

OCCURRENCE OF VOLATILE ORGANIC COMPOUNDS IN GROUND WATER IN THE WHITE RIVER BASIN, INDIANA, 1994-95



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Water samples collected in 1994 and 1995 from 100 monitoring wells (91 shallow and 9 deep) screened in shallow unconsolidated aquifers in the White River Basin were analyzed for 58 volatile organic compounds (VOC's). Twelve different VOC's were detected. Chloroform was the most commonly detected VOC (found in 12 wells), whereas the highest measured VOC concentration was 39 micrograms per liter of 1,1-dichloroethane. No VOC had a measured concentration in ground water that exceeded a U.S. Environmental Protection Agency national drinking-water standard or guideline. Slightly more than fifty percent of the shallow wells in urban settings, as compared to six percent of the shallow wells in agricultural settings, had at least one VOC detected.

INTRODUCTION

In 1991, the U.S. Geological Survey (USGS) began the National Water-Quality Assessment (NAWQA) Program. The long-term goals of the NAWQA Program are to describe the status and trends in the quality of the Nation's rivers, streams, and ground water and to provide a sound, scientific understanding of the primary natural and human factors affecting the quality of these resources (Hirsch and others, 1988).

The White River Basin in Indiana was among the first 20 river basins to be studied as part of the NAWQA Program. A component of the White River Basin study is to determine the occurrence of volatile organic compounds (VOC's) in the shallow aquifers of the basin. VOC's are of national concern because some of the compounds are toxic and (or) carcinogenic. This paper presents the findings from VOC data collected from 100 monitoring wells from June 1994 through August 1995.

VOC's occur in many natural and synthetic materials that are widely used throughout the White River Basin. For example, VOC's are used in the manufacture of paints, adhesives, petroleum products, pharmaceuticals, and refrigerants; they also are used as solvents, hydraulic fluids, and dry-cleaning agents (Smith and others, 1988). In

agricultural areas, VOC's are applied to cropland as active and inactive components of fertilizers, herbicides, insecticides, fungicides, fumigants, and sterilants (Verschuere, 1983). In addition, VOC's occur naturally. For example, crude oil pumped from bedrock in the western part of the basin contains VOC's.

DESCRIPTION OF THE WHITE RIVER BASIN

The White River Basin is part of the Mississippi River system and encompasses 11,350 square miles of central and southern Indiana (fig. 1). The population of the White River Basin in 1990 was approximately 2.1 million people; the Indianapolis Metropolitan Area accounted for about 60 percent of the total population.

There is a variety of land use in the basin. The primary land use is agriculture (fig. 2), which comprises about 70 percent of the basin; forested land is located mostly in the south-central part of the basin; and significant industrialization is present in the cities of Indianapolis, Muncie, and Anderson.

Approximately 55 percent of the population in the White River Basin rely on ground water as their primary source of drinking water. In 1993, about 180 million gallons per day (Mgal/d) of ground water were withdrawn in the basin. By comparison, 270 Mgal/d of surface

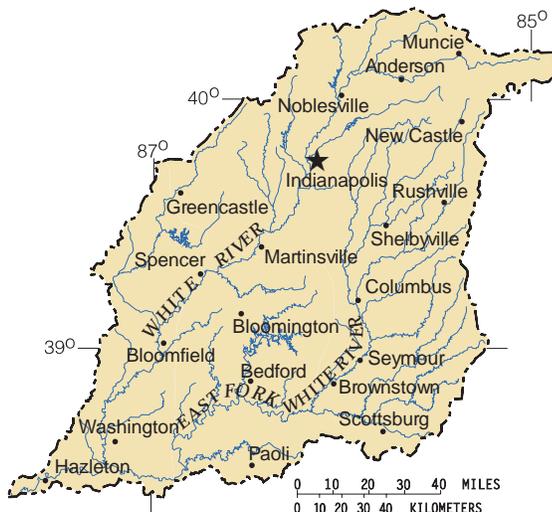


Figure 1. The White River Basin.

