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Geohydrology, Water Quality, and Simulation of Ground-Water Flow in the Vicinity of a Former Waste-Oil Refinery near Westville, Indiana, 1997–2000

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Conversion Factors, Vertical Datum, and Abbreviations

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	4,047	square meter
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.0929	meter squared per day
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.06309	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
million gallons (Mgal)	3,785	cubic meter

Temperature, given in degrees Celsius (°C), can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$°F = 1.8(°C) + 32$$

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units used in this report: Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Concentrations of bacteria are given in colonies per 100 milliliters (col/100 mL).

Specific conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25 degrees Celsius (µmho/cm), formerly used by the U.S. Geological Survey.

Volumes of water-quality samples are given in liters (L) and milliliters (mL).

Other abbreviations used in this report:

DO	dissolved oxygen
NTU	nephelometric turbidity units
ORP	oxidation-reduction potential
PCB	polychlorinated biphenyl
PSI	pounds per square inch
RPD	relative percent difference
SC	specific conductance
SVOC	semivolatile organic compound
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	volatile organic compound

Geohydrology, Water Quality, and Simulation of Ground-Water Flow in the Vicinity of a Former Waste-Oil Refinery near Westville, Indiana, 1997–2000

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Abstract

Geohydrologic and water-quality data collected during 1997 through 2000 in the vicinity of a former waste-oil refinery near Westville, Indiana, define a plume of 1,4-dioxane in ground water that extends to the southwest approximately 0.8 miles from the refinery site. Concentrations of 1,4-dioxane in the plume ranged from 3 to 31,000 micrograms per liter. Ground water containing 1,4-dioxane is discharged to Crumpacker Ditch, approximately one-half mile west of the refinery site. Concentrations of 1,4-dioxane detected in surface water ranged from 8 to 140 micrograms per liter; 1,4-dioxane also is transported in ground water beneath the ditch.

The study area is underlain by glacial deposits of sand and gravel that overlie lacustrine clay and shale. The sand and gravel deposits form an extensive aquifer ranging from 148 to 215 feet thick in the study area. Ground water generally flows from northeast to southwest and the depth to water ranges from about 3 to 36 feet below land surface. The average horizontal hydraulic conductivity of the aquifer, determined from a multiple-well aquifer test, was 121 feet per day, and the transmissivity was 18,600 feet squared per day. Vertical hydraulic conductivity ranged from 24 to 36 feet per day and specific yield ranged from 0.05 to 0.08. Analysis of single-well aquifer tests indicated that horizontal hydraulic conductivity ranged from 0.6 to 127 feet per day and was largest in the lower part of the aquifer. Horizontal gradients averaged about 0.001 feet per foot; estimated ground-water-flow velocities averaged about 0.1 feet per day in the upper and middle parts of the glacial aquifer and about 0.4 feet per day near the bottom of the aquifer.

Analytical results of water samples indicate the ground water generally is a calcium-bicarbonate type with a nearly neutral pH. Specific conductivity ranged from 437 to 1,030 microsiemens per centimeter at 25 degrees Celsius in water from wells upgradient from the refinery site and 330 to 3,780 microsiemens per centimeter at 25 degrees Celsius in water from downgradient wells. Barium, iron, manganese, nickel, and zinc commonly were detected in samples of ground water. Volatile organic compounds (including chlorinated solvents and aromatic hydrocarbons) were consistently detected in samples from shallow wells near the boundaries of the former refinery site. Concentrations

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of 1,4-dioxane were detected in water from wells screened in the upper, middle, and lower parts of the aquifer downgradient from the site and in samples of surface water collected approximately 5 miles downstream from where the plume intersects Crumpacker Ditch.

A three-dimensional, four layer ground-water-flow model was constructed and calibrated to match ground-water levels and streamflow measured during December 1997. The model was used to simulate possible mechanisms of contaminant release, the effect of increased pumpage from water-supply wells, and pumping at the leading edge of the plume as a possible means of remediation. Based on simulation of three waste-oil lagoons, a vertical hydraulic conductivity of 0.2 feet per day was required to move contaminants into the bottom layer of the model at a constant leakage rate of about 98 gallons per minute. Simulations of a disposal well in layer 3 of the model indicated an injection rate of 50 gallons per minute was necessary to spread contaminants vertically in the aquifer. Simulated pumping rates of about 300 and 1,000 gallons per minute were required for water-supply wells at the Town of Westville and the Westville Correctional Facility to draw water from the plume of 1,4-dioxane. Simulated pumping from hypothetical wells at the leading edge of the plume indicated that three wells, each pumping 25 gallons per minute from model layer 3, would capture the plume of 1,4-dioxane.

Introduction

In 1997, the U.S. Environmental Protection Agency (USEPA) began a field investigation of the environmental conditions at a former waste-oil refinery in Westville, Ind. As part of this investigation, the U.S. Geological Survey (USGS) completed a study of geohydrology and water quality in the vicinity of the refinery. Previous investigations had detected contamination in soils at the site (ATEC Associates, Inc., 1985) and in off-site ground water (Dames and Moore, Inc., 1996). The site was listed as a Superfund site by USEPA in 1999.

The USGS study included installing monitoring wells, geophysical logging, aquifer testing, measuring ground-water and surface-water levels, measuring streamflow, and collecting water-quality samples. On the basis of a conceptualization of geohydrologic conditions developed from analysis of the collected data, the USGS constructed a ground-water-flow model for the study area. The calibrated model was used to investigate possible mechanisms of contaminant release, the effects of increased ground-water pumpage from nearby water-supply wells on contaminant distribution, and the capability of remediation by pumping from capture wells.

