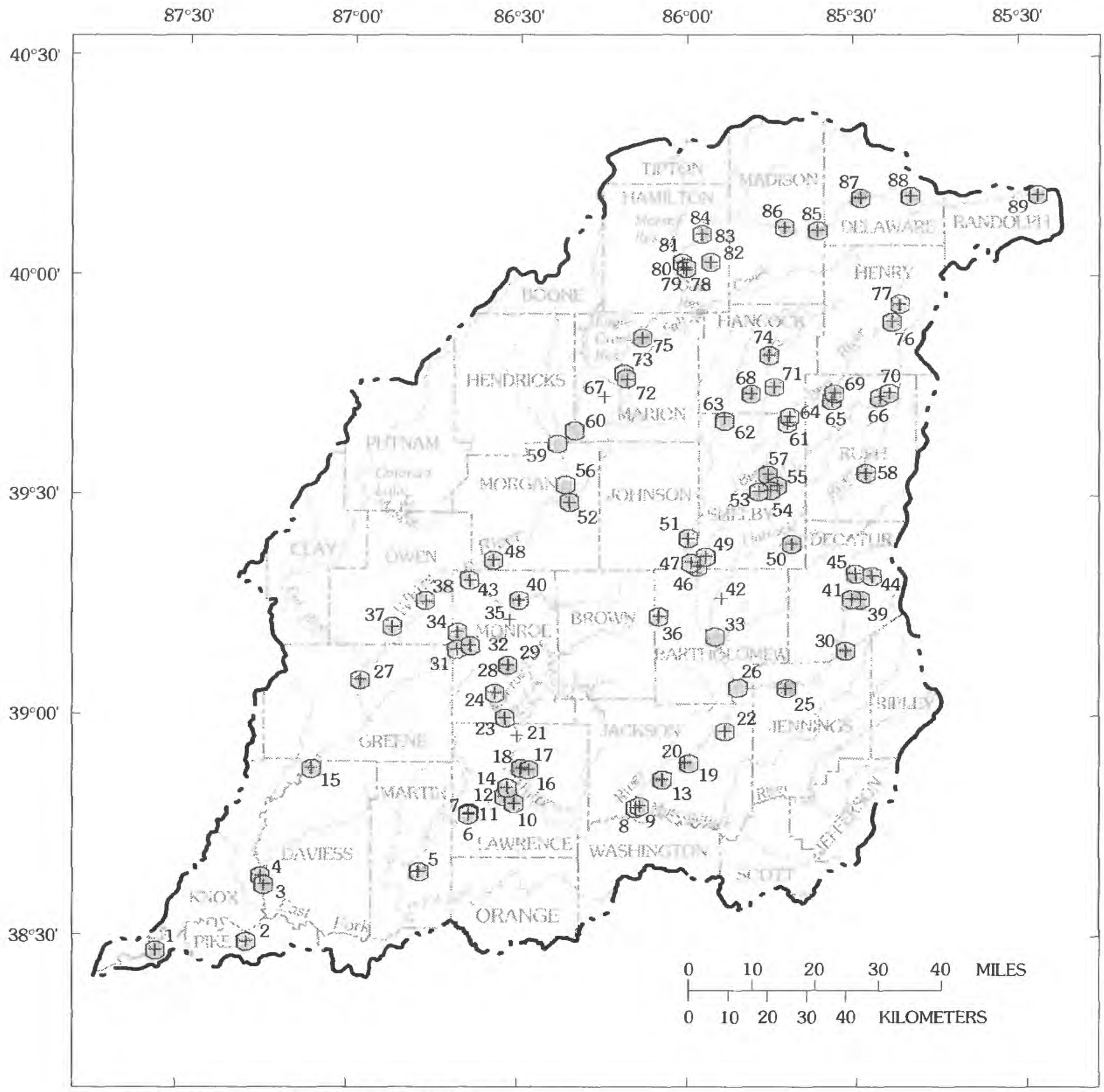
Pesticide loads for the White River at Hazleton were estimated by cubic spline interpolation (Burden and Faires, 1985) between the observed loads. An estimated load was obtained by interpolation for each day that no sample was collected, and the daily estimates were summed to obtain the load for the period of interest. For constituents with observations less than the detection limit, the procedure was done twice—once substituting the detection limit as the observed value and once substituting zero as the observed value. Doing so resulted in a range within which the estimated load falls. The sampling frequency at this site was sufficient to use an interpolation approach. The more commonly used rating-curve method (Cohn and others, 1992) or flow-duration rating-curve method (Crawford, 1991) were not used because the relation between pesticide load and streamflow varied significantly over the period of sample collection. These latter two methods rely on this relation to obtain estimates of the mean load and, as such, were not appropriate for use in this case.

Rank transform analysis of variance (ANOVA) was used to evaluate the hypothesis that hydrogeomorphic strata had no effect on observed atrazine concentrations in 48 small streams (Conover and Iman, 1981; Helsel and Hirsch, 1992). This procedure is similar to classical ANOVA, except that the procedure is applied to the ranks of the data. Ranking data eliminates the need for the assumption of normally distributed data, which is required by classical ANOVA. Rank transform ANOVA is comparable to the Kruskal-Wallis test (Hollander and Wolfe, 1973). The Tukey method of multiple comparisons (Neter and others, 1985) was used to determine which of the strata were different from the others after the hypothesis of no difference had been rejected by rank transform ANOVA.

PESTICIDES IN THE WHITE RIVER BASIN

White River Herbicide Reconnaissance

Eight surface-water sites along the upper reaches of the main and east forks of the White River and their tributaries were sampled for water-soluble herbicides at various seasons during 1989. All eight sites were sampled during the growing season during runoff (May 23–26) and after



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Albers Equal Area projection
Standard parallels 29°30" and 45°30", central meridian -86°

EXPLANATION

SAMPLING SITES

White River Basin boundary
County boundary
Fish
+ Sediment
15 Map reference number

Figure 6. Bottom-sediment and fish-tissue sampling sites in the White River Basin, Ind.

the growing season during base flow (October 17–November 1); three sites also were sampled before the growing season during base flow (March 24–28). All samples were depth-integrated, equal-width increment whole-water samples analyzed for 13 dissolved water-soluble herbicides by C-18 solid-phase extraction followed by GC/MS (Goolsby and others, 1991b; Thurman and others, 1990). Growing-season concentrations of atrazine and alachlor exceeded USEPA Maximum Contaminant Levels (MCL's) for an undetermined period following herbicide application. A MCL is the maximum permissible concentration of a contaminant in water delivered through a public-supply system. This is an enforceable standard established on the basis of possible human-health effects and water-treatment feasibility, among other factors (U.S. Environmental Protection Agency, 1992b). The MCL for atrazine (3 µg/L) was exceeded in 88 percent of the growing-season water samples collected, and 63 percent exceeded the MCL's for atrazine and alachlor (2 µg/L). These MCL's were not exceeded in water samples collected before or after the growing season. All the other compounds measured in this study either did not exceed their MCL's or MCL's have not been established for them.

Five of the herbicides analyzed for were detected less than a third of the time (prometryn, 0 percent; prometon, 11 percent; ametryn, 0 percent; terbutryn, 0 percent; and metribuzin, 32 percent); concentrations of the remaining eight pesticides are summarized in figure 7. Detection limits for these compounds are 0.05 µg/L, except for cyanazine which has a detection limit of 0.2 µg/L. Concentrations of the most frequently detected herbicides sampled throughout the White River Basin are plotted with respect to sampling season. Atrazine is the most abundant of the compounds measured. The atrazine metabolites desethylatrazine and deisopropylatrazine also were found, indicating that they are persistent and mobile. Atrazine and its metabolite desethylatrazine were the most frequently detected of the herbicides. Measurable concentrations were present throughout the year at most sampling sites, indicating that they are somewhat persistent in the environment (atrazine soil half-life = 140 days) (Nash, 1988). On the other hand, alachlor, although it is present in soil in high concentrations during the growing season, is less frequently detected at other times of the year. It has a short soil half-life (50 days) (Nash, 1988) and typically does not persist (as the parent compound) from one year to the next.

Apart from differences in concentration and environmental persistence, the same seasonal pattern is seen with all the herbicides shown. Concentrations are at or near detection limits in March before herbicide application, increase dramatically in May during the growing season just following application, and decrease again to nearly baseline concentrations by harvest in October. Concentrations of water-soluble herbicides in streams change radically depending on the season the streams are sampled. Flow conditions also may affect observed pesticide concentrations in surface-water. Samples collected during the growing season were under high-flow conditions, whereas most of the other samples were collected during low-flow conditions. Results from this study indicate that water-soluble herbicide concentrations have a seasonal or flow dependence or both. More frequent sampling is needed for a detailed assessment of the factors affecting observed pesticide concentrations; this is examined in the following section.

Hazleton Herbicide Study

Surface-water samples were collected near Hazleton, Ind., about 20 mi upstream from the mouth of the White River (fig. 3), from May 1, 1991, through August 26, 1992. Depth-integrated, equal-width increment samples were collected across the same cross section of the river for the entire period of record (Goolsby and others, 1991a). Samples were filtered in the field and analyzed for water-soluble herbicides by C-18 solid-phase extraction followed by GC/MS (Sandstrom and others, 1992) at the USGS NWQL.

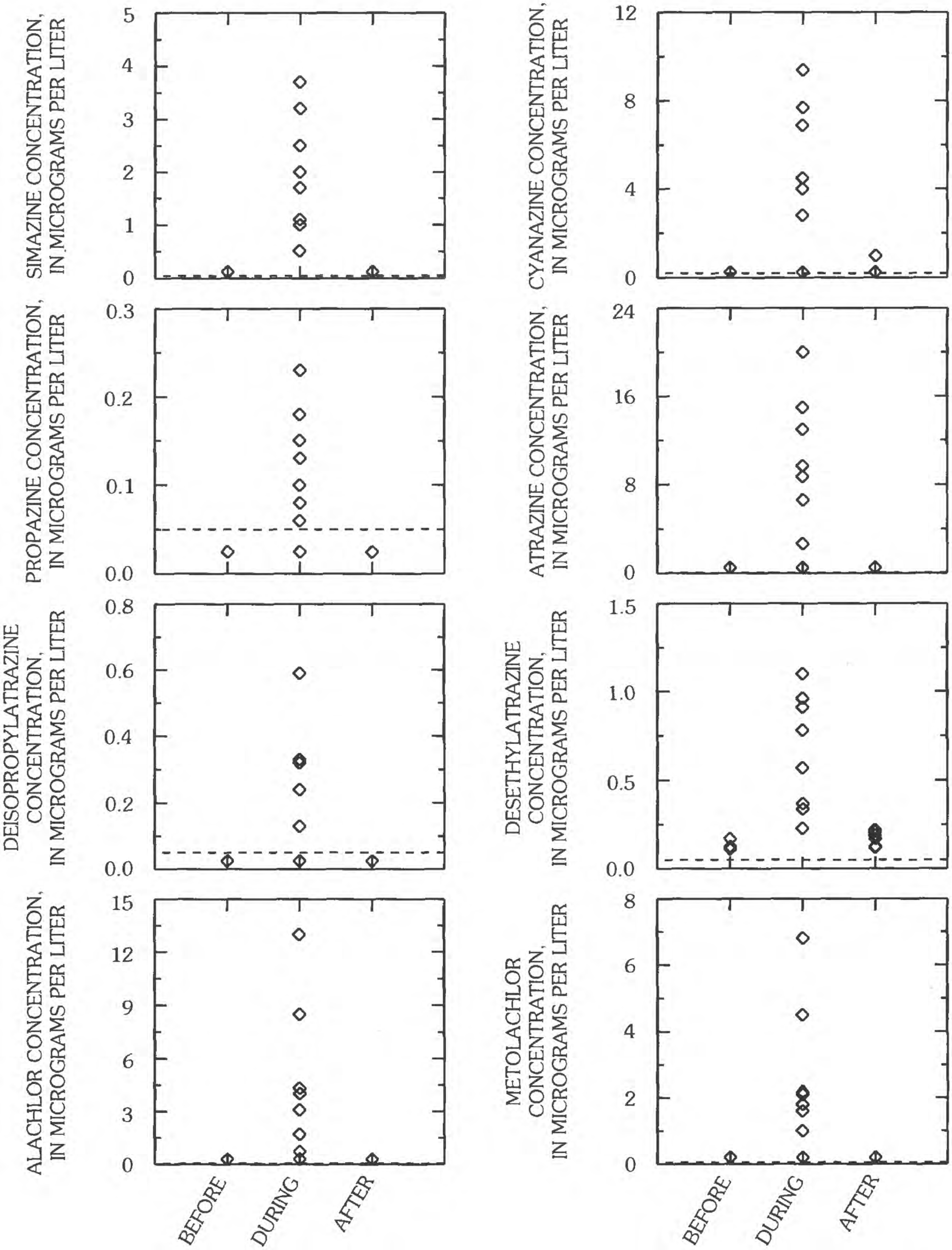


Figure 7. Concentrations of water-soluble pesticides in surface waters throughout the White River Basin, Ind., before, during, and after the 1989 growing season. (There are three observations before and eight observations during and after the growing season. Non-detected values are plotted as one-half the reporting limit which is shown by the dashed line.)

Samples were collected twice weekly from May through August 1991, weekly from September through November 1991, biweekly from December 1991 through February 1992, and weekly throughout the rest of the sampling period.

Figures 8–11 show concentrations and instantaneous loads, along with daily mean streamflow, from May 1991 through August 1992 for four of the most heavily applied water-soluble herbicides in the White River Basin. Eight other pesticides were measured in this study (table 7); they were either not detected or they showed the same trends as the ones presented in this section and are not discussed further. The solid lines in figures 8–11 represent concentration or load, and the dashed lines represent streamflow. Non-detected concentration values are plotted at the detection limit, and corresponding loads are calculated from these. MCL's also are shown by dashed lines in figures 8 and 11. Overall, these data show seasonal characteristics similar to those described in the previous section. Concentrations peak during the first major runoff event after herbicide application and decrease to baseline levels by the end of summer. The same observation was made by Goolsby and others (1991a) and Thurman and others (1992) in studies of the Mississippi River Basin and midwestern United States. In the White River, atrazine and alachlor exceed their MCL's (3 and 2 μg/L, respectively) (U.S. Environmental Protection Agency, 1992b) for 1 to 2 months a year during the growing season. The high concentrations observed in the river during this relatively short period of time, however, have the potential to cause problems with drinking-water supplies over the whole year. Most drinking water in the White River Basin comes from surface-water sources. Drinking-water reservoirs may act as environmental sinks (Buser, 1990) that accumulate high concentrations of pesticides present in spring and early-summer runoff. Conventional water treatments do not remove these pesticides (Baker, 1983). Cyanazine and metolachlor have no set MCL's; their USEPA Lifetime Health Advisory guidelines are 10 and 100 μg/L, respectively (U.S. Environmental Protection Agency, 1988a). These levels were not exceeded in any of the samples collected at Hazleton.

Although streamflow does affect water-soluble pesticide levels, the timing of runoff events appears to be the most important factor affecting levels in the White River. The largest runoff event for the period of this study was in April 1992, but relatively low concentrations of pesticides were observed at this time (prior to application).