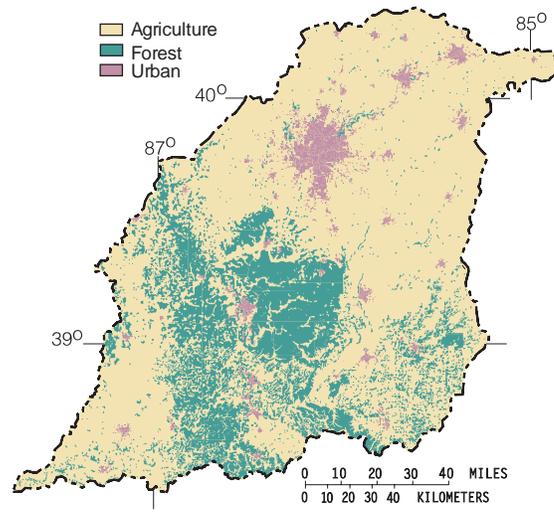


Figure 2. Land use in the White River Basin.

water were withdrawn, excluding withdrawals for cooling water at thermoelectric power plants. Of the total ground-water withdrawals in the basin, public water suppliers accounted for about 51 percent (91 Mgal/d), followed by self-supplied domestic users (23 percent) and self-supplied industrial and commercial users (20 percent) (Indiana Department of Natural Resources, Division of Water, written commun., 1995).

For the purposes of this study, the basin was divided into six hydrogeomorphic regions. These regions are based on factors affecting water quality such as geology, physiography, and hydrology (fig. 3). Three of the regions—the bedrock upland, bedrock lowland and plain, and karst plain—are defined primarily by bedrock geology. The remaining three regions—the till plain, glacial lowland, and fluvial deposits—are defined primarily by characteristics of glacial deposits and are the focus of this paper.

The till plain, which covers the northern part of the basin, typically is underlain by 100 to 200 feet of silty-clay till interlayered with thin (5- to 10-foot thick) layers of sand and gravel. Water-bearing units in the upper 50 feet of the till sequence consist of confined sand and gravel lenses that commonly do not provide well yields sufficient for domestic use. The glacial lowland, located in the southwestern part of the basin, typically is covered by 0 to 100 feet of loess (wind-blown silt), silty-clay till, dune sands, and lake clays overlying coal-bearing shales and sandstones. Shallow unconsolidated water-bearing units rarely provide well yields sufficient for domestic use; bedrock aquifers supply water to most privately-owned wells. The fluvial (river) deposits fill river valleys that cut across the other five hydrogeomorphic regions. The fluvial deposits are composed of approximately 10

to 100 feet of glaciofluvial and recent alluvial deposits of sand, gravel, and silt beneath and adjacent to most of the rivers and major streams in the basin. Fluvial deposits are most extensive along the White River near Indianapolis and south of Bloomfield, and along the East Fork White River near Columbus and Seymour. The fluvial deposits are highly permeable and rapidly recharged, which make them productive aquifers, but vulnerable to contamination.

STUDY APPROACH

The USGS installed four networks of monitoring wells in the White River Basin (fig. 3). The networks are designed to assess the concentrations and distributions of VOC's in shallow ground water associated with four different environmental settings. The settings are defined by a combination of hydrogeomorphic and land-use conditions. Networks in the till plain (20 wells), glacial lowland (22 wells), and fluvial deposits (24 wells) are in agricultural settings. A fourth network in the fluvial deposits (25 wells) is in the urban settings of Indianapolis, Anderson, and Columbus (insets of fig. 3). The 91 wells in these four networks are referred to as "shallow wells" in this paper. Nine additional "deep wells" were drilled adjacent to selected shallow wells to allow comparison of VOC concentrations by depth. The deep wells were completed in the same aquifer as the adjacent shallow wells but were screened 18 to 45 feet deeper. The depth of the deep wells was dictated by the depth to the bottom of the uppermost water-bearing unit or the limit of the drill rig (50 to 70 feet). Six of the nine wells are in the fluvial deposits/agricultural network and the remaining three are in the fluvial deposits/urban network.