Purpose and Scope

This report presents findings of the USGS investigation of geohydrology and water quality near a former waste-oil refinery in Westville, Ind. A description of the study area with emphasis on the geohydrologic setting is given, as is a description of the methods of data collection and analysis. Selected water-quality data are presented to provide a description of water quality in relation to the site of the former refinery. The report also describes the ground-water modeling completed for this investigation and presents the results of model simulations.

Acknowledgments

The authors gratefully acknowledge the assistance of the municipal staff from the Town of Westville, especially Bart Frank, Utility Superintendent. Mr. Frank provided logistical support during the investigation and served as a liaison between the USEPA, USGS, and the Town of Westville. The assistance of Mark Hale, Street Department Superintendent of the Town of Westville, is appreciated. In addition, Michael A. Gifford, Remedial Project Manager (USEPA), is

credited for his initiation of the project and his assistance during much of the field investigation. The assistance of Terry Roundtree and Michael Collins (USEPA) during the later stages of the investigation and report writing also is appreciated.

Field work was completed by USGS and USEPA personnel and their contractors. Drilling expertise was provided by USGS employees of the Western Region Drilling Services Unit in Denver, Colo. Measuring-point altitudes for ground-water-level measurements and other reference marks were surveyed by Jim Kiel of Jim Kiel and Associates, Land Surveyors. Employees of Ecology and Environment, under the direction of Christianne Ottinger, provided assistance during field activities throughout the study. Robert Kay and Patrick Mills of the USGS Illinois District assisted during well installation and sampling. David Cohen and Leslie Arihood of the USGS Indiana District constructed and calibrated the ground-water-flow model.

Description of the Study Area

The site of the former waste-oil refinery (hereafter referred to as the "refinery site" or the "site"), in section 29 of Township 36 North, Range 4 West, on the Westville 7.5-minute quadrangle (U.S. Geological Survey, 1969), is on the north side of Westville in LaPorte County, Ind. The site consists of approximately 15 acres west of the intersection between U.S. Highway 421 and Indiana Highway 2. The study area (fig. 1) is within LaPorte and Porter Counties. In LaPorte County, the study area is defined roughly by County Road 200 South to the north, Wozniak Road to the east, and County Road 800 South to the south. The western boundary for the study area is approximated by County Road 600 East in Porter County.

Although land use surrounding Westville is principally agricultural, local industry includes automobile salvage, trucking, and package shipping and delivery. Agricultural land use predominates immediately to the north and west of the site; residential areas are immediately south and east. An abandoned railroad grade runs along the western edge of the site. The Westville Correctional Facility, operated by the Indiana Department of Correction, is approximately 1 mi south from the center of town.

The water supply for the Town of Westville is drawn from glacial deposits of sand and gravel. At the time of this study, the Town had two water-supply wells (MUN-1 and MUN-2); however, only the western-most well (MUN-1) was pumped on a regular basis. The Town was in the process of establishing a new well field 0.5 mi east of the refinery site (fig. 1). The new well field became operational in February 2000 (after data collection for this study was completed) and the two previous water-supply wells were plugged (Bart Frank, Town of Westville, written commun., 2001). The Westville Correctional Facility has three wells that pump from the same glacial deposits. Numerous privately owned domestic water-supply wells are in use throughout the study area.

Site History

In the mid-1930's, a waste-oil refinery began operations in Westville, Indiana (U.S. Environmental Protection Agency, 1999). The refinery included numerous storage tanks, a filter press, several cracking towers, and a cannery. Waste oil was purchased from a variety of generators and cleaned and refined for automotive and industrial applications.

Lagoons for storing waste oil were constructed at the refinery prior to 1951 and were in use when the site was closed in 1987 (Kartman, 1999). The lagoons were excavated in the native sandy soils and had no bottom liners to prevent the contents from seeping into the ground. Several lagoons had overflowed during heavy precipitation, releasing contaminants to nearby streams (U.S. Environmental Protection Agency, 1999).

After refinery operations ceased in February 1987, the facility remained vacant until 1999, when the refinery works were dismantled and removed. As early as 1984, environmental investigations documented that soils at the site were contaminated with polychlorinated biphenyls (PCB's), volatile organic compounds (VOC's), and lead (ATEC