Table 7. Herbicide concentrations measured near Hazleton, Ind., May 1991–August 1992
[μg/L, micrograms per liter; <, less than]

Herbicide	Median concentration (μg/L)	Maximum concentration (μg/L)	Minimum concentration (μg/L)	Percentage greater than reporting limit
Atrazine	0.69	11	0.17	100
Desethylatrazine	.16	1.1	<.05	98
Metolachlor	.23	4.9	<.05	96
Simazine	.10	.72	<.05	80
Prometon	.06	.20	<.05	58
Alachlor	.05	3.2	<.05	51
Cyanazine	<.20	4.4	<.20	45
Deisopropylatrazine	<.05	.82	<.05	32
Metribuzin	<.05	.40	<.05	31
Propazine	<.05	.07	<.05	5
Ametryn	<.05	.07	<.05	1
Prometryn	<.05	<.05	<.05	0

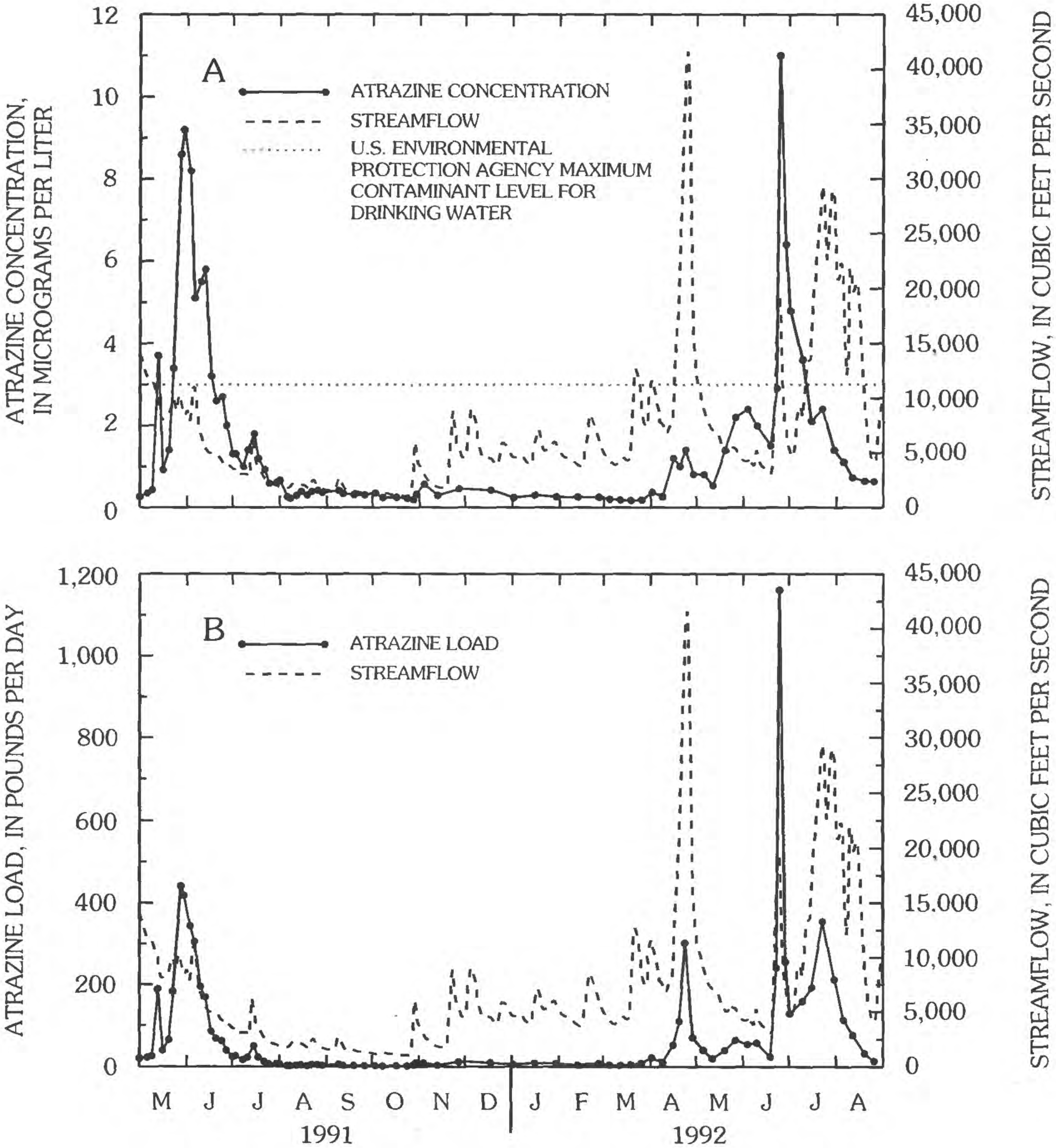


Figure 8. Relation of (A) atrazine concentration, (B) atrazine load, and streamflow to time in the White River near Hazleton, Ind.

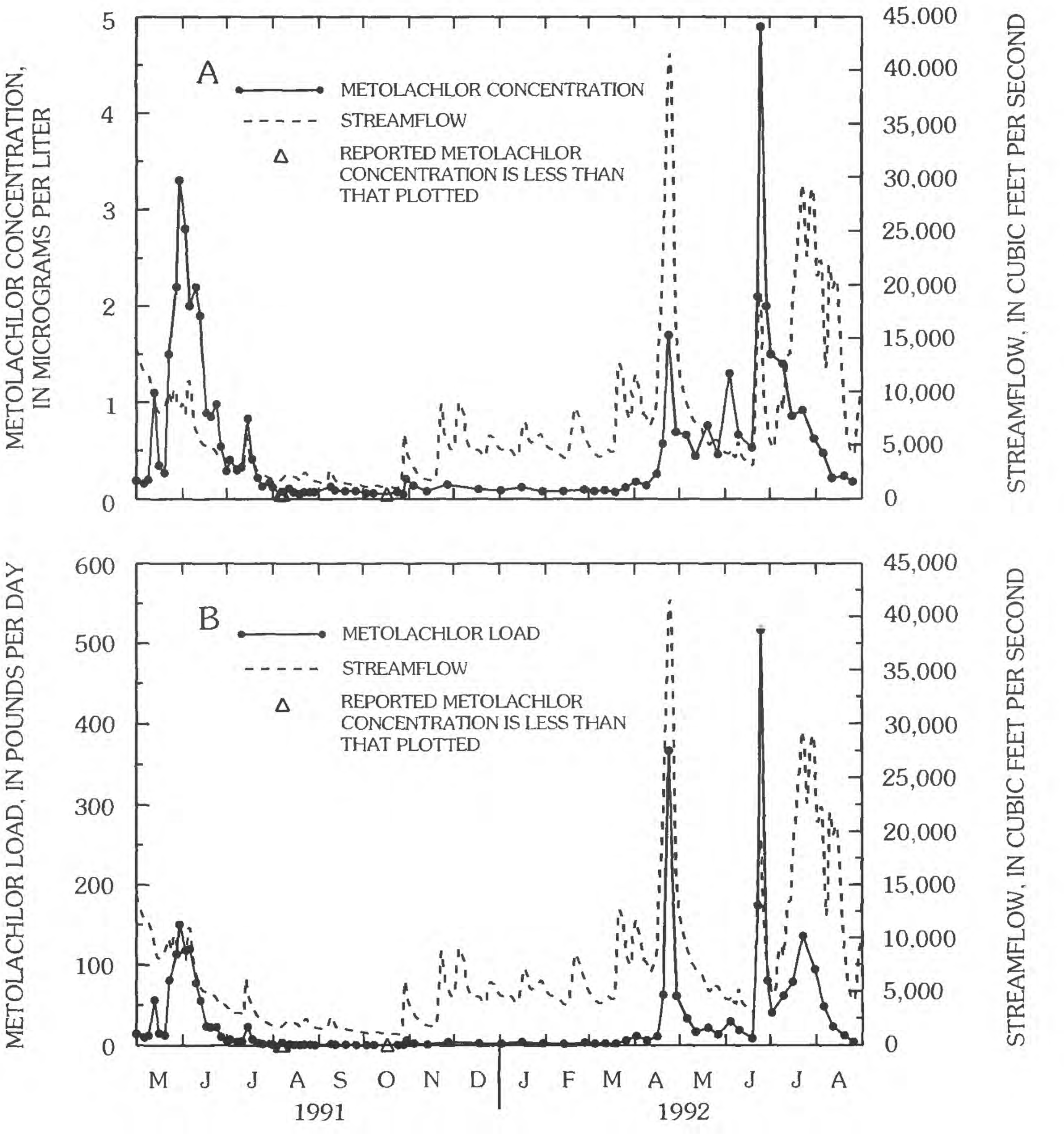


Figure 9. Relation of (A) metolachlor concentration, (B) metolachlor load, and streamflow to time in the White River near Hazleton, Ind. (Δ symbol indicates that the reported value is less than the value plotted.)

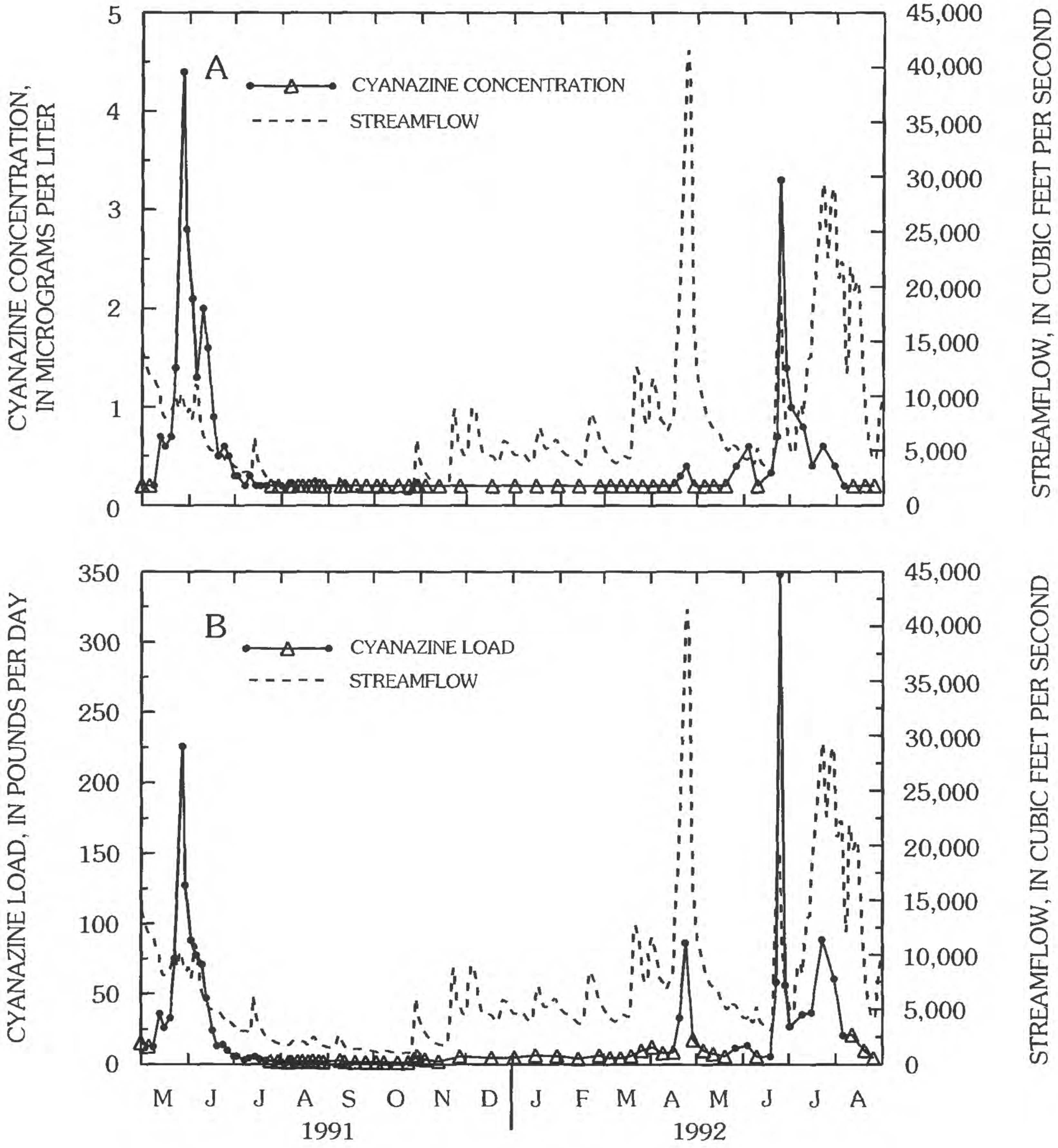


Figure 10. Relation of (A) cyanazine concentration, (B) cyanazine load, and streamflow to time in the White River near Hazleton, Ind. (Δ symbol indicates that the reported value is less than the value plotted.)

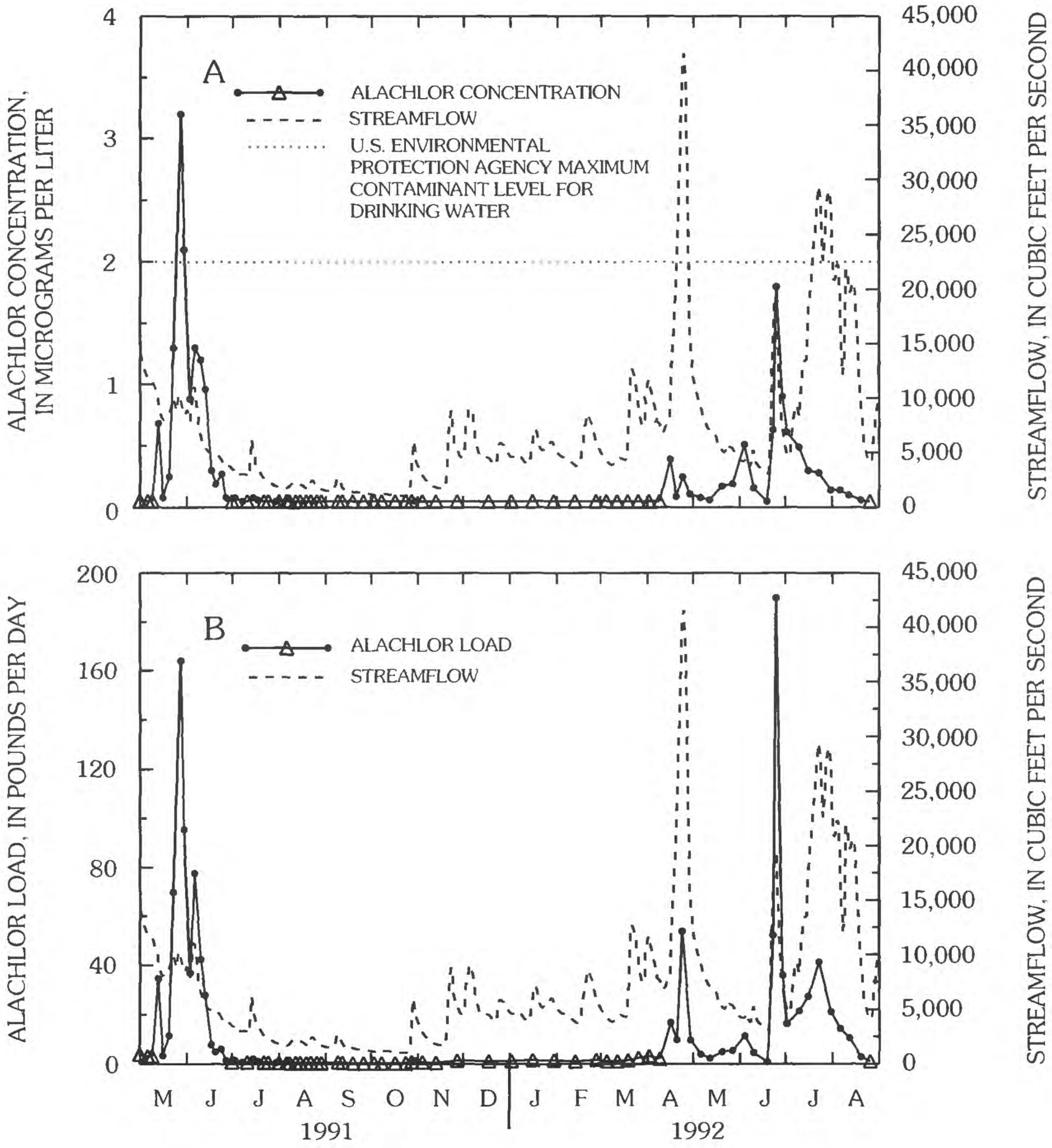


Figure 11. Relation of (A) alachlor concentration, (B) alachlor load, and streamflow to time in the White River near Hazleton, Ind. (Δ symbol indicates that the reported value is less than the value plotted.)

Major runoff events also occurred from the end of July through August 1992 (about 2 months after application), but low levels once again were observed. In contrast, runoff events just after herbicide application (the end of May through the beginning of July 1992) contained high concentrations. These observations imply that the herbicides are more susceptible to runoff soon after application. For about 2 months following herbicide application, concentrations of pesticides in surface water peak temporarily during each storm. The peaks decrease in concentration as the growing season continues. Because the relation of pesticide concentration to flow depends on the timing of individual runoff events (fig. 12), use of a single equation to estimate pesticide loads is inappropriate. This seasonal dependence makes load estimation difficult if pesticide concentration data are sparse or not available. The loads shown in figures 8–11 are instantaneous loads computed from the observed pesticide concentrations and the corresponding flow. These observed loads show the same time and flow dependence as the concentrations in section A of the figures. The loads generally were lower in 1991 than in 1992, presumably because of greater rainfall during 1992.