Well locations within each network were randomly selected. A

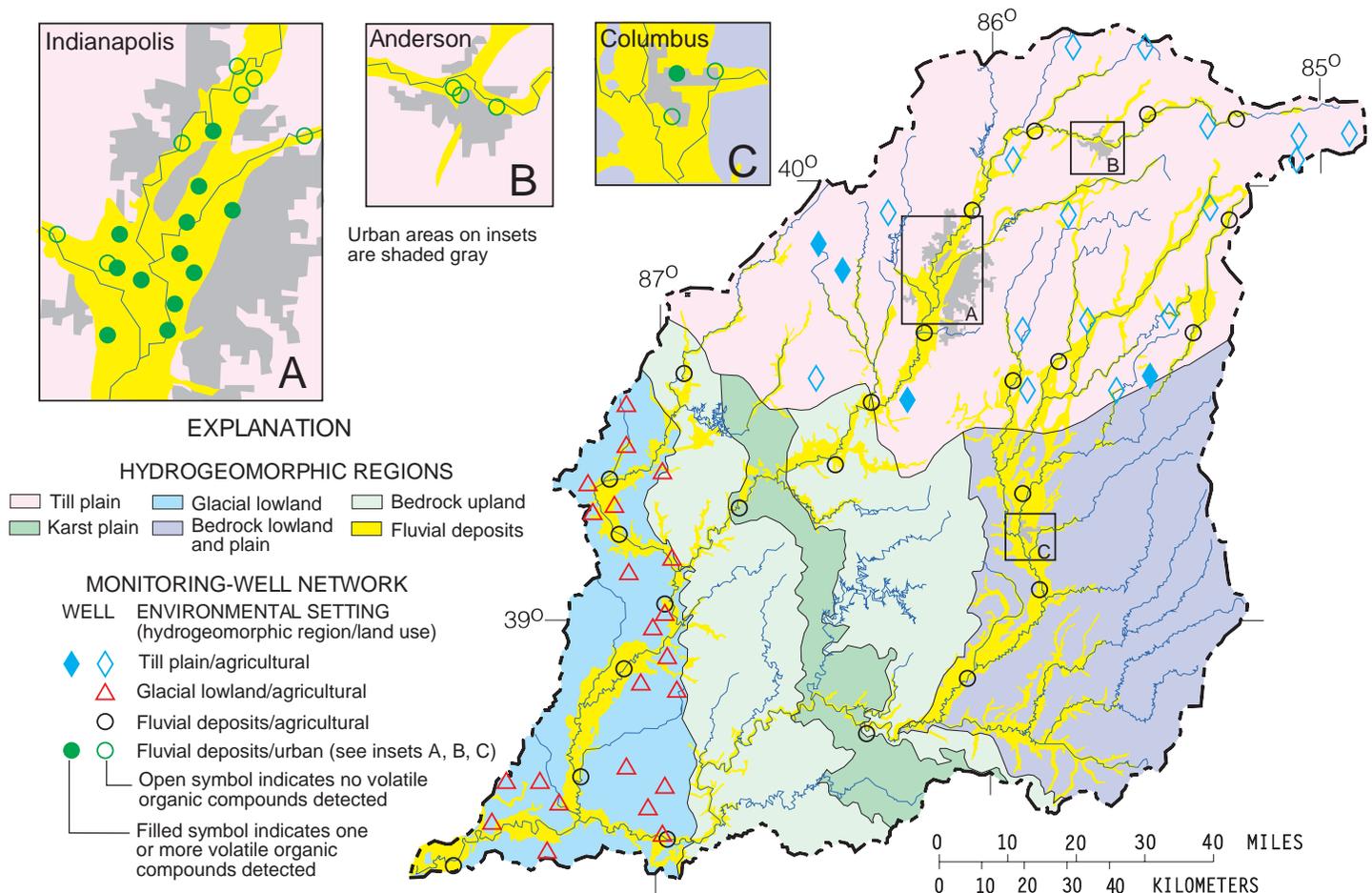


Figure 3. Hydrogeomorphic regions, monitoring-well networks, and shallow wells with detections of volatile organic compounds in the White River Basin, Indiana.

hollow-stem, rotary auger was used to install the 12- to 67-foot-deep wells. Two-inch diameter polyvinyl chloride (PVC) wells with short screens (2.5 to 7.5 feet) were completed in the uppermost water-bearing unit following procedures described in Lapham and others (1995). Median well yields from the till plain and glacial lowland networks were low—0.3 and less than 0.1 gallons per minute, respectively. Median well yields from the fluvial networks were greater than 5 gallons per minute.

Water samples were collected from the 100 wells during the summers of 1994 and 1995 following procedures described in Koterba and others (1995). The samples were analyzed for 58 VOC's (table 1), including most of the VOC's regulated in public-water supplies by the U.S. Environmental Protection Agency (USEPA). The USGS National Water Quality Laboratory determined VOC concentrations by purge and trap capillary column gas chromatography/mass spectrometry methods (Rose and Schroeder, 1995). A quality-assurance program was used in the field (Koterba and others, 1995) and the laboratory (Rose and Schroeder, 1995) to evaluate and ensure the reliability of the analytical data.

FINDINGS

Twelve of the 58 VOC's that were analyzed for in ground water samples (table 1; fig. 4) were detected at or above the reporting limit in at least 1 of the 91 shallow wells. (The reporting limit is the smallest measured concentration of a compound that can be reported reliably by the laboratory using the previously described analytical method.) *Chloroform (trichloromethane) was the most commonly detected VOC, whereas the highest measured VOC concentration was 39 µg/L (microgram per liter) of 1,1-dichloroethane.*

Table 1. Volatile organic compounds analyzed for in ground water in the White River Basin, Indiana

[The reporting limit for all compounds is 0.2 µg/L (microgram per liter) except for 1,2-Dibromo-3-chloropropane, which has a reporting limit of 1.0 µg/L. Names follow convention of International Union of Pure and Applied Chemistry. Names in brackets are common synonyms and acronyms; some of the synonyms are used in text and figure 4.]