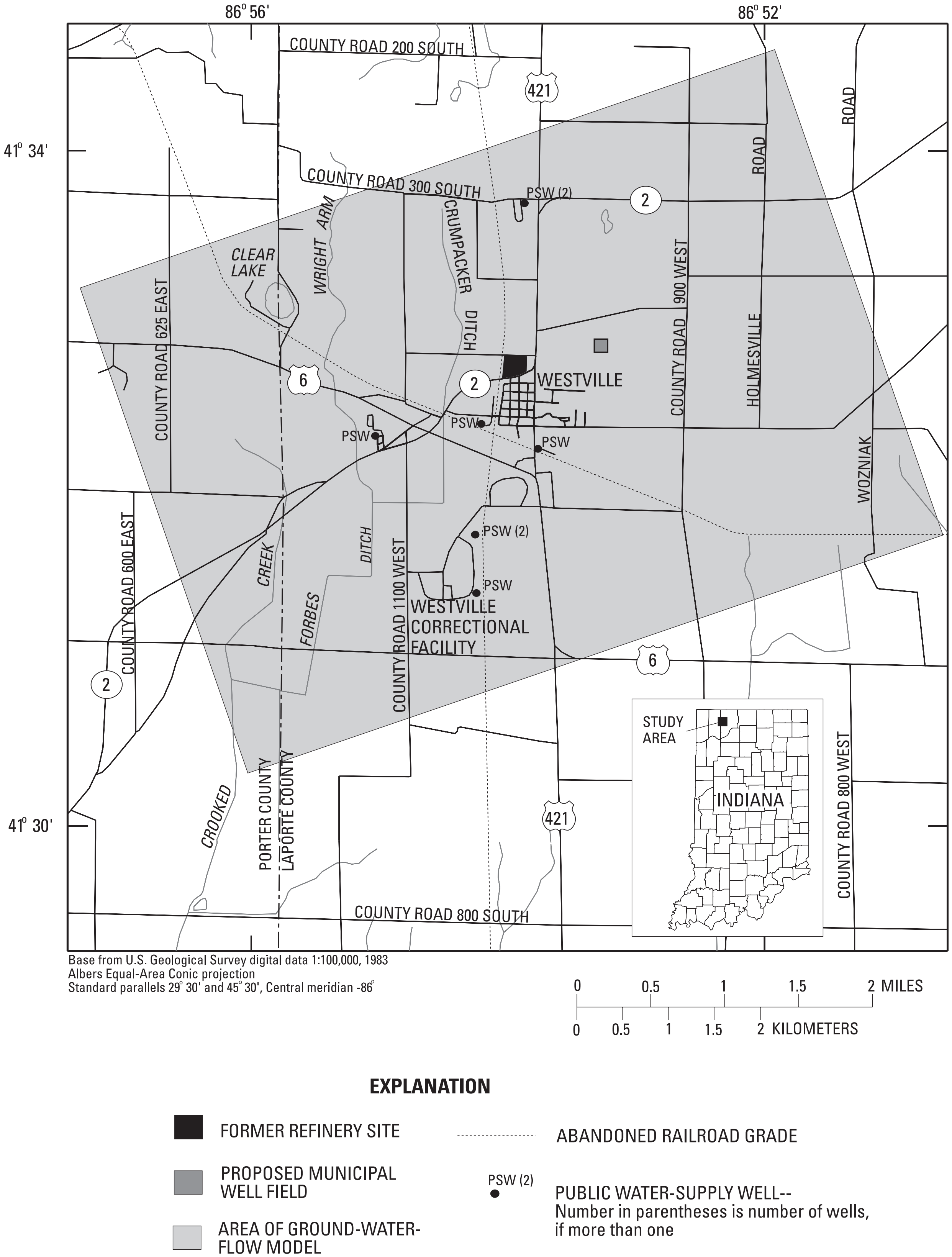


Figure 1. Study area in LaPorte and Porter Counties, Indiana.

Associates, Inc., 1985). By 1996, a less-commonly reported contaminant, 1,4-dioxane, was found in off-site ground water (Dames and Moore, Inc., 1996).

Climate

The climate of the study area is characteristic of the northern midcontinent. Average monthly temperatures range from about 25°F during January to 77°F during July, and the average annual temperature is approximately 50°F (Midwestern Climate Center, 2001). The National Weather Service operates a weather station at Valparaiso, Ind., approximately 9 mi southwest of the refinery site, and one at LaPorte, Ind., approximately 10.5 mi northwest of the site. National Weather Service data from 1961 through 1990 indicate the average annual precipitation is about 40 inches. Average precipitation by month ranges from about 2 to 4 inches and is nearly equally distributed, with slightly more precipitation during spring and summer months compared to fall and winter.

Physiographic and Geohydrologic Setting

A general description of the physical setting of the study area was derived from previous studies completed in LaPorte and Porter Counties (Malott, 1922; Shaver and others, 1986; Indiana Department of Natural Resources, 1990; Fraser and Bleuer, 1991a and 1991b; Bleuer and Woodfield, 1993) and from the Hydrogeologic Atlas of Aquifers in Indiana (Fenelon, Bobay, and others, 1994).

The study area is characterized by rolling terrain to the north and west and generally flat terrain to the south and east. Surface drainage generally is to the south and southwest. The stream nearest the site is the Crumpacker Arm of Forbes Ditch (hereafter referred to as “Crumpacker Ditch”). Crumpacker Ditch discharges into Forbes Ditch, which discharges into Crooked Creek (fig. 1) and then into the Kankakee River, approximately 21 mi southwest of the refinery site.