The estimated daily loads in table 8 were calculated as described in the section on quantitative data-analysis techniques. Atrazine was the most abundant herbicide in the White River with

Table 8. Estimated daily herbicide loads near Hazleton, Ind., May 1991–August 1992
[lb/d, pounds per day; ft^3/s, cubic feet per second; a range is given where the number of undetected observations precluded an exact estimate]

	1991 Growing season (May–August)			
	Mean	Standsrd deviation	Minimum	Maximum
Atrazine load (lb/d)	83	120	2.2	440
Alachlor load (lb/d)	17–18	35	.000– .004	180
Cyanazine load (lb/d)	26–28	46–47	.0 –1.7	250
Metolachlor load (lb/d)	28	41	.00 – .19	160
Metribuzin load (lb/d)	2.3–3.0	3.4–3.7	.00 – .42	14
Simazine load (lb/d)	6.7–6.9	9.1–9.2	.000– .002	35
Average flow (ft^3/s)	5,320	3,520	1,590	14,100
	1992 Growing season (May–August)			
	Mean	**Standard deviation**	**Minimum**	**Maximum**
Atrazine load (lb/d)	130	170	0.004	1,100
Alachlor load (lb/d)	17	27	.00 – .28	190
Cyanazine load (lb/d)	28–32	48–50	.000– .004	340
Metolachlor load (lb/d)	53	73	3.6	510
Metribuzin load (lb/d)	4.6–5.5	5.9–6.4	.00 – .56	40
Simazine load (lb/d)	11	9.1	1.3	44
Average flow (ft^3/s)	11,200	7,640	3,070	29,400
	Nongrowing season (September 1991–April 1992)			
	Mean	**Standard deviation**	**Minimum**	**Maximum**
Atrazine load (lb/d)	17	42	1.1	310
Alachlor load (lb/d)	1.9–2.9	7.5–7.7	.000– .005	58
Cyanazine load (lb/d)	2.2–7.2	11	.0 –1.1	86
Metolachlor load (lb/d)	12	48	.00 – .11	380
Metribuzin load (lb/d)	1.1–2.3	6.1–6.2	.00 – .27	50–51
Simazine load (lb/d)	3.0–3.3	6.1–6.2	.00 – .25	37
Average flow (ft^3/s)	5,780	6,170	1,020	41,600

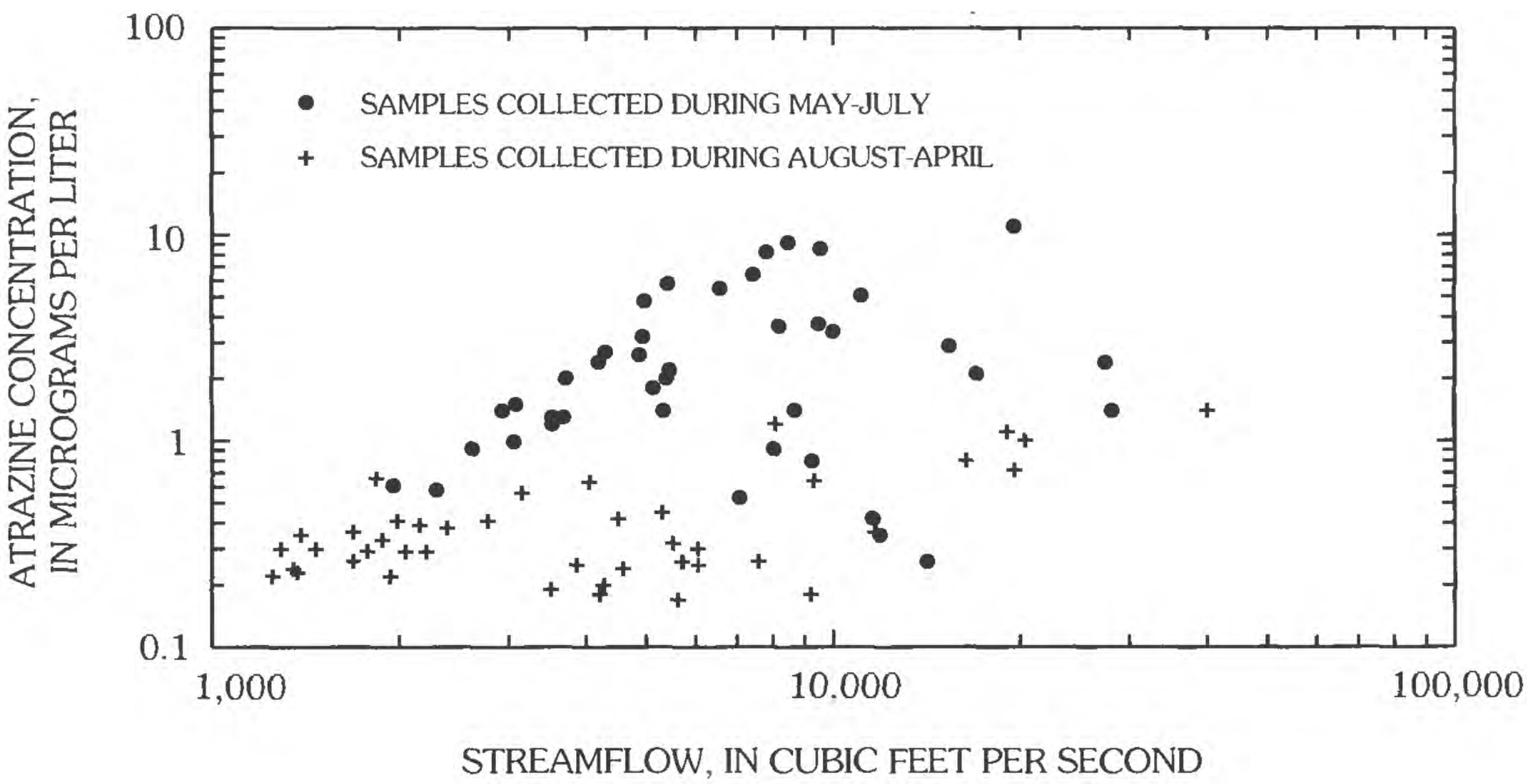


Figure 12. Relations among season, atrazine concentration, and streamflow in the White River near Hazleton, Ind., May 1991-September 1992.

an average daily load of 61 lb/d carried at Hazleton for the period of record (May 1991–August 1992); 26 lb/d of metolachlor, 16 lb/d of cyanazine, and 10 lb/d of alachlor also were transported at Hazleton. The average streamflow near Hazleton for this period was 7,000 ft^3/s, but the long-term average is 11,800 ft^3/s (Stewart and Deiwert, 1992). Thus, the loads listed above probably are lower than average because observed loads are flow dependent, especially during May and June. The 1991 growing season was particularly dry. Most water-soluble herbicide loading to the White River occurs during the growing season. Runoff during this season, especially just following application, contains high concentrations of herbicides, whereas nongrowing-season runoff contains low concentrations. This difference in the relation between concentration and runoff leads to low loadings from November through March, with little dependence on how much runoff occurs during this time. The difference in loads between growing and nongrowing seasons indicates that the herbicides are not as readily available for transport by runoff after they have been in the soil for long periods. Biotic/abiotic degradation, adsorption to soil, volatilization, infiltration to ground water, and uptake by plants are some of the processes that could account for the lack of availability.

The 1991 use of herbicides in the White River Basin is estimated to have been 2,340,000 lb of atrazine; 2,080,000 lb of alachlor; 1,520,000 lb of metolachlor; and 476,000 lb of cyanazine, based on data from the Indiana Agricultural Statistics Service (1992). Loads carried in the White River at Hazleton from May 1991 through April 1992 were 14,000 lb of atrazine; 2,700 lb of alachlor; 6,300 lb of metolachlor; and 4,500 lb of cyanazine. Thus, 0.60 percent of the atrazine, 0.13 percent of the alachlor, 0.41 percent of the metolachlor, and 0.95 percent of the cyanazine that was applied in 1991 entered the White River. In 1991, Indiana had the fourth driest June–August of this century (Gann and Danekas, 1992), so the percentages reported are likely lower than those that would be observed during a year with normal amounts of precipitation during the growing season. Larger percentages of the triazine herbicides (atrazine and cyanazine) were loaded to the river than were the chloroacetamides (alachlor and metolachlor). The triazines generally are less water soluble and more persistent on soil than the chloroacetamides (Sine, 1992; Verschueren, 1983). This longer residence time on soil means that more of the triazines are available for runoff (as the parent compounds) throughout the growing season. Other factors, such as farming practices, herbicide formulations used, and method of application, probably also affect the amount of herbicide runoff.

The atrazine metabolites desethylatrazine and deisopropylatrazine also are present in the White River near Hazleton (fig. 13). These metabolites are generated through the microbial decomposition of atrazine. Because straight-chain alkyl groups are more susceptible to microbial attack than branched groups (Swisher, 1982), desethylatrazine is the more abundant biotic decomposition product. High relative concentrations of the metabolites were sustained longer into the growing season than those of atrazine (July–August 1992 data in figs. 8 and 13); the metabolites run off for a longer time into the growing season, possibly because the metabolites take time to form and, thus, are present in relatively higher concentrations late in summer and (or) possibly because the metabolites are more persistent or less mobile than the parent compound.

Examination of the ratio of desethylatrazine to atrazine over the period of record (fig. 14) shows two trends: the metabolite-to-parent ratio is lower during the first half of the growing season than the rest of the year, and the ratio generally is high prior to the growing season but is lowered slightly by runoff events occurring during this time. The first trend is easily explained by the application of atrazine during the first part of the growing season. The residual atrazine from the previous year's application has had a chance to degrade, so its desethylatrazine/atrazine ratio is relatively high; but around May additional atrazine is applied during crop planting. This newly applied atrazine has a very low desethylatrazine/atrazine ratio and drives down the observed ratio in surface water.

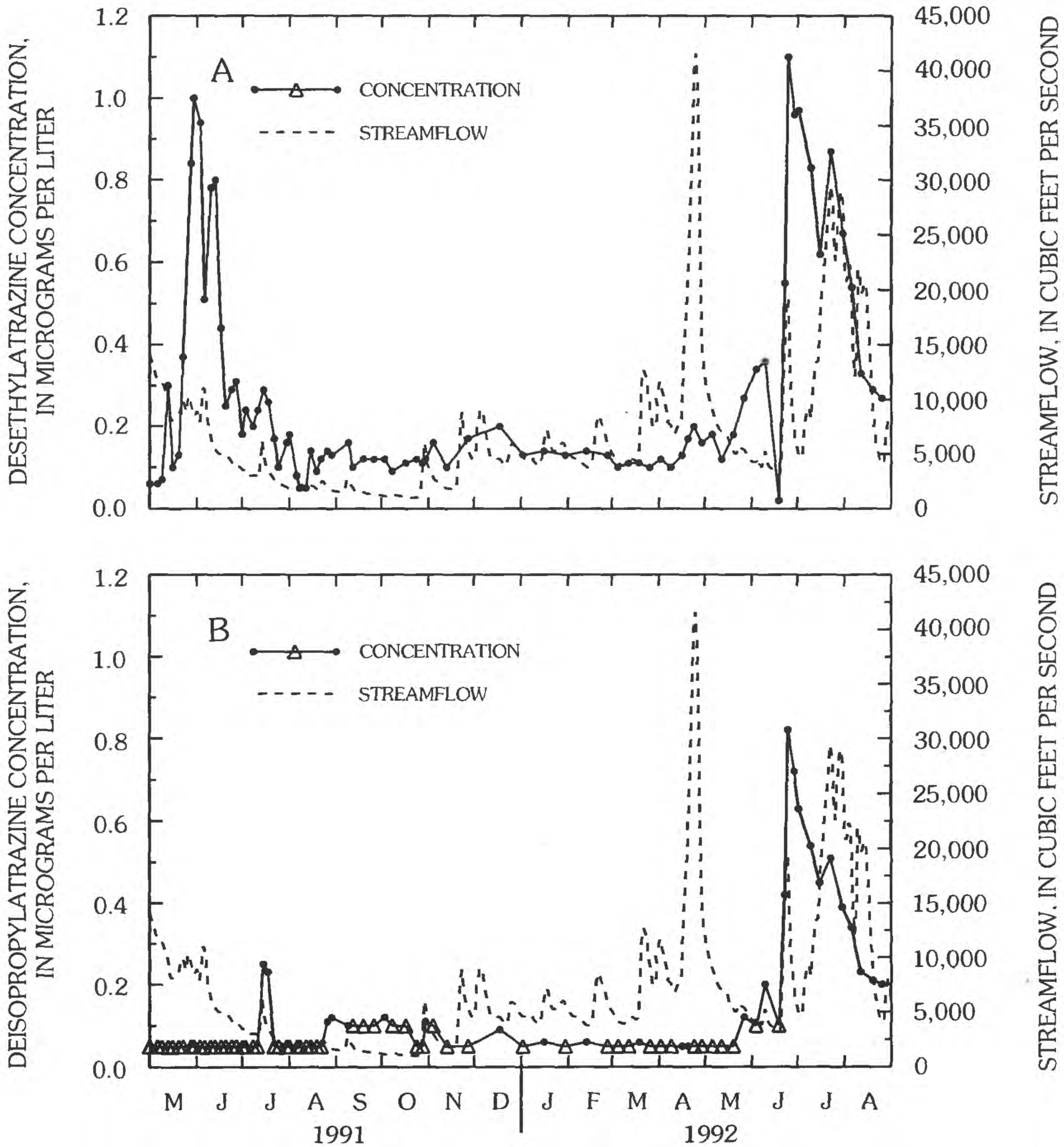


Figure 13. Relation of (A) desethylatrazine concentration, (B) deisopropylatrazine concentration and streamflow to time in the White River near Hazleton, Ind. (Δ symbol indicates that the reported value is less than the value plotted.)

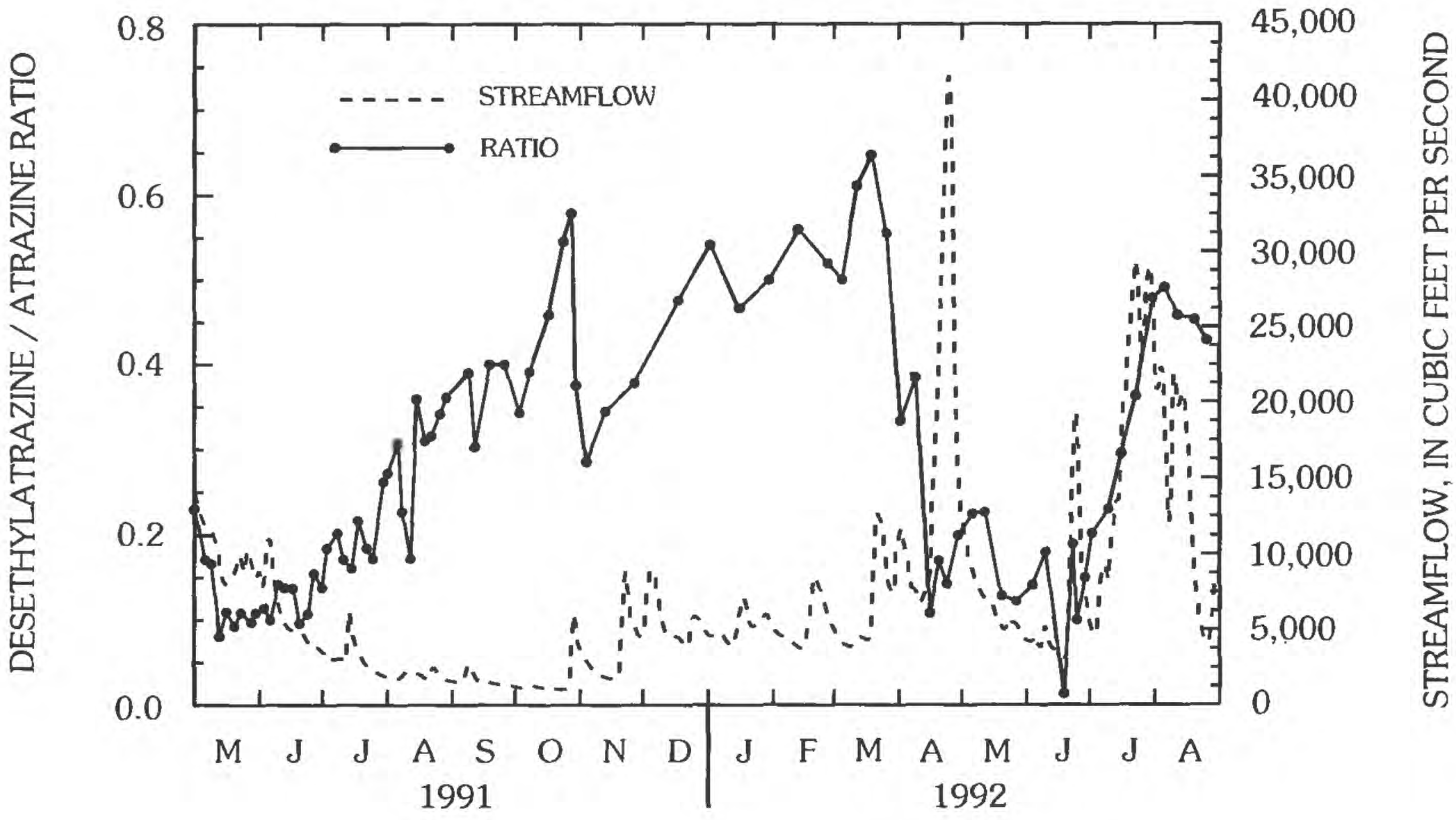


Figure 14. Ratios of desethylatrazine to atrazine concentration in the White River near Hazleton, Ind.