Compound		
Benzene	1,1-Dichloroethane	Styrene
Bromobenzene	1,2-Dichloroethane	1,1,1,2-Tetrachloroethane
Bromochloromethane	1,1-Dichloroethane	1,1,2,2-Tetrachloroethane
Bromodichloromethane	<i>cis</i> -1,2-Dichloroethene	Tetrachloroethene
Bromomethane [Methyl bromide]	<i>trans</i> -1,2-Dichloroethene	Tetrachloromethane [Carbon tetrachloride]
<i>n</i> -Butylbenzene	Dichloromethane [Methylene chloride]	Tribromomethane [Bromoform]
<i>sec</i> -Butylbenzene	1,2-Dichloropropane	1,2,3-Trichlorobenzene
<i>tert</i> -Butylbenzene	1,3-Dichloropropane	1,2,4-Trichlorobenzene
Chlorobenzene	2,2-Dichloropropane	1,1,1-Trichloroethane
Chlorodibromomethane	1,1-Dichloropropene	1,1,2-Trichloroethane
Chloroethene [Vinyl chloride]	<i>cis</i> -1,3-Dichloropropene	Trichloroethene [TCE]
2-Chlorotoluene	<i>trans</i> -1,3-Dichloropropene	Trichlorofluoromethane
4-Chlorotoluene	Ethylbenzene	Trichloromethane [Chloroform]
1,2-Dibromo-3-chloropropane [DBCP]	Hexachlorobutadiene	1,2,3-Trichloropropane
1,2-Dibromoethane [EDB]	Isopropylbenzene	1,1,2-Trichloro-1,2,2-trifluoroethane
Dibromomethane	<i>p</i> -Isopropyltoluene	1,2,4-Trimethylbenzene
1,2-Dichlorobenzene	Methylbenzene [Toluene]	1,3,5-Trimethylbenzene
1,3-Dichlorobenzene	Methyl <i>tert</i> -butyl ether [MTBE]	Xylenes
1,4-Dichlorobenzene	Naphthalene	
Dichlorodifluoromethane	<i>n</i> -Propylbenzene	

The USEPA establishes maximum concentrations of VOC's in public drinking water that will not cause adverse health effects in humans. These maximum concentrations, known as drinking-water standards or guidelines, have been set for approximately two-thirds of the VOC's that were analyzed for in this study. *No VOC had a measured concentration in ground water that exceeded a national drinking-water standard or guideline for public water supplies* (U.S. Environmental Protection Agency, 1995). Maximum concentrations of VOC's in ground water (or a reporting limit if a VOC was not detected) were no more than half their respective USEPA drinking-water standard or guideline; the exception to this is 1,2-dibromo-3-chloropropane and 1,2-dibromoethane, which have reporting limits that are greater than their drinking-water standards. Although the monitoring wells installed for this study are not used for drinking water, some households use shallow ground water as a drinking-water supply, especially in the fluvial deposits.

Samples from shallow wells in the nine pairs of shallow and deep wells had a greater frequency of detections and higher concentrations of VOC's than samples from the deep wells. VOC concentrations are expected to be higher in shallow ground water because most sources of VOC's originate at or near the land surface. At least one VOC was detected in each shallow well in all three paired-well sets in urban settings. Only one of the five detections of VOC's in the shallow wells was repeated in the corresponding deep well. In this one instance, the concentration in the deep well was less than one-fourth the concentration in the shallow well. The six sets of paired wells underlying agricultural land had no detectable VOC's in either the shallow or the deep well.

VOC's were detected in only 4 of the 66 wells in agricultural settings (fig. 3). No VOC's were detected above the reporting limit in agricultural settings overlying the glacial lowland or fluvial deposits. Only three compounds—chloroform, dichloromethane (methylene chloride), and methyl *tert*-butyl ether (MTBE)—were detected in ground water underlying the till plain (fig. 4). The probable source of the MTBE, which was detected in only one well, is an above-ground fuel storage tank adjacent to the well.