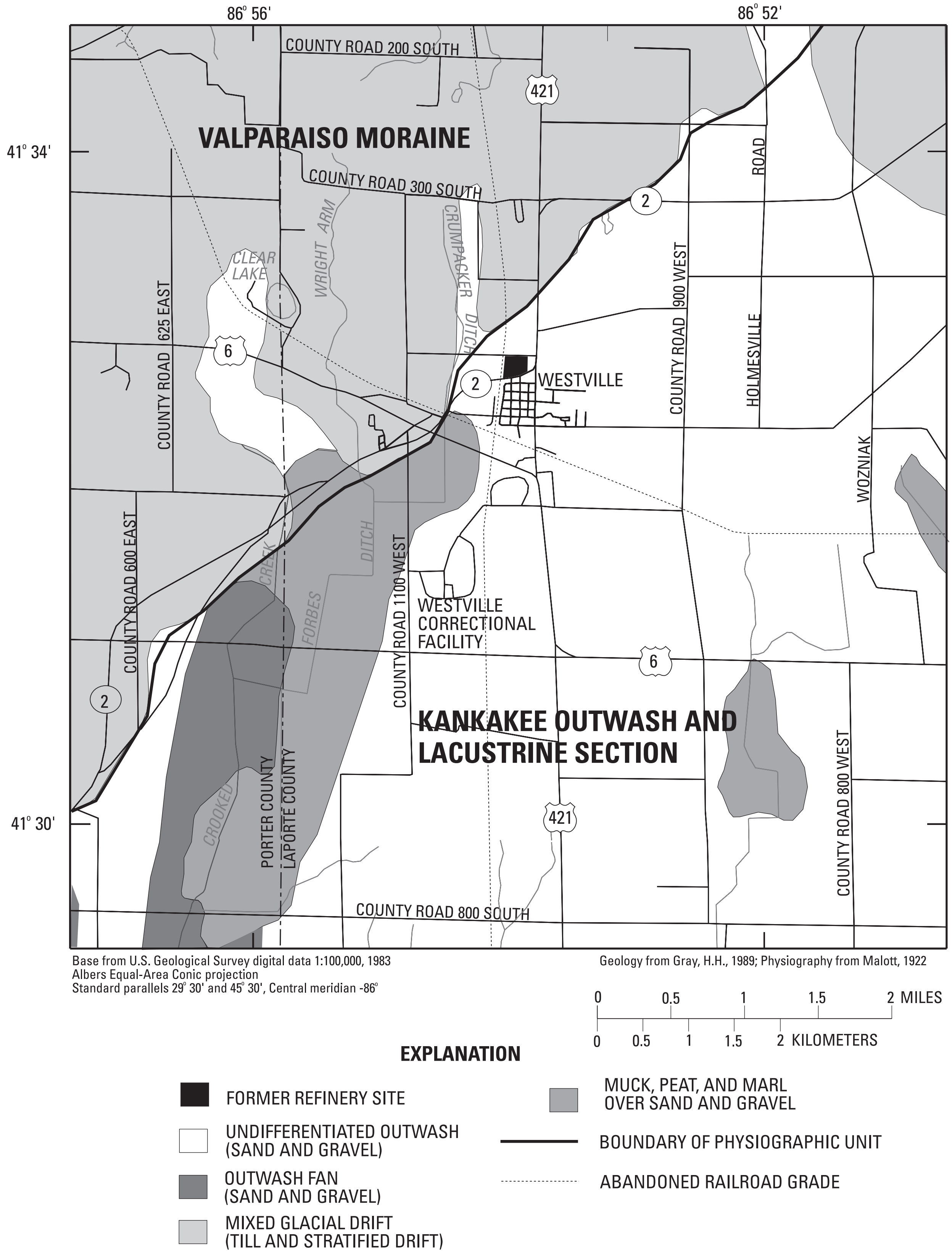
Malott (1922) defined and described the physiographic regions of Indiana and, in some cases, subdivided regions into sections. Within this framework, the study area is in the Northern Moraine and Lake Region and lies on the boundary between the Kankakee Outwash and Lacustrine Section and the Valparaiso Moraine (fig. 2). Soils in the study area are described as moderately to well drained (U.S. Department of Agriculture, 1982).

The Kankakee Outwash and Lacustrine Section is an intermorainal lowland, trending northeast to southwest and primarily consisting of thick wind- and water-deposited sand and gravel (Fraser and Bleuer, 1991b, p. 1). In scattered areas, the sand and gravel are overlain by thin, discontinuous deposits of muck, peat, and marl (fig. 2). Lacustrine clay and silt underlie the sand and gravel.

The Valparaiso Moraine is a topographic high that curves around the southern end of Lake Michigan. In most areas, the Valparaiso Moraine contains three types of deposits. At the base and resting directly on bedrock are relatively continuous and widespread lacustrine deposits of clay and silt. The core of the moraine primarily is sand, while clayey till caps the moraine (Fraser and Bleuer, 1991a, p. 2–3). Near their common boundary, the sand units of the Valparaiso Moraine and the Kankakee Outwash are interfingered. Clayey till is present in some locations near the northern and western boundaries of the study area.

The sand forming the core of the Valparaiso Moraine and the sand in the Kankakee Outwash and Lacustrine Plain are hydraulically connected and have similar hydraulic properties. These sand units form the principal aquifer within the study area. Northwest of the refinery site, the aquifer is part of the Valparaiso Moraine; at and south of the site, the aquifer is part of the Kankakee Outwash. In the study area, the deposits of sand average about 150 ft in thickness.

The Ellsworth Shale of Devonian and Mississippian Age underlies the unconsolidated deposits. The Ellsworth Shale contains alternating beds of grayish-green and brownish-black shale with thin and discontinuous lenses of limestone and dolomite (Shaver and others, 1986, p. 42). In the study area, bedrock altitudes range from less than 600 ft above sea level to the north to greater than 650 ft above sea



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

Geology from Gray, H.H., 1989; Physiography from Malott, 1922

Figure 2. Physiographic regions and surficial geology in the study area in LaPorte and Porter Counties, Indiana.

level to the south. A map of the bedrock surface in Indiana shows a bedrock valley, or trough, trending from southeast to northwest in the study area (Gray, 1982).

Methods of Data Collection and Analysis

This investigation included installation and geophysical logging of monitoring wells, measurement of water levels, hydraulic testing of the aquifer, determination of ground-water and surface-water interactions, collection and analysis of water-quality samples, and development and testing of a ground-water-flow model. The methods used were those of the USEPA (1992, 1993a, 1993b, and 1993c) or the USGS (Rantz and others, 1982; Lapham and others, 1997; Wilde and others, 1998).