The second trend is less clear, but it probably is caused by the difference in desethylatrazine/atrazine ratios present in runoff and ground water (Thurman and others, 1992). Desethylatrazine/atrazine ratios in ground water typically are high (usually >1), whereas ratios in runoff are much lower. The increased desethylatrazine/atrazine ratios observed during low-flow conditions prior to herbicide application may be attributable to recharge by contaminated ground water with a high desethylatrazine/atrazine ratio (Thurman and others, 1992). The increased ratio observed prior to herbicide application also may be attributable to *in situ* decomposition of atrazine on soil. If the atrazine is decomposing over time, then soil ratios of desethylatrazine/atrazine would be expected to increase with time, provided that the desethylatrazine is stable; this change in ratio may be reflected in the surface-water concentrations. This hypothesis is supported by the relatively high desethylatrazine/atrazine ratios observed during high flows in July and August 1992. If ground-water discharge were the only factor affecting desethylatrazine/atrazine ratios in surface waters, then the ratio observed during this time should have been lower to reflect the high part of the surface water attributable to overland runoff. The high desethylatrazine/atrazine ratio observed during this period implies that the runoff had a high desethylatrazine/atrazine ratio at this time of year. Although additional data collection and analysis is required to fully address observed trends, a combination of ground-water discharge and *in situ* decomposition effects best accounts for the ratios shown in figure 14.

Organochlorine Pesticides in Large Streams

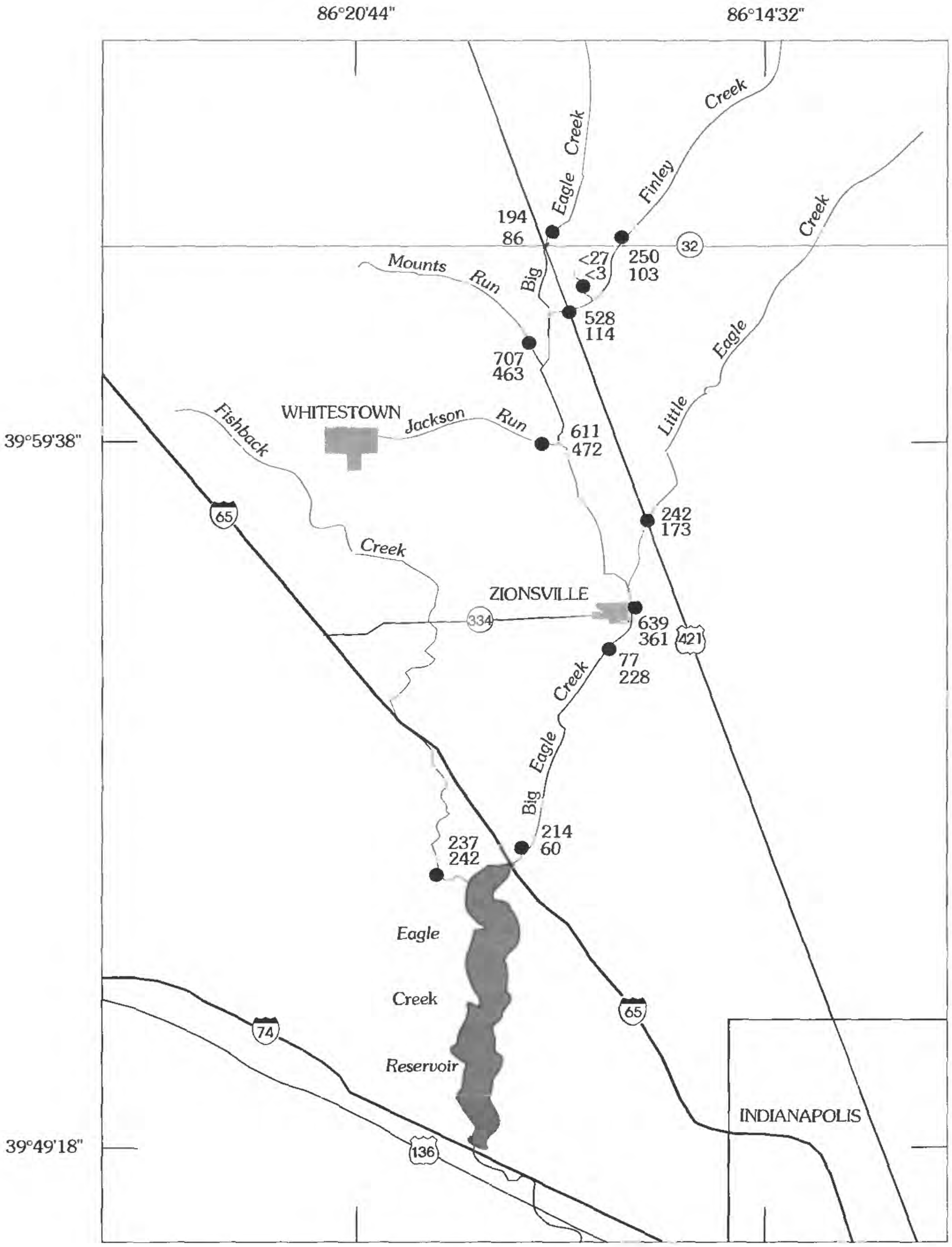
Twelve surface-water sites throughout the White River Basin (fig. 3) were sampled quarterly by the IDEM from March 1989 through December 1990 for 16 chlorinated pesticides. These pesticides are all lipophilic and have been out of use since the mid-1970's—but they still are ubiquitous environmental contaminants. As discussed in the section on the solubility properties of pesticides, lipophilic compounds have a low solubility in water. Thus, lipophilic pesticides present in natural waters may be expected to be associated with the solid or dissolved organic matter in the water. Grab samples of whole water were collected from the center of flow and were analyzed by standard USEPA methods (Indiana Department of Environmental Management, 1986). Detection limits ranged from 0.01 to 2.0 µg/L. Because of the physical properties of lipophilic compounds, it is unlikely that they would be present in these samples at concentrations much higher than the detection limits used in this study unless the samples contained high concentrations of dissolved or suspended organic carbon. Lipophilic pesticides were detected in a relatively small percentage of the samples collected (19 percent), and most concentrations were just above detection limits. Aldrin, alpha-BHC, and heptachlor epoxide were the most frequently detected compounds. The USEPA drinking-water guidelines (Maximum Contaminant Level, Drinking-Water Equivalent Level, Lifetime Level) (U.S. Environmental Protection Agency, 1988a; U.S. Environmental Protection Agency, 1992b) and Water-Quality Criteria Maximum Concentrations for the protection of fresh-water organisms (U.S. Environmental Protection Agency, 1990) for the three pesticides were not exceeded except for heptachlor epoxide which was found at a concentration of 0.4 µg/L, twice the MCL for drinking water, at two sites—the White River at Perkinsville and the White River at Yorktown. Half the samples with lipophilic pesticide detections were collected from September 11–14, 1989, during a storm following a dry period. It is likely that the elevated concentrations observed during this period resulted from increased soil erosion or resuspension of contaminated bottom sediments. It appears that concentrations of lipophilic pesticides in water may be related indirectly to streamflow and the intensity of storm events because these factors affect the amount of bottom-sediment resuspension and soil erosion.

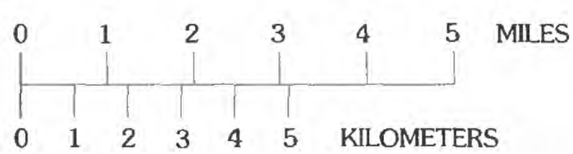
Pesticide Concentrations in Surface Waters and Bottom Sediments in the Eagle Creek Watershed

Bottom-sediment samples sieved to <63 µm particle size were collected during August 1980 at 11 sites along Eagle Creek and its tributaries (fig. 15), upstream from Eagle Creek Reservoir which supplies some of the drinking water for the city of Indianapolis. Three of the 11 sites were resampled in October 1982 for bed sediments and surface water, and surface water was again resampled at the three sites in December 1982 and April 1983. Bed sediment was collected at several sediment-deposition areas at each site and analyzed for particle size and organic-carbon content after sieving to <63 µm particle size. Surface-water samples were unfiltered. Suspended-sediment concentration was measured in the water samples. All bottom-sediment and water samples were analyzed for 26 pesticides, including organo-chlorine insecticides, organo-phosphorus insecticides, and chlorinated-phenoxy acid herbicides (Wangsness, 1983). The bottom sediment contained elevated concentrations of chlordane and dieldrin as well as measurable concentrations of DDT and its degradation products. Diazinon also was detected at 2 of the 11 sediment sampling sites. The three sediment sites resampled 2 years later contained concentrations of chlordane and dieldrin similar to those of the original samples (average log-percent difference of 37 percent); concentrations of DDT and related compounds were more variable (average log-percent difference of 184 percent). It is not known whether the variability is related to heterogeneous contaminant distribution in the sediment or to lessened analytical precision close to the detection limit.

Chlordane, dieldrin, and DDT are lipophilic chlorinated insecticides. Because of their toxicity, environmental persistence, and tendency to bio-accumulate, these compounds have been out of general use in the United States since the 1970's. Chlordane use has been severely restricted since 1978 and is now banned, and DDT and dieldrin were banned in 1972 and 1975, respectively (Manahan, 1991). Although no longer in use, these compounds still are present in aquatic systems. Lipophilic contaminants are readily adsorbed into the organic material associated with sediments where they can remain for decades. High concentrations of chlordane and dieldrin were present in bottom sediments throughout the Eagle Creek watershed (fig. 15). These results are for the <63 µm fraction of the bed sediments only; this fraction comprised less than 1 percent by weight in 10 of 11 samples. Thus, the values reported here may not accurately represent the degree of native sediment contamination. The <63 µm sediment samples at several sites exceeded the USEPA Sediment Quality Criterion of 309 µg/kg sediment-organic carbon for chlordane in bottom sediments. The criteria of 828 and 9,000 µg/kg sediment-organic carbon for DDT and dieldrin, respectively (U.S. Environmental Protection Agency, 1992a), were not exceeded, but significant concentrations of the compounds were detected. This is of some concern because water flowing over and through these sediments is the source of drinking water for much of Indianapolis.

The spatial distribution of sediment-bound chlordane and dieldrin on <63 µm particles is shown in figure 15. The concentrations reported are adjusted to the organic-carbon content of the <63 µm sediments by dividing the contaminant concentration in dry sediment by the organic-carbon content of the sediment. The organic-carbon contents of the <63 µm sediments ranged from 3.3 to 4.2 percent. Lipophilic compounds preferentially adsorb to sediments with high organic-carbon contents. To eliminate the effect of differing organic-carbon levels on contaminant concentrations and to allow contaminant levels on sediments of differing organic content to be compared directly, adjustment to organic carbon is done. The highest concentrations were found near the mouths of the northern tributaries to Big Eagle Creek. Chlordane and dieldrin concentrations have a statistically significant correlation at the 11 sites investigated in this study (Kendall's correlation coefficient = 0.53, probability level = 0.024).





EXPLANATION

242
173 SAMPLING SITE--Top number is chlordane concentration. Bottom number is dieldrin concentration in micrograms per kilogram of organic carbon.

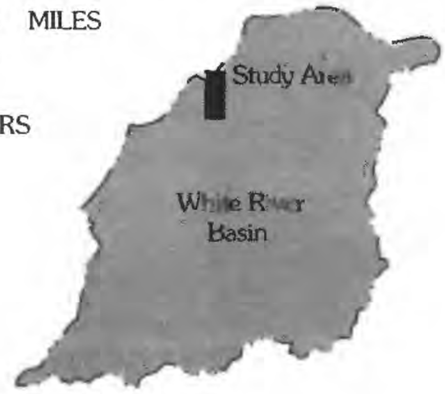


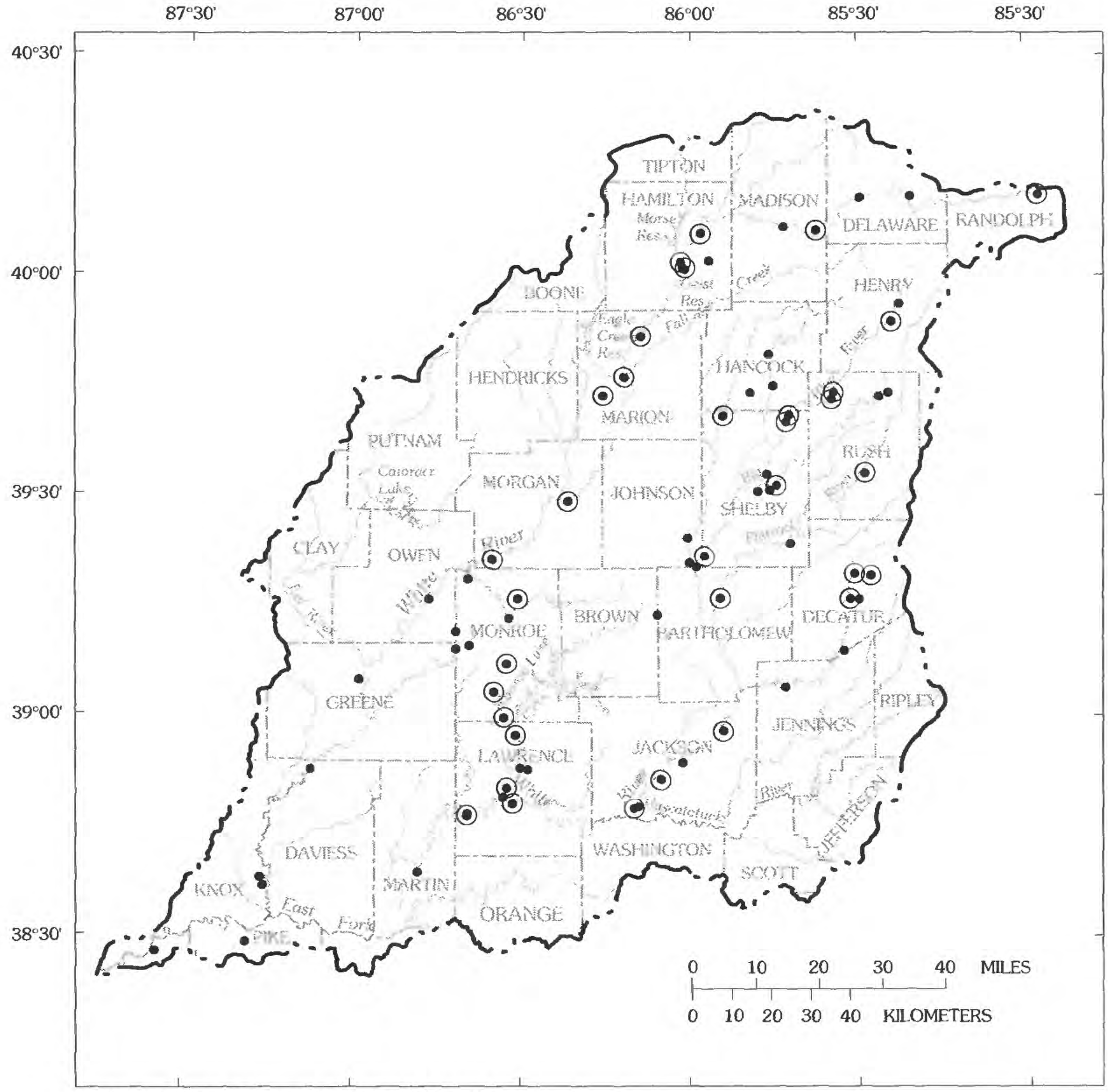
Figure 15. Organic carbon adjusted chlordane and dieldrin concentrations in less than 63 micron particle-size sediments upstream from Eagle Creek Reservoir, Ind., 1980.