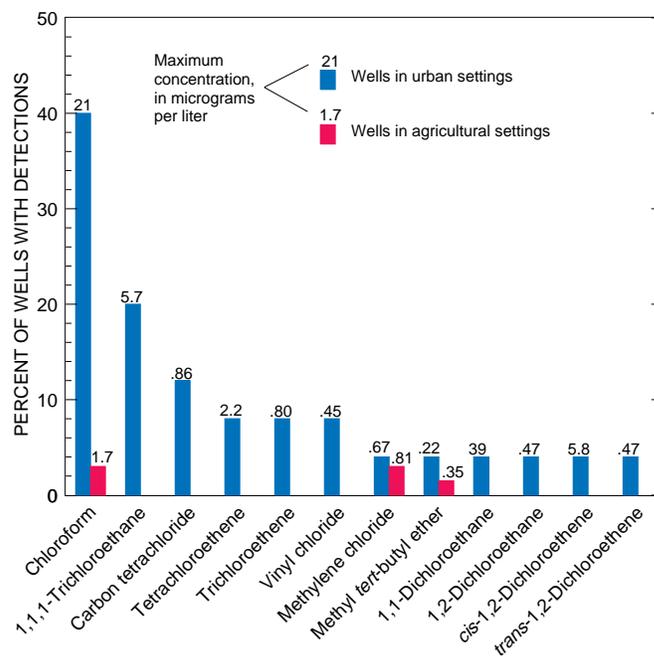


Figure 4. Volatile organic compounds detected in water from shallow wells in unconsolidated deposits underlying urban and agricultural land of the White River Basin, Indiana.

Most of the ground water with detectable VOC's in the White River Basin underlies urban land (figs. 3 and 4). Slightly more than half of the shallow wells in urban settings, as compared to six percent of the shallow wells in agricultural settings, had at least one VOC detected above the reporting limit. With the exception of one well in Columbus, the wells with detections of VOC's in urban settings were in Indianapolis.

Chloroform was the most frequently detected VOC (40 percent of wells) in ground water underlying urban land. The median detected concentration of chloroform in urban settings was 0.5 µg/L; all of the chloroform detections were in Indianapolis. Chloroform is used as a solvent, dry-cleaning agent, and fumigant ingredient, and it is used in the manufacture of many products including refrigerants, plastics, and synthetic rubber (Verschuere, 1983). In addition, chloroform is a by-product in auto exhaust, chlorinated drinking water, and chlorinated municipal sewage (Howard and others, 1990). Two potential sources for the widespread, low-level concentrations of chloroform in ground water in Indianapolis are chlorinated drinking water and atmospheric deposition.

A likely source of the low concentrations of chloroform in ground water underlying urban land in the White River Basin is chlorinated public-supply water. Chloroform is formed in drinking water during and after chlorination when naturally occurring humic substances in raw water react with chlorine. Chlorinated surface water generally has much higher concentrations of chloroform than chlorinated ground water because of high concentrations of humic substances in surface water. Concentrations of chloroform in public-supply water that is representative of the chlorinated water distributed to most of Indianapolis ranged from about 20 to 100 µg/L from 1993-95; typical concentrations were about 40 to 70 µg/L (Indiana Department of Environmental Management, written commun. 1995). These chloroform concentrations in Indianapolis public-supply water are significantly higher than in the ground water underlying the city. Public-supply water can recharge the fluvial aquifer through a variety of ways that include lawn sprinklers, leaking water lines, leaking sewer lines, septic systems, and industrial settling ponds. Most of the wells in urban settings with no detectable chloroform are (1) in Anderson and Columbus—cities with relatively low chloroform concentrations (5 µg/L or less) in their public-water supply, (2) in areas of Indianapolis not served by public-supply water, or (3) in recently developed areas of Indianapolis (northeast side).

Atmospheric deposition is probably a minor source of chloroform in ground water. Ambient concentrations of chloroform in the air in Indianapolis are probably less than 1 part per billion by volume (ppbv) (Balbant Patel, Indiana Department of Environmental Management, oral commun., 1996; Larry Cupitt, U.S. Environmental Protection Agency, written commun., 1995; Shah and Singh, 1988). A concentration of 1 ppbv of chloroform in the air would enable approximately 0.04 to 0.1 µg/L of chloroform to enter the ground water from rainwater¹. The maximum calculated chloroform concentration in rainwater (0.1 µg/L) is not high enough to account for even the lowest concentration of chloroform detected in the ground water (0.2 µg/L).

¹The concentration range in rainwater was calculated from a modified form of Henry's Law, as presented in Schwarzenbach and others (1993), and assumes that concentrations of chloroform in the air and precipitation reach equilibrium. The concentration range was calculated using air temperatures of 2 and 25 degrees Celsius, a pressure of 1 atmosphere, and Henry's Law constants of 297.5 pascals times cubic meters per mol (at 25 degrees Celsius) (Mackay and others, 1993) and 116.0 pascals times cubic meters per mol (at 2 degrees Celsius) (Dewulf and others, 1995).

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