Previous Monitoring-Well Network

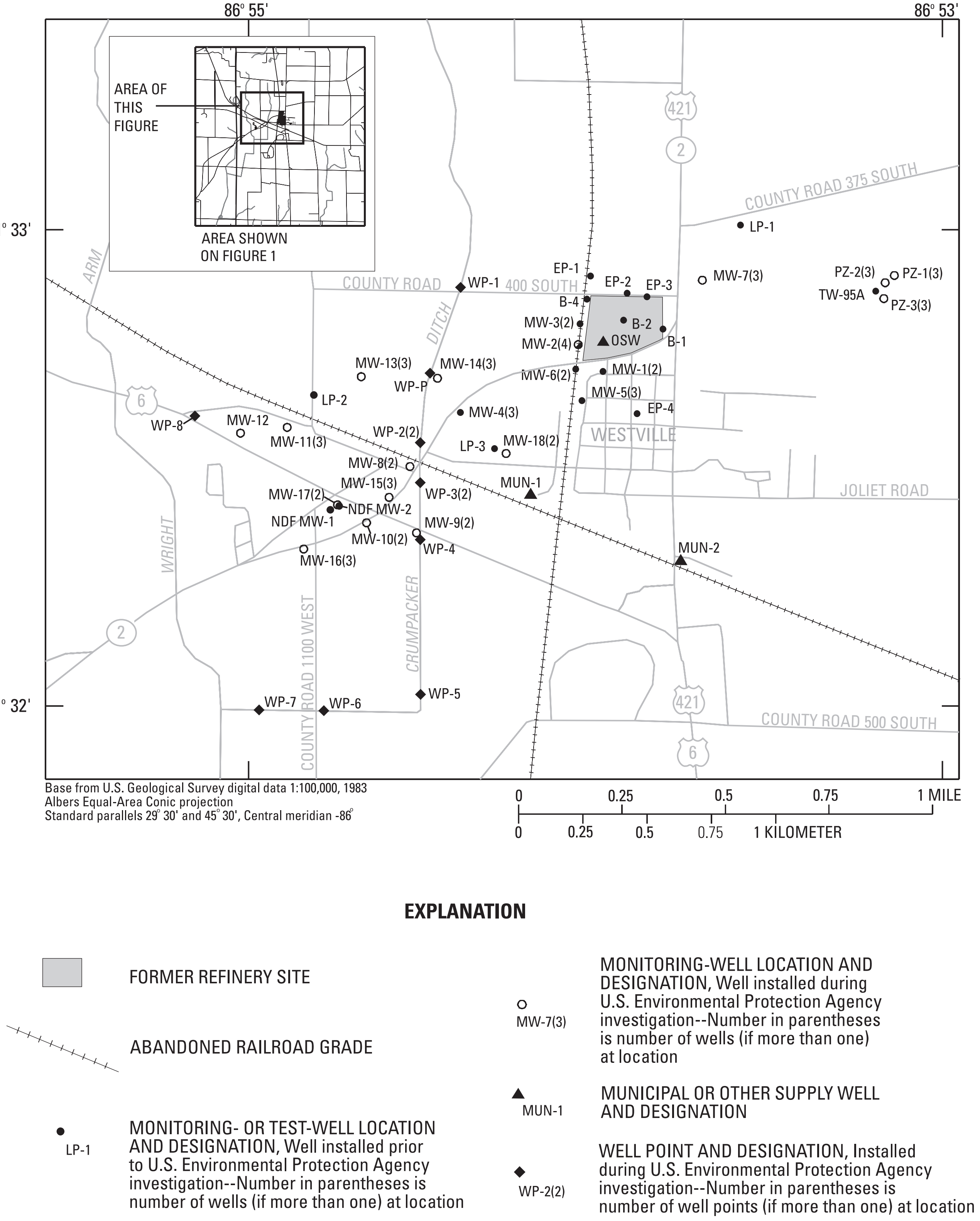
Prior to this investigation, monitoring wells were installed for several geotechnical or environmental studies at the former refinery site (fig. 3). Four wells (wells B-1 through B-4) were installed at the site during 1985 (ATEC, Associates, Inc., 1985). Well B-3, near the southwest corner of the site and not shown on figure 3, was destroyed prior to this investigation. In 1986, the LaPorte County Health Department installed wells LP-1 through LP-3 northeast and southwest of the site (EIS Environmental Engineers, Inc., written commun. to LaPorte County Health Department, 1986). Four wells were installed by the USEPA in 1987—two wells (wells EP-2 and EP-3) along the northern site boundary, one well (well EP-1) along the abandoned railroad grade northwest of the site and one well (well EP-4) in a residential area south of the site. Studies completed by Dames and Moore, Inc., (1996) resulted in the installation of 14 wells at sites MW-1 through MW-6. These sites generally are west and south of the refinery; and at each site, two or three wells were completed at different depths. Data for this investigation were collected from all of the wells installed for previous studies.

Several wells not associated with previous studies of the refinery also were used for this investigation. Water levels were measured in an abandoned well on the refinery site (well OSW, which was rehabilitated during the investigation) and in two wells (wells NDF-MW-1 and NDF-MW-2) installed at a gasoline station approximately 1 mi southwest of the site (EMES, Inc., 1992). The NDF wells also were sampled for water quality. A test well (well TW-95A) installed for the Town of Westville (Peerless-Midwest, Inc., 1996) was used to measure water levels and served as the pumped well for the multiple-well aquifer test. In addition, the USEPA collected water-quality samples from privately owned water-supply wells in the study area.

Installation of Monitoring Wells and Well Points

For this investigation, 31 monitoring wells (for collection of water levels and water samples) were installed to various depths at 13 sites (site MW-2 and sites MW-7 through MW-18) and 9 observation wells (for collection of water levels) were installed at sites PZ-1 through PZ-3 (fig. 3) at the Town of Westville’s new well field. Well installation was completed in three phases. Twenty-three wells were installed at sites MW-2, MW-7 through MW-11, and PZ-1 through PZ-3 during March–May 1997; 7 wells were installed at sites MW-12 through MW-14 during September 1997; and 10 wells were installed at sites MW-15 through MW-18 during November 1997 (table A1, at the back of the report). Site locations for each phase of well installation were selected based upon evaluation of the data collected from previously installed wells.