This correlation is an indication that the compounds may be derived from similar sources. It is unlikely that Jackson Run, Mounts Run, and Finley Creek all have similar point sources of chlordane and dieldrin upstream from the sampling sites. These compounds probably occur in the study area from nonpoint sources related to their former use as contact insecticides. It is not known why the tributaries tend to have higher concentrations of chlordane and dieldrin than the rest of the study area. The high pesticide concentrations may be related to higher erosion rates or bank slump along the tributaries, but data on these are unavailable. The bottom materials at the tributaries are composed primarily of sand and gravel; thus, the tributaries do not appear to be in regions of fine-grained-sediment deposition, and one would not expect them to preferentially accumulate sediment-bound contaminants from upstream sources.

Surface water was sampled at Finley Creek sites and the Big Eagle Creek site (fig. 15) just upstream from the reservoir during low flow in October 1982 and during high flow in December 1982 and April 1983. Chlordane and dieldrin were not detected in any of the water samples, probably because the detection limits were too high to determine a possible relation between sediment and water concentrations with flow. The surface-water monitoring and Eagle Creek studies indicate that the concentrations of lipophilic pesticides in surface waters generally are below method detection limits. More sensitive analytical methods are needed to examine the occurrence of lipophilic pesticides in water and the relations among pesticide concentrations, sediment, and streamflow.

Pesticide Concentrations in Bottom Sediments and Fish

The IDEM collected 104 bottom-sediment samples at 84 stream sites throughout the White River Basin from August 1983 through October 1989 (Indiana Department of Environmental Management, Office of Water Management, unpub. data, 1993). Sediment grab samples were collected at several areas within a stream site and composited; sediment depositional areas were selected. Unsieved native sediments were analyzed for 29 lipophilic pesticides using standard USEPA methods (U.S. Environmental Protection Agency, 1982). All sampling locations and sites where at least one pesticide was detected are shown in figure 16. Many of the samples were collected in regions of known or suspected contamination; thus, the results shown in figure 16 might not be representative of the White River Basin as a whole. Several areas of concern in the basin are the upstream part of the main fork of the White River between Noblesville and Martinsville, the upstream part of the Big Blue River, the Clear Creek area near Lake Monroe, and Sand Creek near Greensburg. These areas consistently had lipophilic pesticides detected in bottom sediments. The most frequently detected pesticides were dieldrin, components of technical chlordane, and DDT-related compounds. The East Fork White River at Rockford and Sand Creek downstream from Greensburg had the highest observed dieldrin concentrations (18 and 0.6 mg/kg, respectively). Salt Creek had the highest trans-nonachlor and oxychlordane concentrations (0.12 and 0.23 mg/kg, respectively). Stoney Creek at Noblesville had the highest concentrations of o,p′-DDD and o,p′-DDE (0.74 and 0.94 mg/kg, respectively). Caution must be used when quantitatively comparing concentrations between sites in this study because the reported concentrations in sediment are not adjusted for sediment particle size or organic-carbon content. Lipophilic contaminants adsorb to the organic coating on sediment particles. In general, the smaller the sediment particle size, the larger the surface area, and thus the higher the organic-carbon content. Because the lipophilic contaminants only interact with the organic coating, organic-rich sediments with small particle size can accumulate higher concentrations of lipophilic contaminants (on a weight contaminant to weight sediment basis) than can organic-poor sediments with comparatively large particle size. Thus, differences in observed concentration could be due to differences in the organic-carbon content and particle size of the sediments. Failure



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Albers Equal Area projection
Standard parallels 29°30" and 45°30", central meridian -86°

EXPLANATION

SAMPLING SITES

- White River Basin boundary
- County boundary
- Stream sampling site
- Stream sampling site where pesticides were detected

Figure 16. Stream-sediment sampling sites and locations in the White River Basin, Ind., where pesticides were detected, 1983-90.

to adjust the particle size and organic-carbon content will tend to cause potential problems to be underestimated because pesticides may be present but not detected if large particle-size or low organic-carbon-content sediments were collected. This may be what is occurring in the downstream part of the main fork of the White River. Pesticides were not detected in sediments in this area, but it is not known whether this is due to the low mobility of contaminated upstream sediments, dilution of the sediment-bound pesticides by clean sediments, differences in the particle size and organic-carbon content of sediments in the two parts of the river, or some combination of these causes.

Most pesticide data on fish tissue and whole-fish samples for the White River Basin pertain to organochlorine pesticides. These pesticides have been in use since the 1940's and include compounds such as aldrin, chlordane, dieldrin, DDT, and endrin. Chemical properties of these compounds (high toxicity, chemical stability, low volatility, high lipid solubility, and slow rate of degradation) make them effective pesticides but also make them dangerous to accidentally exposed organisms. These pesticides bioaccumulate in organisms and tend to biomagnify through food chains, as described in the "Solubility Properties of Pesticides" section of this report (Metcalf and others, 1973; Veith and others, 1980). Organochlorine pesticides can cause acute—as well as chronic—health problems in living organisms. These pesticides act as neurotoxicants. Symptoms of acute exposure to these pesticides in mammals—including humans—are headaches, vomiting, hyperactivity, tremors, and psychological disorders (Amdur and others, 1991). In addition, reproduction of fish is adversely affected by the bioaccumulation of these pesticides in the yolk sac of the fry. Other effects of these pesticides on fish include hyperactivity as well as periodic sequences of persistent tremoring (Amdur and others, 1991). The synergistic effects of chronic exposure to low levels of many different pesticides is not well understood.

To assess the hazard of a particular pesticide in the environment, one may compare the concentrations found in the environmental component of interest—for example, fishes—to a threshold value. Commonly cited guidelines and standards are available for pesticide concentrations in edible fish tissue (U.S. Food and Drug Administration [USFDA] Action Levels and USEPA Tolerance Limits) (U.S. Food and Drug Administration, 1990; U.S. Environmental Protection Agency, 1990) and for whole fish (National Academy of Sciences [NAS] Recommended Maximum Tissue Concentrations) (National Academy of Sciences, 1972). These guidelines/standards have been developed to protect biota and human health. The USFDA Action Levels and USEPA Tolerance Limits are appropriate for use with the data described in this report. USFDA Action Levels are enforceable limits at which the USFDA can take legal action to remove fish from the market if pesticide residues greater than the defined limits are found in the tissue. The Action Levels are the most commonly used guidelines/standards for edible fish tissue and were applied to fish fillets as well as whole fish. USEPA Tolerance Limits are only available for selected currently used pesticides and do not include any of the organochlorine pesticides; therefore, these limits were not useful in the context of this report. The only national guidelines that apply directly to whole fish are the preliminary recommendations made by the NAS, which are intended to protect fish-eating birds and mammals. The NAS guidelines are used exclusively for whole-fish samples. A listing of USFDA Action Levels as well as NAS Recommended Maximum Tissue Concentrations for organo-chlorine pesticides discussed in this report are presented in table 9.

As previously discussed, the IDEM collected fish tissue and whole-fish samples for organochlorine-pesticide analysis from 80 stream sites within the White River Basin from 1983–90.

Table 9. U.S. Food and Drug Administration Action Levels and National Academy of Sciences Recommended Maximum Tissue Concentrations for selected pesticides in edible fish tissue and whole-fish samples
[USFDA, U.S. Food and Drug Administration; NAS, National Academy of Sciences; mg/kg, milligram per kilogram; --, information not available]

Pesticide	USFDA Action Level[1] (mg/kg)	NAS Recommended Maximum Tissue Concentration[2] (mg/kg)
Aldrin	[3]0.3	0.1
α-BHC	[4] .3	.1
b-BHC	[4] .3	.1
g-BHC (Lindane)	[4] .3	.1
cis/trans-Chlordane	[5] .3	.1
cis/trans-Nonachlor	[5] .3	.1
DDT	[6]5.0	1.0
DDE	[6]5.0	1.0
DDD	[6]5.0	1.0
Dieldrin	[3] .3	.1
Endosulfan I and II	--	.1
Endrin	.3	.1
Heptachlor	[7] .3	.1
Heptachlor epoxide	[7] .3	.1

[1]USFDA Action Levels apply to edible fish tissue unless otherwise specified (U.S. Food and Drug Administration, 1990).

[2]NAS Recommended Maximum Tissue Concentrations apply to whole-fish samples (National Academy of Sciences, 1972).

[3]USFDA Action Level is for aldrin plus dieldrin.

[4]USFDA Action Level applies to frog legs.

[5]USFDA Action Level is for cis/trans-chlordane plus cis/trans-nonachlor.

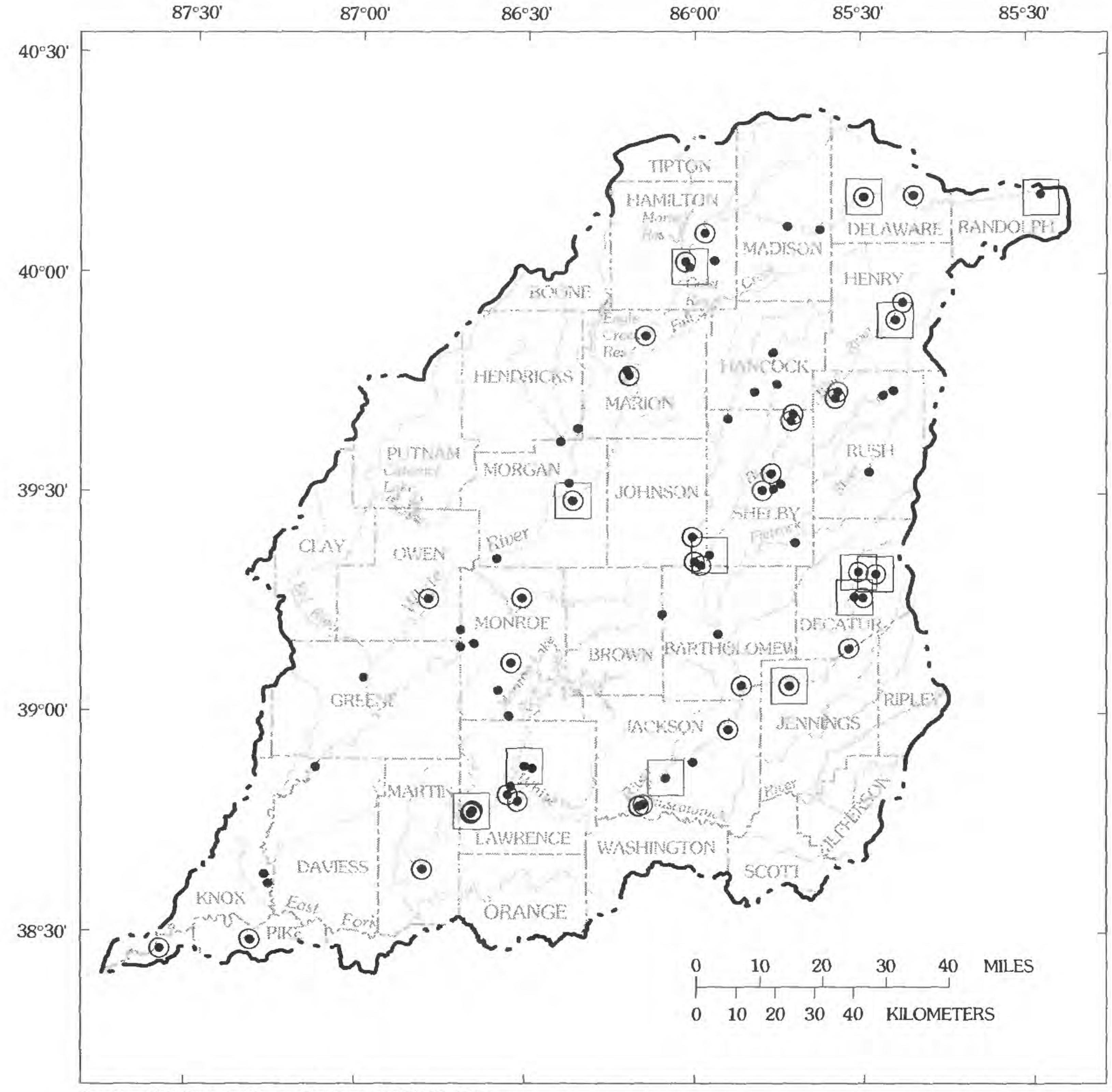
[6]USFDA Action Level is for DDT plus DDE plus DDD.

[7]USFDA Action Level is for heptachlor plus heptachlor epoxide.

Many of the sites chosen were in regions of known or suspected contamination and may not accurately represent typical pesticide concentrations in fish in the White River Basin. Most of these data are for whole-fish samples (189 observations or 73 percent), whereas the remaining data are for fillets (70 observations or 27 percent). Fish used in the IDEM study were caught with electrofishing techniques. A total of 26 species of fish was collected, and the pesticide-residue levels in the fish were measured by the use of a standard method (U.S. Department of Health, Education and Welfare, 1982). A map of the sampling sites, showing stream sites where pesticide concentrations in whole fish or fish tissue exceeded USFDA Action Levels or NAS Recommended Maximum Tissue Concentrations, is presented in figure 17.

A limited number of sites have been sampled by the IDEM to examine temporal trends in pesticide residues in fish fillets. Of these limited number of sites (31 sites), concentrations of pesticide residues exceeding the USFDA Action Levels were found in only two fish fillets. These fillets were from carp at Stoney Creek south of Noblesville and from the main fork of the White River downstream from Muncie; the fillets contained elevated concentrations of trans-chlordane (0.400 mg/kg) and trans-nonachlor, (0.408 mg/kg), respectively. The USFDA Action Level for these compounds is 0.300 mg/kg. The IDEM set fish-consumption advisories for both of these stream reaches soon after the fish tissues were analyzed in 1987.

In most cases, however, fish-consumption advisories in Indiana are not based on concentration of contaminants in fish fillets but in whole fish (Indiana Department of Environmental Management, 1990). The USFDA Action Levels were designed for edible fish tissue only but, if the action level is exceeded in a whole-fish sample, further analysis of edible fish tissue may be warranted. The IDEM uses a conservative approach and issues consumption advisories based on whole fish or fillets. A listing of current fish-consumption advisories for pesticides in fish collected from rivers and streams in the White River Basin is presented in table 10. These fish-consumption advisories were issued in 1987 and 1988 and are applicable as of June 12, 1992 (L. Bridges, Indiana Department of Environmental Management, oral commun., 1993). Two sites with fish-consumption advisories are on the East Fork White River or its tributaries, whereas the three remaining sites are on the main fork of the White River or its tributaries. The scope of the advisories ranges from limiting fish consumption to no more than 1 meal (1/2 lb) per week to a total ban on consuming fish collected from these areas.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Albers Equal Area projection
Standard parallels 29°30" and 45°30", central meridian -86°

EXPLANATION

SAMPLING SITES

- White River Basin boundary
- County boundary
- Stream sampling site
- Stream sampling site where pesticide concentrations exceed NAS guidelines
- Stream sampling site where pesticide concentrations exceed USFDA action level

Figure 17. Fish sampling sites and locations in the White River Basin, Ind., where pesticide concentrations exceed National Academy of Sciences (NAS) guidelines and U.S. Food and Drug Administration (USFDA) Action Levels.

Table 10. Fish-consumption advisories for the rivers and streams of the White River Basin, Ind.[1]
[lb, pound; D/S, downstream]

River or stream	Year issued	Pesticide of concern	Fish species	Scope of advisory
East Fork White River below Williams Dam in Lawrence County	1987	Chlordane	Catfish and carp	No more than 1 meal (1/2 lb) per week
White River in Delaware County	1988	Chlordane	Carp	No carp should be eaten
White River from Noblesville D/S to the Hamilton/Marion County line	1988	Chlordane	All	No more than 1 meal (1/2 lb) per week
Stoney Creek D/S from Wilson Ditch south of Noblesville	1988	Chlordane	All	Do not consume fish from these areas
Sand Creek and Muddy Fork of Sand Creek near Greensburg	1987	Chlordane	All and dieldrin	No more than 1 meal (1/2 lb) per week

[1]These data are applicable as of June 12, 1992 (Lee Bridges, Indiana Department of Environmental Management, oral commun., 1993).