The vertical placement of the well screens and the well-naming convention initially were consistent with those used for wells installed by Dames and Moore, Inc. (1996), whereby an “S” indicates a water-table well, “D” indicates a well screened near the middle of the aquifer (generally 80 ft deep) and “XD” indicates a well screened at the bottom of the aquifer (approximately 148 to 210 ft deep). An additional category of wells, designated with “MD,” was installed at sites MW-2, MW-15, MW-17, and PZ-1 through PZ-3. The MD wells generally are between 100 and 150 ft deep. Placement of the well screen for D and MD wells at sites MW-15



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

EXPLANATION

▨ FORMER REFINERY SITE

ABANDONED RAILROAD GRADE

● LP-1 MONITORING- OR TEST-WELL LOCATION AND DESIGNATION, Well installed prior to U.S. Environmental Protection Agency investigation--Number in parentheses is number of wells (if more than one) at location

○ MW-7(3) MONITORING-WELL LOCATION AND DESIGNATION, Well installed during U.S. Environmental Protection Agency investigation--Number in parentheses is number of wells (if more than one) at location

▲ MUN-1 MUNICIPAL OR OTHER SUPPLY WELL AND DESIGNATION

◆ WP-2(2) WELL POINT AND DESIGNATION, Installed during U.S. Environmental Protection Agency investigation--Number in parentheses is number of well points (if more than one) at location

Figure 3. Locations of monitoring wells, well points, and other wells used during the study of geohydrology and water quality near Westville, Indiana.

through MW-18 was determined from interpretation of geophysical logs.

Well drilling was completed using 4.25-in. inside-diameter hollow-stem augers. The boreholes were logged lithologically from cuttings returned to land surface and by observation of the drill rig during drilling. Attempts were made to collect samples of the aquifer sediments during drilling at site MW-7; however, hydrostatic pressure caused sand to heave upwards into the augers when the plug at the bottom of the augers was removed to obtain a sample, even at shallow depths of 20 ft below the water table.

Water used for drilling operations was obtained from the Westville municipal water system. Samples of the water were analyzed several times during the three phases of well installation. Based on the analytical results, no contaminants associated with the refinery site were detected. The drilling rig, augers, and equipment were cleaned between each drilling location with a high-pressure, hot-water cleaner.

With the exception of well MW-12, all wells are constructed of 2-in.-diameter schedule 40 polyvinyl chloride (PVC) risers with type 304, 10-slot, stainless-steel well screens. Wells screened across the water table (S wells) are constructed with 10-ft-long screens. Wells screened below the water table (M, MD, and XD wells) are constructed with 5-ft-long screens.

The well screen and riser pipe were installed through the augers and the aquifer sediments (sand) were allowed to collapse around the well screen. If the collapsed sand did not rise at least 2 ft above the top of the screen, a filter pack of coarse, washed quartz sand was placed down the annular space between the augers and riser pipe. A high-solids bentonite grout was used to fill the borehole above the filter pack as the augers were removed. A 6-in.-square outer protective casing with a lock was installed around each well and set in place in a concrete pad.

The drilling rig could not reach the MW-12 site—at this location, a 2-in. hole was excavated with a hand-turned bucket auger to a depth of 17 ft. A 10-ft stainless-steel screen with a drive point and a stainless-steel riser were lowered into the hole. The well was driven approximately 3 more feet into the underlying materials with a fence-post driver. Bentonite chips were used to grout the annular space from 2 to 3 ft below ground level. The remaining construction details for well MW-12 are the same as those described for the other wells.

To remove fine sand and silt that accumulated in and around the well screen during installation and to assure hydraulic connection between the well and the aquifer, the wells were developed by vigorous surging, bailing, and/or overpumping. Well-development progress was measured by monitoring field water-quality characteristics, primarily turbidity. Development ceased when successive measurements of turbidity were 5 or less nephelometric turbidity units (ntu) after surging, or when a volume of water greater than 10 times that used to install the well was removed.

Well points (WP) 1 through 7 and well point WP-P were installed at selected locations along Crumpacker Ditch (fig. 3). Data collected from the well points aided the interpretation of ground-water/surface-water interactions. Well point WP-8 was installed to determine the relation between ground water and a small pond near an area where 1,4-dioxane was detected in water from a privately owned water-supply well.

Well points were constructed of 2-in.-diameter stainless steel and had 1- or 2-ft-long screens and short (about 5 ft) risers. The well points were installed by hand augering into the streambed sediments as deeply as possible and then driving the screen and riser to the desired depth. The top of the well screen was installed deep enough into the streambed so that sediments would provide a seal around the well riser above the top of the screen and isolate the screen from the surface water. In general, the tops of the screens were greater than 1.6 ft below the streambed; the screen for WP-8 was 1.2 ft beneath the bottom of the small pond.

The altitudes of the tops of the concrete pads for the monitoring wells and the tops of the well risers for the monitoring wells and well points were surveyed by a professional land surveyor licensed by the State of Indiana. Altitudes of the streambed at the well-point locations also were determined by the surveyor. A few locations were surveyed by the USGS and USEPA. Latitude and longitude were determined at each location by USEPA personnel, using a global-positioning system capable of reporting to 0.01 second of latitude or longitude. Selected information about the wells used for this investigation is listed in table A1 at the back of the report.

Geophysical Logging

Borehole geophysical surveys of natural gamma, electromagnetic induction, and neutron absorption were completed in selected monitoring wells to acquire lithologic data as well as information that may be related to the movement of contaminants in the aquifer. The wells were logged by the USGS Borehole Research Group, by the USGS Indiana District, and by the USEPA Superfund Division (table 1). Selected wells in the area of ground-water contamination were logged for electromagnetic induction periodically during the study.