Chlordane was included in each of the fish-consumption advisories, whereas dieldrin was included only at Sand Creek and Muddy Fork Sand Creek. Since the time that these fish-consumption advisories were issued, chlordane and dieldrin concentrations appear to be declining (Indiana Department of Environmental Management, 1990). For example, no fish samples that have pesticide concentrations exceeding the USFDA Action Levels have been collected since 1988. The fish-consumption advisories, however, are still in effect in those areas of concern.

All of the pesticides of concern that have exceeded USFDA Action Levels or NAS Recommended Maximum Tissue Concentrations at least once during the IDEM's collection period from 1983–90 are presented in table 11. The compounds cis- and trans-chlordane, trans-nonachlor and dieldrin were found to exceed USFDA Action Levels at 5 to 13 percent of the sites, whereas the same compounds exceeded the NAS Recommended Maximum Tissue Concentrations at 30 to 59 percent of the sites. NAS Recommended Maximum Tissue Concentrations for these compounds are three times lower than the USFDA Action Levels and, therefore, are more conservative. The NAS Recommended Maximum Tissue Concentrations, however, are not legally enforceable. Certain species of fish accumulated organochlorine pesticides to levels that exceeded USFDA Action Levels. Bottom-feeding fish like carp, river carpsuckers, black redhorse, yellow bullhead, black bullhead, channel catfish, white sucker, and northern hogsucker were predominant on the list, whereas two predator species (largemouth bass and green sunfish) also were included in this group.

Overall, cis- and trans-chlordane and dieldrin are the organochlorine pesticides that have caused the most problems within the White River Basin with respect to bioaccumulation in fish tissue. The persistent nature of these pesticides makes them bioavailable to aquatic biota for very long periods. There is, however, some indication that the concentrations of these pesticides in the environment are declining. During their sampling from 1979–84, the IDEM found fish that contained these pesticides at levels exceeding the USFDA Action Levels at 14 stream sites within the basin. This number dropped to five sites during sampling that occurred from 1985–86, and three sites during 1987–89. Chlordane and dieldrin have been banned from general agricultural use since 1978 and 1975, respectively (Manahan, 1991).

Table 11. Pesticides of concern and percentage exceedances of U.S. Food and Drug Administration Action Levels and National Academy of Sciences Recommended Maximum Tissue Concentrations for whole fish from the White River Basin, Ind., 1983–90

[USFDA, U.S. Food and Drug Administration; NAS, National Academy of Sciences]

Pesticide of concern[1]	Total number of sampling sites	Number exceeding USFDA levels[2]	Percent exceedance	Number exceeding NAS levels[3]	Percent exceedance
Aldrin	80	2	1	0	0
β-BHC	80	0	0	2	1
cis-Chlordane	80	4	5	28	35
trans-Chlordane	80	7	9	24	30
cis-Nonachlor	80	0	0	3	4
trans-Nonachlor	80	10	13	47	59
Oxychlordane	80	1	1	0	0
Dieldrin	80	8	10	38	48
DDT	80	0	0	1	1
Heptachlor	80	2	1	0	0
Heptachlor epoxide	80	1	1	3	4

[1]Those pesticides that have exceeded USFDA and (or) NAS levels at least once during the collection period.
[2]USFDA Action Levels apply to edible fish tissue.
[3]NAS Recommended Maximum Tissue Concentrations apply to whole-fish samples.

Comparing figures 16 and 17, it is clear that areas with sediment contamination also tend to have fish with elevated levels of lipophilic pesticides and, conversely, areas that contain fish with elevated levels tend to have contaminated sediments. This covariance is expected because contaminated bottom sediments are a major source of contaminants to fish and other aquatic organisms. Fish commonly are used as biological indicators of sediment pollution because they accumulate and concentrate lipophilic contaminants. Bottom-feeding fish may be particularly good indicators because they tend to be relatively nonmigratory and interact directly with contaminated sediments rather than accumulating the contaminants through the food chain. Bottom-feeding fish can tolerate low dissolved oxygen concentrations; this tolerance may bring them into close contact with contaminated areas.

Only 3 of the 13 sites where USFDA Action Levels for edible fish tissues were exceeded were at locations where no lipophilic pesticides were found in the bulk sediments. The bottom-dwelling fish (carp and bullhead) sampled at these three sites obviously were exposed to lipophilic pesticides at some point in their lives. These fish may have moved from nearby areas where sediments are contaminated to the locations where they were caught. Concentrations of lipophilic contaminants in fish, such as carp and bullhead, have been shown to track local sediment contamination, but the spatial resolution of contamination achievable with these organisms is on the order of a few miles (Shiraishi and others, 1989; Black and others, 1981).

The White River Basin generally appears to have moderate concentrations (below USEPA and USFDA limits) of lipophilic pesticides in bottom sediments and fish. There are, however, several localized areas of serious contamination where USFDA Action Levels or NAS guidelines are exceeded. These areas include Pleasant Run Creek near Bedford, Muddy Fork Sand Creek, Clear Creek near Lake Monroe, Stoney Creek downstream from Noblesville, and sections of the Big Blue River and main fork of the White River (fig. 17). These areas are suspected of being contaminated by point sources such as sewage-treatment plants, landfills, and various industries within the basin (Indiana Department of Environmental Management, 1990). It is not known whether other unsampled locations in the White River Basin are contaminated. Although this data set covers a wide variety of conditions, many potential point sources and significant sections of the basin, such as the Muscatatuck and Eel Rivers, have not been investigated.

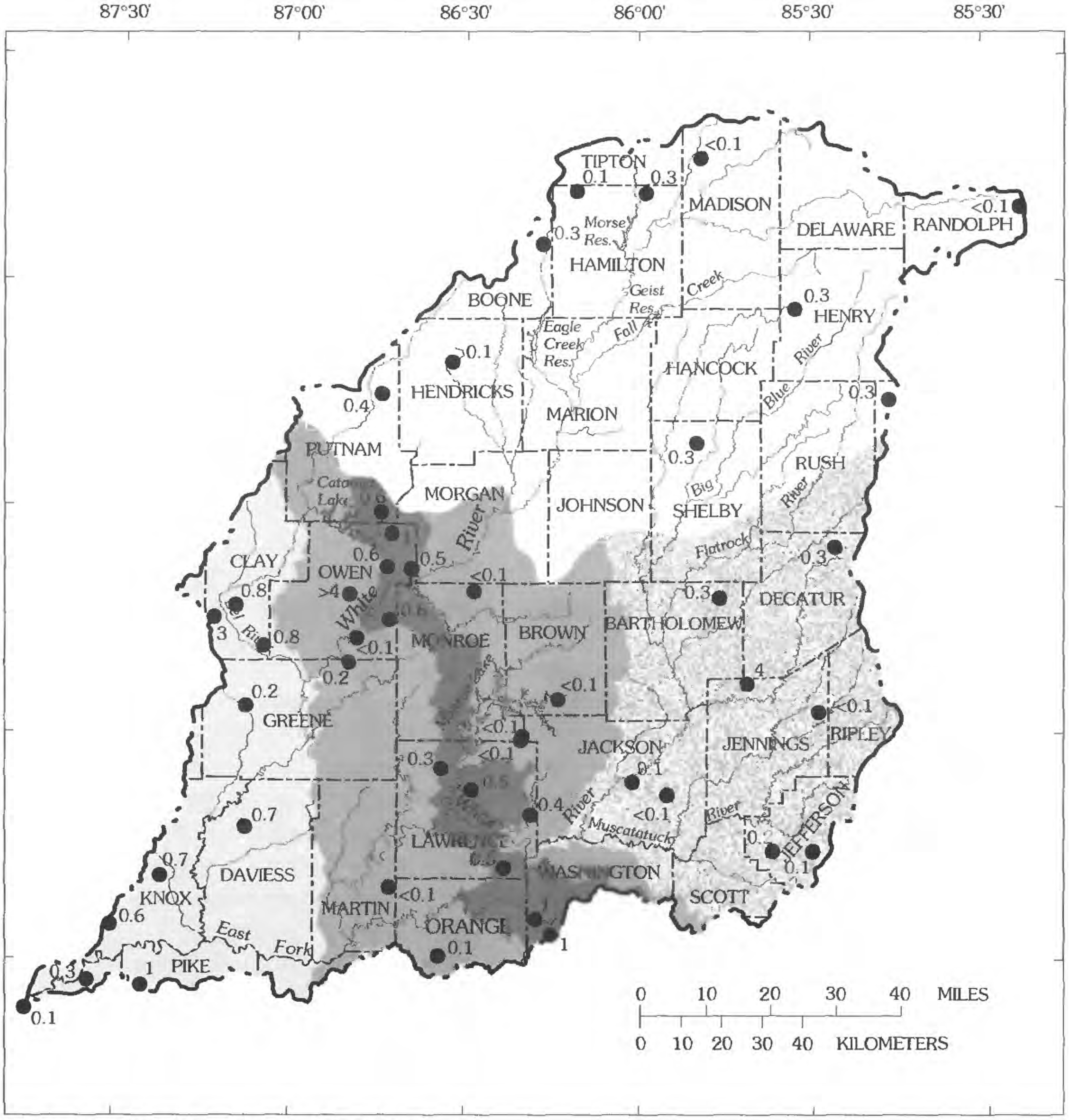
Atrazine in Small Streams During Low Flow

The low evapotranspiration rates characteristic of winter months lead to increased soil moisture and ground-water recharge. The resulting increase in ground-water levels often results in sustainable base flows during periods with no precipitation. During base-flow conditions, the water in the streams sampled is thought to be solely from ground-water discharge because there are no other inputs during this time. Sampling surface water under these conditions provides information on ground-water/surface-water interactions and the likelihood of contaminant transport between the ground-water and surface-water systems. Because of the ease of water movement through the surficial material, regions of high hydraulic conductivity such as those in karst limestone have higher degrees of ground-water/surface-water interaction and a greater potential for ground-water contamination than less permeable regions such as those in glacial till or bedrock.

Surface-water grab samples were collected at 48 small stream sites (0.58–24.1 mi^2 drainage area) (fig. 18) throughout the White River Basin in March 1992 during base-flow conditions (0.01–1.3 $ft^3/s/mi$). The samples were collected in the center of flow and analyzed with a magnetic-particle-based enzyme-linked immunosorbent assay (ELISA) method. This method is not completely specific for atrazine. High cross-reactivity has been observed between atrazine, ametryn, propazine, and prometryn, but not with atrazine degradation products (Rubio and others, 1991; Thurman and others, 1990). The pesticides that interfere with atrazine measurement by this method, however, are not common in the White River Basin. These compounds were detected in less than 5 percent of the surface-water samples collected near Hazleton, Ind., 20 mi upstream from the mouth of the river. Still, the ELISA method used in this study should be considered only semiquantitative because of its reduced specificity relative to other commonly used analytical techniques.

Concentrations of atrazine at the 48 sites sampled are shown in figure 18. The median concentrations by strata are till plain, 0.3 µg/L; bedrock upland, <0.1 µg/L; glacial lowland, 0.7 µg/L; bedrock lowland and plain, 0.2 µg/L; and bedrock karst plain, 0.6 µg/L. The three data points at 3 µg/L or higher are several times greater than the rest of the data set and may be analytical artifacts caused by incomplete retention of the magnetic particles used in the ELISA method. Thus, the three values may not accurately represent the actual concentrations at the time of sampling. With the exception of these sites, the highest atrazine concentrations are in the karst and glacial lowland strata. A nonparametric analysis of variance on all the atrazine concentrations in the different strata shows that the karst strata has statistically higher concentrations than others (probability level = 0.0002).

Permeability of surficial material appears to be the primary factor affecting the amount of atrazine found in surface waters during base-flow conditions. Karst limestone is characterized by sinkholes and subterranean tunnels caused by the dissolution of limestone. This leads to high hydraulic conductivity and extensive ground-water/surface-water interaction; thus, an increase in ground-water contamination from the leaching of herbicides through cropland or from contaminated surface water recharging shallow aquifers during spring high flows is likely. The glacial lowland is composed primarily of loess, which also is quite permeable; elevated atrazine concentrations also were observed in this stratum.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Albers Equal Area projection
Standard parallels 29°30" and 45°30", central meridian -86°

EXPLANATION

HYDROGEOMORPHIC STRATA

- Till plain
- Bedrock upland
- Glacial lowland
- Bedrock lowland and plain
- Karst plain

White River Basin boundary

County boundary

<0.1 Atrazine concentration in micrograms per liter
<less than
>greater than

Figure 18. Atrazine concentrations in small streams in the White River Basin, Ind., March 1992.

Atrazine concentrations in the till plain were close to the median concentration observed in this study (0.3 µg/L), although this stratum has the highest percentage of agricultural land (81 percent) in the basin. This stratum is covered with a thick layer of glacial till that has a relatively low hydraulic conductivity, 10^{-4} to 10^{-10} cm/s. Thus, very high pesticide concentrations are not expected even though the area is heavily agricultural. Although glacial till is relatively impermeable, ground-water resources underlying the till stratum still are susceptible to pesticide contamination from agriculture over fractured areas in the till and areas of alluvium or outwash located within the till stratum. These alluvial flood plains are very susceptible to contaminant leaching. The flood plains are often row cropped, with pesticides directly applied. This practice could significantly affect the levels of water-soluble pesticides present in shallow aquifers within the flood plain.

Significantly lower concentrations of atrazine were observed in the bedrock uplands compared to those in the other strata. This stratum is composed of the least permeable rocks in the basin near the surface. The bedrock uplands also have the highest relief in the basin. In addition, the bedrock uplands contain a smaller percentage of agricultural areas (31 percent). It is possible that the atrazine may be washed from high-lying areas by overland runoff before infiltrating through the soil and bedrock. In this case, the observed atrazine concentrations could be related to hydrogeomorphology, or land use, or both.

Assuming the atrazine present in the streams during this study was a result of ground-water discharge, areas of high hydraulic conductivity appear to have higher levels of water-soluble pesticides in their shallow ground water than regions of lower hydraulic conductivity or higher relief. Because land use is somewhat uniform in the White River Basin, it does not affect the amount of pesticides found in the shallow ground water as much as the physical properties of the overlying material do. The presence of atrazine in base-flow samples indicates widespread contamination of shallow ground water that discharges to streams.

Pesticide Occurrence in Ground Waters

From August 1987 through August 1991, 101 wells were sampled; samples were analyzed for water-soluble and lipophilic pesticides (fig. 5) by various agencies. Many types of wells, including private, municipal, and observation wells, were sampled. The wells ranged in depth from 12 to 470 ft and were located throughout the different hydrogeomorphic strata in the White River Basin. Of all the wells sampled, water from only four had detectable concentrations of pesticides (table 12). One private well of unknown depth located in the karst stratum had measurable concentrations of DDT, DDE, aldrin, lindane, endrin, and heptachlor in April 1989. None of the compounds exceeded USEPA limits for drinking

Table 12. Water-soluble herbicides detected in ground water in the White River Basin, Ind.
[ft, feet; µg/L, microgram per liter; NA, not analyzed; --, not available]

Hydrogeomorphic strata	Aquifer type	Well type	Depth (ft)	Sampling date	Pesticides detected	Concentration (µg/L)
Till	Outwash	Observation	12	8/89	Atrazine	0.1
Bedrock lowland	Outwash	Municipal	62	3/91	None	--
and plain				7/91	Atrazine	.08
Bedrock upland	Outwash	Observation	24	4/91	Atrazine	.14
					Deisopropylatrazine	.10
					Desethylatrazine	.37
				8/91	Atrazine	.34
					Deisopropylatrazine	.42
					Desethylatrazine	NA

water but aldrin, which does not have a MCL, was detected in relatively high concentration (10 µg/L). The well was resampled in June 1989, but no pesticides were detected.

At the three other wells, ground water has been contaminated with atrazine (table 12). Although all atrazine concentrations are well below the MCL of 3 µg/L, elevated concentrations relative to the amount detected in March and April (before the growing season) were detected in the wells sampled in July and August (after the growing season). From this limited amount of data, it appears that water-soluble pesticide concentrations in ground water may fluctuate seasonally in a similar fashion to fluctuations of these pesticides in surface water, but with a greater lag time between application on the land and detection in ground water. Elevated atrazine concentrations are observed in August in ground water, but atrazine concentrations in surface water have typically gone down by this time. This difference could be related to the time of travel of atrazine through the unsaturated zone.