Natural gamma logs measure the relative amounts of naturally occurring gamma radiation in geologic materials. This radiation is primarily the result of the decay of the radioisotopes Potassium-40, Uranium-238, and Thorium-232. These radioisotopes are most commonly associated with clay minerals; therefore, natural gamma logs can be used to interpret the relative amounts of clay in a deposit (Keys and MacCary, 1971, p. 64–65).

Electromagnetic induction logging measures the decay of an electrical field in geologic materials when an electrical field is induced and then removed. The electromagnetic log indicates the conductivity of the geologic materials, which is controlled primarily by water content. If no other factors are present, the electromagnetic log should correlate closely with the natural gamma log. For example, if more clay is present (higher natural-gamma response), then a higher electromagnetic response is expected. Electromagnetic logs, however, also are sensitive to the conductivity of fluids in the aquifer. If a ground-water contaminant that increases conductivity is present, a higher electromagnetic reading is expected (Mack, 1993).

Table 1. Summary of subsurface geophysical logging completed in monitoring wells near Westville, Indiana

[NG, natural gamma; EM, electromagnetic induction; USGS, U.S. Geological Survey; IN, Indiana District; N, neutron; BRG, Borehole Research Group; USEPA, U.S. Environmental Protection Agency]

Well name	Date logged	Type of logs	Logged by
MW-2XD	07/02/97	NG, EM	USGS-IN
	11/02/97	NG, EM, N	USGS-BRG
MW-4XD	11/25/96	EM	USEPA
	07/02/97	NG, EM	USGS-IN
	05/10/00	EM	USEPA
MW-7XD	07/01/97	NG, EM	USGS-IN
	11/01/97	NG, EM, N	USGS-BRG
MW-8D	07/01/97	NG, EM	USGS-IN
	11/02/97	NG, EM, N	USGS-BRG
MW-9XD	07/01/97	NG, EM	USGS-IN
MW-10XD	07/01/97	NG, EM	USGS-IN
	11/02/97	NG, EM, N	USGS-BRG
	08/18/99	EM	USEPA
	05/10/00	EM	USEPA
	08/25/00	EM	USEPA
MW-11XD	07/01/97	NG, EM	USGS-IN
MW-13XD	11/01/97	NG, EM, N	USGS-BRG
MW-14XD	11/01/97	NG, EM, N	USGS-BRG
MW-15XD	11/12/97	NG, EM	USGS-IN
	08/18/99	EM	USEPA
	05/10/00	EM	USEPA
	08/25/00	EM	USEPA
MW-16XD	11/14/97	NG, EM	USGS-IN
MW-17XD	11/14/97	NG, EM	USGS-IN
PZ-1XD	11/1/97	NG, EM, N	USGS-BRG
PZ-2XD	11/1/97	NG, EM, N	USGS-BRG
PZ-3XD	11/01/97	NG, EM, N	USGS-BRG
TW-95A	11/25/96	NG, EM	USEPA
	11/01/97	NG, EM, N	USGS-BRG

Neutron absorption logging measures hydrogen content, which correlates to water content and porosity of the aquifer materials (Keys and MacCary, 1971, p. 74). The neutron tool uses a radioactive source to emit radioactive particles that are absorbed by hydrogen atoms, a principle component of water. A high neutron count indicates few neutrons are being absorbed by hydrogen/water, which in turn indicates low aquifer porosity.

Aquifer Hydraulic Testing

Single-well and multiple-well aquifer testing were used to characterize the hydraulic properties of the geologic materials in the study area. Analysis of single-well aquifer-test data provided estimates of horizontal hydraulic conductivity of the aquifer sediments in the vicinity of the well screen. Analysis of data collected during the multiple-well aquifer test provided estimates of horizontal and vertical hydraulic conductivity, transmissivity, and specific yield for a larger part of the aquifer than that tested by the single-well method. Information from the aquifer tests was used to estimate the rate of ground-water flow through the aquifer.

Single-Well Aquifer Tests

Single-well aquifer tests (slug tests) were completed in 48 of the monitoring wells to provide estimates of horizontal hydraulic conductivity of the aquifer. Hydraulic conductivity is determined from the rate of rise or fall of the water level in a well after a known volume or "slug" of water is displaced suddenly. Generally, the faster the water level returns to its pre-test static level, the higher the hydraulic conductivity of the aquifer sediments around the well screen. Falling-head and rising-head slug tests were completed as appropriate for the type of well being tested.

To complete a falling-head slug test, the static water level in the well was measured and a submersible pressure transducer was placed in the well approximately 10 ft below the water surface. The water level was allowed to stabilize; then, a solid cylindrical polyvinyl chloride (PVC) slug with a known volume was inserted quickly into the water column and water-level changes with time were recorded by a data logger. Data were collected until the water level returned to and stabilized at or near the pre-test static level. After completing the falling-head slug test, a rising-head slug test was done by rapidly removing the PVC slug from the water column and monitoring the water-level response. For the S-series wells (wells with the screened interval intersecting the water table), only rising-head tests were completed.

For most of the slug tests, the water level responded in a decreasing exponential manner in returning to the pre-test static water level (fig. 4A). This type of response is referred to as the overdamped response (van der Kamp, 1976, p. 5). For several of the tests, water levels quickly returned to, rose above, and then returned to the static level, indicating a critically damped response

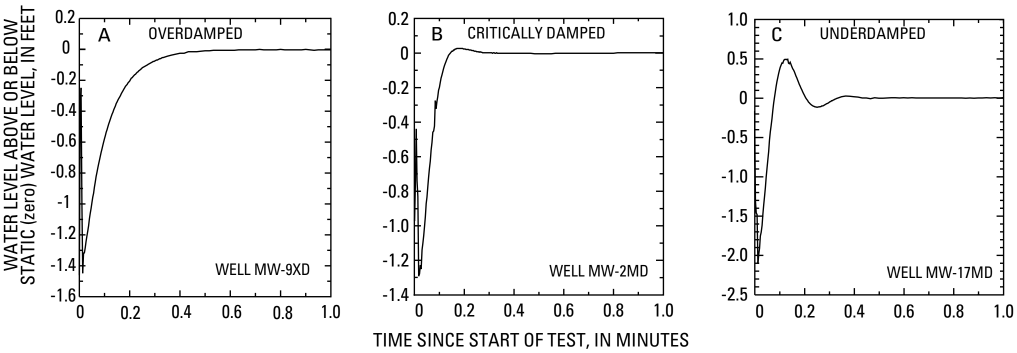


Figure 4. Examples of common responses of water levels to slug tests in monitoring wells near Westville, Indiana; (A) overdamped response, (B) critically damped response, and (C) underdamped response.