Atrazine metabolites are found in surface-water and ground-water systems, but the metabolite-to-parent compound ratio is higher in ground water, possibly because atrazine in ground water has had a relatively long time to decompose while moving through the unsaturated zone and (or) because the metabolites may have a higher mobility through soils than the parent compound. It has been suggested that this difference in ratio could be used to track ground-water/surface-water interaction (Thurman and others, 1992).

The wells in this study with measurable amounts of atrazine are within different strata, but they all are in outwash aquifers. Alluvial outwash is highly permeable and susceptible to contamination from surface sources. This may explain why atrazine was only found in outwash aquifers. It has previously been noted that outwash areas commonly are row cropped where pesticides are applied directly. It appears that the most important factors affecting water-soluble pesticide occurrence in wells are the permeability of overlying materials and land use. The same observation applies to the base-flow samples discussed in the previous section.

NEED FOR ADDITIONAL DATA COLLECTION

Water-soluble herbicides, such as atrazine, are widespread in the surface waters of the White River Basin—commonly attaining concentrations of 10 to 20 µg/L or several times the USEPA MCL for drinking water—during late spring and early summer. Spring runoff commonly is stored in reservoirs for drinking-water use throughout the year. Water-quality data indicate that these water-soluble herbicides persist in lakes as well (Buser, 1990). Thus, measurement of concentrations of commonly encountered herbicides such as atrazine, metolachlor, cyanazine, and alachlor in lakes and reservoirs would provide information on the environmental fates of these compounds and allow examination of possible human-health implications. Only a small part (about 1 percent) of the atrazine, metolachlor, cyanazine, and alachlor applied in the basin are transported out of the basin (as the parent compounds) by streams. To understand the environmental fate of these pesticides, many environmental compartments such as air, ground water, surface water, and the unsaturated zone need to be sampled so that a mass-balance approach can be applied. Herbicide-degradation products also need to be monitored. Most currently used herbicides are degraded by biotic and abiotic processes to a variety of relatively stable decomposition products that may be more or less toxic than the parent compounds. An understanding of the transport and fate of these herbicides in the environment would be improved if all major decomposition products were measured along with the parent compounds in all environmental compartments. Few studies have been done on the occurrence of water-soluble insecticides in the White River Basin on a basin-wide basis.

Further work in this area is warranted because of the current use of these insecticides and the potential for migration of these insecticides into surface and ground waters.

Although the spatial and temporal occurrence of herbicides and the relation of pesticide concentrations to streamflow in streams is beginning to be understood in the White River Basin, further study is needed. Long-term, high-frequency sampling is needed to address these aspects. The effects of post-herbicide application rainfall timing and intensity need to be studied; for example, how do runoff rate and amount differ between years with heavy rain immediately after application and years with no rainfall for extended periods after herbicide application? Temporal and flow effects on herbicide concentrations in surface water can be separated by sampling during as many combinations of season and streamflow as possible. Additional long-term data are required to study yearly and seasonal variations in herbicide loads in the White River. Smaller streams also need to be sampled regularly to examine land use and hydrogeomorphic effects on herbicide concentrations and loads. Also, because farming practices, pesticide formulations, and application methods have a major effect on pesticide occurrence, transport, and fate in the environment, specific information on these factors in the White River Basin is needed.

Measurement of the ratio of atrazine to its metabolites in surface water, the unsaturated zone, and shallow aquifers many times throughout the year would allow an investigation of the mechanisms of ground-water contamination and the interaction of ground water/surface water. Are herbicides entering aquifers from infiltration through the unsaturated zone in permeable soils or through recharge from contaminated surface water? Do pesticide concentrations in ground water vary seasonally? The atrazine-to-metabolites ratio may be useful for a detailed investigation of the extent of ground-water/surface-water interactions, provided that surface runoff into streams and ground water that discharges into streams are relatively constant and the ratios for each are measurably different. Outwash aquifers and aquifers in the karst strata appear to be especially sensitive to shallow ground-water contamination from water-soluble herbicides such as atrazine. Study of these aquifers in additional detail would be desirable because they may be the most likely aquifers to be contaminated by currently used pesticides.

Previously used lipophilic pesticides such as organochlorine insecticides also have been detected in the White River Basin. Lipophilic pesticide concentrations have been measured in water, stream-bottom sediment, and fish, but a systematic study of pesticide interactions among these compartments has not been done. To effectively study the occurrence of lipophilic pesticides in surface waters of the White River Basin, analytical methods more sensitive than those used in this study need to be developed and applied. The relation of lipophilic pesticide concentrations in surface waters to factors such as concentrations of dissolved organic carbon, suspended organic carbon, suspended sediment, pesticides in stream-bottom sediments and streamflow need to be investigated to determine the primary factors that affect pesticide concentrations in streams in the White River Basin. Bottom-sediment sampling procedures that allow collection of representative and quantitative samples need to be developed to facilitate quantitative comparison between sites. Ancillary data, such as sediment organic-carbon content and particle size, also need to be collected to aid in data interpretation because these properties of sediments greatly affect the adsorption of lipophilic compounds.

The concentration of lipophilic pesticides in fish and other aquatic biota is of great interest to scientific and regulatory communities because these compounds tend to bioaccumulate, concentrating in the lipids of the organism to potentially dangerous levels. Little is known about the effects of chronic low-level exposure to mixtures of pesticides. Stream-bottom sediments seem to be the primary source of lipophilic pesticides to organisms in the White River Basin, but the relation between sediment and fish contamination is difficult to investigate because different species have different habitats and physiologies; thus, various species may accumulate contaminants to different extents. Age and sex of the organism also influence the amount of pesticides that accumulate in fish tissues. The accumulation of contaminants in fish tissues is complicated further by the mobility of fish, which obscures the relation between fish and local sediment contamination. Many of the above difficulties can be overcome to some degree by sampling a more abundant, less mobile, and physiologically simpler aquatic organism, such as the asiatic clam Corbicula fluminea which is widespread in the White River Basin and other areas of the Nation. These organisms could be used instead of fish for the study of pesticide interactions between stream-bottom sediments and benthic organisms. Because only one species would be used in the study, the difficulties associated with quantitative interspecies comparisons would be avoided. From a public health standpoint, however, some fish sampling still would be necessary to determine pesticide residues in edible fish tissue for the issuance of fish-consumption advisories.

The occurrence of pesticides has been, and continues to be, one of the foremost environmental problems in the White River Basin. The presence of previously used lipophilic pesticides is still a problem two decades after their use was discontinued, and each year millions of pounds of water-soluble herbicides and other pesticides still are applied in the basin. Although we are beginning to gain an understanding of pesticide occurrence and environmental fate through the retrospective analysis of previously collected data, much work remains to be done to address adequately the important issues at hand.

SUMMARY AND CONCLUSIONS

Several areas of the White River Basin are contaminated by pesticides. Extensive data on the occurrence of pesticides in all areas of the basin are not available at this time; thus, some problems may not have been recognized or addressed yet. Further data collection and research needs on the occurrence, transport, and fate of pesticides in the White River Basin have been addressed in the "Need for Additional Data Collection" section. On the basis of data sets analyzed in this report, the most significant problems appear to be contamination of surface waters from water-soluble herbicides, contamination of stream-bottom sediments and biota from organochlorine insecticides, and infiltration of water-soluble pesticides into shallow aquifers.

On the basis of geographical distribution, contamination of surface waters from currently used water-soluble herbicides such as triazines and acid amides is the most widespread pesticide problem that has been studied in the basin. Large and small streams in all hydrogeomorphic strata contain measurable amounts of these compounds during parts or all of the year. Concentrations of herbicides in streams increase sharply in spring, following application (typically in May and June). During this time, atrazine and metolachlor concentrations often exceed USEPA MCL's for potable waters by several fold. The elevated stream herbicide concentrations in spring have the potential to contaminate drinking-water supplies all year because spring runoff commonly is stored in reservoirs, and typical water-treatment processes do not remove the herbicides. Stream concentrations of herbicides typically peak during the first major storm after application and remain elevated for as long as 2 months, as is the case during the growing season. During the time prior to and following the growing season, herbicide concentrations in streams are much lower and are not as strongly related to the occurrence of storms, as is the case during the growing season.

Of the measured herbicide loads moving past Hazleton, Ind., near the mouth of the White River, atrazine loads were the highest, followed by loads of metolachlor, cyanazine, and alachlor, respectively. In 1991, a particularly dry year in Indiana, less than 1 percent of the above-mentioned herbicides applied in the White River Basin were transported past the mouth of the river; about 70 percent of this 1 percent was carried during the growing season (May through August). A larger proportion of the triazines that were applied were detected in the White River at Hazleton compared to the proportion of acid amides that were applied. Alachlor was the most heavily used herbicide of the four but was the least frequently detected. This low frequency of detection may be related to the comparatively short environmental persistence of alachlor relative to that of other compounds.

Atrazine and one of its metabolites, desethyl-atrazine, were detected in surface waters all year, indicating that these compounds are persistent for at least several months. Concentrations of atrazine metabolites in streams remain elevated longer into the growing season than the parent compound, indicating that the metabolites are being formed by atrazine decomposition during the growing season and (or) that they may be more environmentally persistent than the parent compound. During the winter and early spring, the desethylatrazine/atrazine ratio in surface waters is higher than it is during the remainder of the year possibly because atrazine is decomposing on the soil, therefore generating more desethylatrazine over time, or possibly because ground waters typically have high desethylatrazine/atrazine ratios and ground-water discharge comprises a comparatively large part of the streamflow during this time of year. Desethylatrazine is more abundant and may form more rapidly than deisopropylatrazine. No data are available for the other atrazine degradation products.

Although currently applied water-soluble pesticides are common in surface waters throughout the White River Basin, lipophilic pesticides applied in previous years, such as organochlorine insecticides, are often not detected in surface waters in the basin possibly because lipophilic compounds accumulate in the organic matter associated with sediments and biota rather than in the water column. Dieldrin, components of technical chlordane, and DDT-related compounds are the lipophilic pesticides most frequently found in stream-bottom sediments in the White River Basin. Areas of the basin where stream-bottom sediments contain the highest known sediment concentrations of these pesticides include Clear Creek and Salt Creek near Lake Monroe, Sand Creek, and the headwaters of the Big Blue River near New Castle, and the White River between Noblesville and Martinsville. The lipophilic pesticides at these locations are suspected of coming from point sources. These environmentally persistent pesticides also appear to be coming from nonpoint sources in areas of lower contamination than these locations, such as the Eagle Creek watershed.

Areas where stream-bottom sediments are contaminated also tend to have fish that are contaminated. Carp and other bottom-dwelling fish contain the highest concentrations of lipophilic pesticides of the 26 species collected. Five fish-consumption advisories have been set by the IDEM for various locations throughout the White River Basin; four of these were set because chlordane concentrations were above USFDA Action Limits, and one was set because chlordane and dieldrin concentrations exceeded the Action Limits. The compounds cis-chlordane, trans-chlordane, trans-nonachlor, and dieldrin were the pesticides most often exceeding USFDA Action Limits and NAS Recommended Maximum Tissue Concentrations in fish of the White River Basin. USFDA limits were exceeded at 5 to 13 percent of the sites where fish were collected, and NAS concentrations were exceeded at 30 to 59 percent of the sites for the four pesticides listed above. The most serious pesticide contamination of fish known in the basin is in the areas of Pleasant Run near Bedford, Stoney Creek downstream from Noblesville, Muddy Fork Sand Creek and the headwaters of the Big Blue River near New Castle, Clear Creek near Lake Monroe, and the White River between Noblesville and Martinsville. Based on data collected during 1979–89 by the IDEM, however, pesticide levels in fish of the White River Basin appear to be declining.

Of 101 wells sampled throughout the White River Basin for a variety of pesticides, detectable concentrations of pesticides were found at only 4 wells. Water from three of the four wells was contaminated with atrazine. The metabolite-to-parent compound ratio for atrazine is higher in ground water than in surface water. Based on limited amounts of data, atrazine concentrations in ground water at wells appear to fluctuate seasonally; atrazine concentrations are found to be more elevated later in the year in ground water than in surface waters. This time lag may be because the travel time of atrazine through the unsaturated zone to the aquifers is relatively long, or because the aquifers are storing contaminated water from nearby surface-water sources during the spring flush of herbicides. All of the wells where detectable amounts of atrazine were found are in outwash aquifers, indicating that this aquifer type may be particularly susceptible to water-soluble pesticide contamination.

Ground-water/surface-water interaction was examined by measuring atrazine concentrations in small streams throughout the White River Basin under base-flow conditions. Streams developed on karst hydrogeomorphic strata had the highest base-flow atrazine concentrations in the basin. The hydraulic conductivity between shallow aquifers and surface waters in the karst stratum is large.

This characteristic makes karst areas susceptible to ground-water contamination from contaminated surface waters. Soil permeability seems to be the primary factor affecting the amount of soil-applied herbicides, such as atrazine, found in streams during base flow. Atrazine concentrations were lowest in streams developed on the high relief areas of the bedrock uplands strata, the surficial material of which has low permeability. This stratum is the least agricultural of the five strata in the White River Basin. Ground water in the till, which underlies the most heavily farmed areas in the basin, has intermediate concentrations of atrazine. Glacial till is not particularly permeable, but the strata still are susceptible to contamination through fractures, sand lenses, and especially outwash areas. Overall, shallow ground water in regions of high hydraulic conductivity have higher water-soluble pesticide concentrations in shallow ground water than ground water in regions of low hydraulic conductivity. The physical properties of overlying material seem to be the main factors determining the concentrations of pesticides in shallow aquifers and ground-water wells, although a variety of other factors, such as land use and farming practices, also can affect observed concentrations.

The White River Basin is in one of the most intensely agricultural areas of the Nation. Large amounts of pesticides have been and currently are used in the basin, potentially causing water-quality problems and other environmental problems. Many of these problems have been investigated to some degree in previous studies, but many important questions remain unanswered and many aspects of problems have not been considered yet. Continued data collection and large-scale study of the effects of historically and presently applied pesticides in the White River Basin would broaden our understanding of pesticide fate in the environment.

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SUPPLEMENTAL DATA

Table 3. Names and locations of sites in the White River Basin, Ind., where multiple water samples were collected

[i.d., identification; there are no degree, minute, and second signs in the latitudes and longitudes]

Map reference number (fig. 3)	Site i.d. number	Latitude	Longitude	Site name
1	FC0.6	394654	0861036	Fall Creek at Indianapolis
2	EC1	394411	0861148	Eagle Creek at Indianapolis
3	EC21	395437	0861708	Eagle Creek at Indianapolis
4	IWC9	395207	0860830	Indianapolis Water Company Canal
5	EW168	385912	0855356	East Fork White River near Seymour
6	EW79	384807	0863844	East Fork White River at Williams
7	WR348	401055	0845808	White River at Winchester
8	WR309	401042	0852940	White River at Yorktown
9	WR 279	400830	0855248	White River at Perkinsville
10	WR210	393335	0861628	White River at Waverly
11	WR192	392602	0862654	White River at Martinsville
12	WR46	383042	0871716	White River at Petersburg
13	03351000	395435	0860620	White River near Nora
14	03354000	392951	0862402	White River near Centerton
15	03357500	393211	0865835	Big Walnut Creek near Reelsville
16	03361000	394438	0853433	Big Blue River at Carthage
17	03362500	392139	0855951	Sugar Creek near Edinburg
18	03363900	391406	0855536	Flatrock River at Columbus
19	03366500	384815	0854026	Muscatatuck River near Deputy
20	03371500	384610	0862430	East Fork White River near Bedford
21	395309086190800	395309	0861908	Fishback Creek at Wilson Road
22	395315086180100	395315	0861801	Eagle Creek at Lafayette Road
23	395440086170700	395440	0861707	Eagle Creek at 100 North Road near Indianapolis
24	395641086154600	395641	0861546	Eagle Creek below High School Avenue near Zionsville
25	395739086153500	395739	0861535	Eagle Creek at Willow Avenue near Zionsville
26	395745086151500	395745	0861515	Little Eagle Creek at 121st Street West near Zionsville
27	395935086170200	395935	0861702	Jackson Run at North 68th Road near Zionsville
28	395954086163800	395954	0861638	Eagle Creek at West 146th Street near Zionsville
29	400056086171900	400056	0861719	Mounts Run at 950 East Road near Zionsville
30	400132086163900	400132	0861639	Finley Creek at Highway 421 near Zionsville
31	400152086163200	400152	0861632	Ditch to Finley Creek near Zionsville
32	400230086153700	400230	0861537	Finley Creek at 1100 East Road near Zionsville
33	400507086162100	400504	0861620	Eagle Creek at County Road 300 North near Big Springs
34	03374100	382923	0873300	White River at Hazleton

Table 4. Names and locations of atrazine synoptic study sites in the White River Basin, Ind.

[i.d., identification; there are no degree, minute, and second signs used in the latitudes and longitudes]

Map reference number (fig. 4)	Site i.d. number	Latitude	Longitude	Site name
1	401203086103201	401203	0861032	Prairie Creek at Six Points Road near Ekin
2	394535086434901	394535	0864349	Plum Creek at Groveland
3	400507086162100	400504	0861620	Eagle Creek at County Road 300 North near Big Springs
4	394946086314201	394946	0863142	West Fork White Lick Creek near Maplewood
5	401144085583701	401144	0855837	Weasle Creek at Fall Road near Omega
6	401624085490501	401624	0854905	Big Duck Creek at County Road 1400 North near Elwood
7	400952084541301	400952	0845413	White River at Base Road East near Harrisville
8	394453085165801	394453	0851658	Shawnee Creek at County Road 750 West near Bentonville
9	395645085330501	395645	0853305	Sugar Creek at County Road 100 North near Cadiz
10	393917085495201	393917	0854952	Snail Creek at County Road 900 North near Finley
11	391800087082701	391800	0870827	Conneley Ditch at County Road 61 West near Clay City
12	391626087121301	391626	0871213	Watkins Creek at County Road 105 South near Old Hill
13	03360125	391244	0870343	Pond Creek at County Road 108 East near Daggett
14	390455087063201	390455	0870632	Lattas Creek at Kramer Road near Linton
15	383610087290301	383610	0872903	Williams Ditch at Main Street Road near Purcell
16	384241087204401	384241	0872044	Flat Creek at Dutton Road near Ragsdale
17	382504087432001	382504	0874320	Brown Ditch at County Road near East Mount Carmel
18	382822087234801	382822	0872348	Little Conger Creek at Cart Road near Union
19	382854087325401	382854	0873254	Robb Creek at County Road 870 North at Hazleton
20	384903087063001	384903	0870630	Findley Lateral at County Road 1100 North near Plainville
21	391932086490301	391932	0864903	Rattlesnake Creek at County Road 225 North near Vandalia
22	391038086491201	391038	0864912	Lick Creek at County Road 265 West at New Hope
23	391349086474401	391349	0864744	Mills Creek at County Road 400 South near Pottersville
24	384119086420401	384119	0864204	South Fork at Willow Valley
25	383230086333901	383230	0863339	Upper Sulfur Creek at County Road 100 South near French Lick
26	391955086274801	391955	0862748	Little Indian Creek at Hacker Creek Road near Hindustan
27	390551086133701	390551	0861337	Gravel Creek near Elkinsville Road at Story
28	03371520	385048	0861806	Back Creek at Leesville
29	390035086194601	390035	0861946	Moseray Branch at Hunter Creek Road near Yellowstone
30	390102086194001	390102	0861940	Taylor Branch at Hunter Creek Road near Yellowstone

Table 4. Names and locations of atrazine synoptic study sites in the White River Basin, Ind.

Map reference number (fig. 4)	Site I.d. number	Latitude	Longitude	Site name
31	393007086434601	393007	0864346	Higgins Branch at County Road 675 East near Cloverdale
32	392722086420201	392722	0864202	Brush Creek at County Road 1150 North at Quincy
33	392304086424401	392304	0864244	Limestone Creek at County Road 650 North near Carp
34	392248086384401	392248	0863844	Indian Creek near Highway 67 near Whitaker
35	391613086421301	391613	0864213	McCormicks Creek at County Road 300 East at Highets Corner
36	385646086331601	385646	0863316	Tributary to Gullets Creek at 400 West Road near Judah
37	385401086280901	385401	0862809	Pleasant Run at County Road 50 East near Bedford
38	384353086223501	384353	0862235	Fishing Creek at County Road 900 South at Stonington
39	383720086172000	383719	0861719	Lost River at County Road at Claysville
40	383509086145301	383509	0861453	South Fork Lost River at County Road 100 South near Livonia
41	385504086005301	385504	0860053	Indian Creek at Shields Road at Shields
42	385319085545701	385319	0855457	Grassey Fork at County Road 50 North near Seymour
43	384607085370601	384607	0853706	Dry Branch at County Road 1250 West near Deputy
44	392536085261501	392536	0852615	Middle Branch Clifty Creek at County Road 225 East near Sandusky
45	391902085455901	391902	0854559	Haw Creek at County Road 775 East at Hope
46	384601085301501	384601	0853015	Chicken Run at County Road 200 North near Neavill Grove
47	390751085412201	390751	0854122	Bear Creek at County Road 500 South near Alert
48	03368000	390413	0852910	Brush Creek near Nebraska

Table 5. Names and locations of ground-water sampling sites in the White River Basin, Ind.

[i.d., identification; there are no degree, minute, and second signs used in the latitudes and longitudess]

Map reference number (fig. 5)	Site i.d. number	Latitude	Longitude
1	401544085492301	401544	0854923
2	401542085492301	401542	0854923
3	401320085464301	401320	0854643
4	401228085401301	401228	0854013
5	401139085360601	401139	0853606
6	401126085121101	401126	0851211
7	401116085070001	401116	0850700
8	401022085502801	401022	0855028
9	400949085060501	400949	0850605
10	400532086183901	400532	0861839
11	400520085532401	400520	0855324
12	400427085503701	400427	0855034
13	400340085422101	400340	0854221
14	400313085350701	400313	0853507
15	400218085263101	400218	0852631
16	395846086021000	395846	0860210
17	395816086042001	395817	0860412
18	395410086054601	395410	0860546
19	395119086191601	395119	0861916
20	394732086115501	394732	0861155
21	394632086092701	394632	0860927
22	394536086345801	394536	0863458
23	394425085552601	394425	0855526
24	394309086364201	394309	0863642
25	394229086003301	394229	0860033
26	393952086482201	393952	0864822
27	393743085180401	393743	0851804
28	393738085253101	393738	0852531
29	393712086125401	393712	0861254
30	393652087004801	393652	0870048
31	393706086122601	393706	0861226
32	393617086132501	393617	0861325
33	393616086134501	393616	0861345
34	393545085274701	393545	0852747
35	393536086251801	393536	0862518

Table 5. Names and locations of ground-water sampling sites in the White River Basin, Ind.—Continued

Map reference number (fig. 5)	Site i.d. number	Latitude	Longitude
36	393451086115101	393451	0861151
37	393423086161001	393423	0861610
38	393250086590302	393250	0865903
39	393235086570701	393235	0865707
40	393127086144801	393127	0861448
41	393104087025301	393104	0870253
42	393015085275701	393015	0852757
43	394420085342001	392953	0853406
44	392943086014701	392943	0860147
45	392939086070301	392939	0860703
46	392844086212401	392844	0862124
47	392711086263201	392711	0862632
48	392622085504101	392622	0855041
49	392611086425701	392611	0864257
50	392546085375201	392544	0853758
51	392528086205601	392528	0862056
52	392417086273701	392417	0862737
53	392416086303001	392416	0863030
54	392320087104301	392320	0871043
55	392254085333201	392254	0853332
56	392151086261501	392151	0862615
57	392022085371801	392022	0853718
58	391939087060301	391939	0870603
59	391929087172800	391929	0871728
60	391907085382401	391907	0853824
61	391804087120101	391804	0871201
62	391824085461601	391824	0854616
63	391816085463101	391816	0854631
64	391752086441301	391752	0864413
65	391722085391601	391722	0853916
66	391557087113401	391557	0871134
67	391405087073201	391405	0870732
68	391335087011101	391335	0870111
69	391327086520301	391327	0865203
70	391303086534101	391303	0865341
71	391240085474901	391240	0854749

Table 5. Names and locations of ground-water sampling sites in the White River Basin, Ind.—Continued

Map reference number (fig. 5)	Site i.d. number	Latitude	Longitude
72	391034085562001	391034	0855620
73	390658085572201	390658	0855722
74	390231085513101	390231	0855131
75	390133086572401	390133	0865723
76	385444087063001	385444	0870630
77	385319086032401	385319	0860324
78	384935086305301	384935	0863053
79	384623087155701	384623	0871557
80	384040086515601	384040	0865156
81	384040086271201	384040	0862712
82	384037086270001	384037	0862700
83	383959086473201	383959	0864732
84	383904087141101	383904	0871411
85	383906086331401	383906	0863314
86	383752086332301	383752	0863323
87	383748086285301	383748	0862853
88	383719086333301	383719	0863333
89	383652086251301	383652	0862513
90	383643086273101	383643	0862731
91	383603086251501	383603	0862515
92	383601086244301	383601	0862443
93	383552086252101	383552	0862521
94	383536086240501	383536	0862405
95	383512086234301	383512	0862343
96	383512086231201	383512	0862312
97	383510086235901	383510	0862359
98	383114087315701	383114	0873157
99	383117087053101	383117	0870531
100	383034087175401	383034	0871754
101	382942086543701	382942	0865437

Table 6. Names and locations of bottom-sediment and fish-tissue sampling sites in the White River Basin, Ind.

[D/S, downstream; U/S, upstream; Hwy, highway; STP, sewage treatment plant; S, south; NE, northeast; N, north; there are no degree, minute, and second signs in the latitudes and longitudes]

Map reference number (fig. 6)	Latitude	Longitude	Site name	Location
1	382923	0873300	at Hazleton	West Fork White River
2	383042	0871716	at Petersburg	West Fork White River
3	383822	0871420	D/S Washington	West Fork White River
4	383930	0871454	U/S Washington	West Fork White River
5	384020	0864724	at Shoals	East Fork White River
6	384807	0863844	D/S Williams Dam	East Fork White River
7	384815	0863837	at Williams Dam	East Fork White River
8	384857	0860936	D/S Medora	East Fork White River
9	384912	0860852	U/S Medora (U/S Hwy 234)	East Fork White River
10	384933	0863047	U/S Bedford STP	East Fork White River
11	385026	0863229	D/S Bedford (U/S Salt Creek)	East Fork White River
12	385135	0863155	D/S Hwy 450	Salt Creek
13	385246	0860451	D/S Brownstown (U/S Hwy 50)	East Fork White River
14	385401	0862812	U/S Central Foundry, Bedford	Pleasant Run Creek
15	385401	0870614	at Elnora	West Fork White River
16	385415	0862931	D/S Central Foundry, Bedford	Pleasant Run Creek
17	385415	0862931	D/S General Motors, Peerless Road	Pleasant Run Creek
18	385415	0862931	U/S General Motors, Peerless Road	Pleasant Run Creek
19	385454	0860010	D/S Seymour at Indian Creek	East Fork White River
20	385500	0860100	D/S Seymour	East Fork White River
21	385837	0863021	at Guthrie	Salt Creek
22	385913	0855356	U/S Seymour	East Fork White River
23	390101	0863222	at Harrodsburg	Clear Creek
24	390423	0863412	at Fluckmill Road	Clear Creek
25	390502	0854310	at Scipio	Sand Creek
26	390506	0855136	D/S Columbus at Azalia	East Fork White River
27	390601	0865752	at Worthington	West Fork White River
28	390810	0863200	U/S Bloomington	Clear Creek
29	390810	0863201	at Country Club Road	Clear Creek

Table 6. Names and locations of bottom-sediment and fish-tissue sampling sites in the White River Basin, Ind.—Continued

Map reference number (fig. 6)	Latitude	Longitude	Site name	Location
30	391003	0853244	at Westport	Sand Creek
31	391012	0864059	at Hwy 43, at Whitehall	Richland Creek
32	391042	0863834	U/S confluence with Conard's Branch	Richland Creek
33	391200	0855536	U/S Columbus at Flatrock River	East Fork White River
34	391229	0864052	at Acuff Road	Stouts Creek
35	391414	0863138	at Mel Curry Road, Bloomington	Bean Blossom Creek
36	391443	0860530	U/S Franklin (Hwy 144)	Young's Creek
37	391644	0864631	D/S Spencer	West Fork White River
38	391649	0864542	at Spencer	West Fork White River
39	391653	0853008	at Mount Pleasant Cemetery	Sand Creek
40	391653	0863007	D/S Greensburg	Sand Creek
41	391657	0853139	D/S Delta Faucet (County Road 250 S)	Muddy Fork Sand Creek
42	391704	0855428	U/S Columbus	Flatrock River
43	391927	0863849	at Moon Road near Stinesville	Bean Blossom Creek
44	392003	0852801	U/S Greensburg (County Road 80 NE)	Sand Creek
45	392021	0853054	U/S Delta Faucet (Hwy 3)	Muddy Fork Sand Creek
46	392120	0855841	D/S Edinburgh STP	Big Blue River
47	392150	0855950	at Atterbury State Fishing Area	Sugar Creek
48	392210	0863435	at Paragon	West Fork White River
49	392240	0855717	U/S Edinburgh	Big Blue River
50	392421	0854206	at Geneva	Flatrock River
51	392508	0860018	D/S Franklin (County Road 400 S)	Young's Creek
52	392958	0862117	Henderson Ford Bridge	West Fork White River
53	393121	0854753	D/S Shelbyville STP	Big Blue River
54	393131	0854548	D/S General Electric at Shelbyville	Little Blue River
55	393208	0854438	U/S General Electric at Shelbyville	Little Blue River
56	393219	0862159	Brooklyn Bridge	White Lick Creek
57	393339	0854616	U/S Shelbyville, Morristown Road	Big Blue River
58	393349	0852857	D/S Rushville	Flatrock River

Table 6. Names and locations of bottom-sediment and fish-tissue sampling sites in the White River Basin, Ind.—Continued

Map reference number (fig. 6)	Latitude	Longitude	Site name	Location
59	393750	0862329	U/S County Road 900 S	White Lick Creek
60	393939	0862026	D/S County Road 700 S, U/S Mooresville	East Fork White Lick Creek
61	394038	0854250	D/S Morristown (Hwy 52)	Big Blue River
62	394058	0855355	D/S New Palestine	Sugar Creek
63	394126	0855357	U/S New Palestine	Sugar Creek
64	394129	0854224	U/S Morristown	Big Blue River
65	394340	0853458	D/S Carthage	Big Blue River
66	394402	0852631	D/S Mays (Hwy 3)	Little Blue River
67	394406	0861512	Tributary to Mars Ditch by Bradbury	Drexel Run
68	394433	0854913	D/S Eli Lilly (County Road 300 S)	Little Sugar Creek
69	394435	0853433	U/S Carthage (5th Street)	Big Blue River
70	394436	0852447	U/S Mays (County Road 900 N)	Little Blue River
71	394530	0854509	D/S Greenfield (Steel Road)	Brandywine Creek
72	394639	0861125	Michigan Street Bridge	West Fork White River
73	394719	0861152	Near Lafayette Road	Eagle Creek
74	394943	0854557	U/S Greenfield (County Road 300 N)	Brandywine Creek
75	395207	0860830	Broad Ripple Park	West Fork White River
76	395408	0852415	D/S New Castle (County Road 200 S)	Big Blue River
77	395632	0852253	U/S New Castle (County Road 75 N)	Big Blue River
78	400107	0860047	D/S Stoney Creek, Noblesville	West Fork White River
79	400123	0860043	D/S Firestone, Noblesville	Stoney Creek
80	400125	0860112	U/S Stoney Creek, Noblesville	West Fork White River
81	400205	0860130	D/S Noblesville	West Fork White River
82	400214	0855625	U/S Noblesville (Hwy 38)	Stoney Creek
83	400555	0855800	U/S Noblesville	West Fork White River
84	400556	0855759	at Riverwood (U/S Dam)	West Fork White River
85	400623	0853731	U/S Anderson	West Fork White River
86	400650	0854318	D/S Anderson	West Fork White River
87	401043	0852944	D/S Muncie	West Fork White River
88	401055	0852049	U/S Muncie	West Fork White River
89	401059	0845815	U/S Winchester	West Fork White River

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