(fig. 4B). For a few of the tests, water levels oscillated above and below the static water level, providing an underdamped response (fig. 4C). The oscillatory responses of the critically damped and underdamped conditions are often indicative of highly permeable aquifer materials (Sepulveda, 1992, p. 1).

The analytical method of Bouwer and Rice (1976) and Bouwer (1989) was used to analyze data from tests that resulted in an overdamped response. Although this method was developed to analyze data from rising-head tests, it also is appropriate for falling-head tests provided that the pre-test static water level is above the screened interval of the tested well. Tests that resulted in an underdamped response were analyzed using the method of van der Kamp (1976) which provides an estimate of transmissivity. Horizontal hydraulic conductivity was calculated by dividing the transmissivity by the screen length. An appropriate analytical method was not determined for slug tests that resulted in critically damped responses, and horizontal hydraulic conductivity was not calculated.

The Bouwer and Rice (1976) and the van der Kamp (1976) methods assume the following conditions:

- The aquifer is homogeneous and isotropic.
- Drawdown of the water table in the vicinity of the well is negligible.
- Flow above the water table (in the capillary fringe) can be ignored.
- Head loss, as the water enters the well, is negligible.

All of these conditions are probably met or at least approximated in the glacial aquifer in the vicinity of the well screens. The Bouwer and Rice (1976) method was developed for unconfined aquifers. The method of van der Kamp (1976) assumes a fully penetrating well in a confined aquifer; however, if vertical hydraulic conductivity is small compared to horizontal hydraulic conductivity, the flow induced by the small stress applied by the test should be primarily horizontal. In addition, wells for which slug-test data showed an underdamped response were in the MD or XD series, where the depth below the water table would partially confine the aquifer. Therefore, the assumption was made that the Bouwer and Rice and the van der Kamp methods would provide reasonable estimates of horizontal hydraulic conductivity.

Multiple-Well Aquifer Test

A constant-discharge, multiple-well aquifer test was completed at the Town of Westville's new well field (fig. 1). Analysis of the test results provided estimates of horizontal and vertical hydraulic conductivity, transmissivity, and specific yield for the aquifer. The location for the aquifer test was selected because of the presence of a 5-in.-diameter test well (TW-95A) at the site. In addition, the location was not near the area of ground-water contamination and therefore avoided the need to treat the pumped water prior to disposal.

The aquifer test was divided into three phases. The first phase consisted of pre-test monitoring of water levels in wells LP-1; MW-7S, D, and XD; MW-5S and XD; and PZ-1S, MD, and XD (locations shown on fig. 3). Water levels were collected every half hour by use of submersible pressure transducers and data loggers. The water-level data were inspected to identify the presence and magnitude of background trends in ground-water levels that might affect interpretation of drawdown in the observation wells during pumping. The second phase of the aquifer test consisted of pumping well TW-95A at a rate of 86 gal/min for 3,048 minutes (a little more than 2 days) and monitoring water levels in wells at sites PZ-1, PZ-2, and PZ-3. Water levels also were monitored in background wells during pumping to determine if ambient processes were affecting the test results. The third phase of the aquifer test consisted of monitoring the recovery of water levels in all the observation wells and in the pumped well once the pumping ceased. Recovery was monitored for 2,440 minutes, by which time all water levels had recovered to, or above, the pre-pumping water levels.

During the test, water levels were monitored using submersible pressure transducers rated at 0-5 psi or 0-10 psi in all of the wells except the pumped well. These transducers are capable of accurately detecting water-level changes of 0.01 ft.

Water levels in the pumped well were monitored with a 0-30 psi transducer capable of accurately detecting water-level changes of 0.05 ft. Water levels were recorded by data loggers. The frequency of data collection was determined by the elapsed time since pumping started or ceased. Water levels were recorded every 0.0083 minutes during the first minute after starting or stopping the pump, every 0.2 minutes from 1 to 10 minutes, every 2 minutes from 10 to 100 minutes, and every 15 minutes after 100 minutes. The accuracy of the water levels obtained with the pressure transducers was checked periodically with manual measurements, using an electric tape.

Barometric pressure was measured and recorded during the aquifer test and precipitation was measured at one manual gage and one automated gage, both approximately 1 mi southwest of the test location. Barometric-pressure readings were compared with water levels in the background wells to determine the effect of barometric-pressure fluctuations on ground-water levels during pumping. Changes in ground-water levels caused by changes in barometric pressure and precipitation in wells that were unaffected by the pumping were applied when necessary to correct drawdown data from the affected wells.

A flowmeter was connected to the discharge line to monitor whether discharge from the pumped well remained constant. Water was pumped from well TW-95A into two holding tanks. Another pump was used to move the water from the holding tanks to a Town of Westville sewer, a distance of about 1,000 ft. The holding tank had a series of inner compartments with baffles that restricted the flow of water among compartments; this caused the compartment into which the water was pumped to overflow. Because the pump and discharge hose to the sewer did not have the capacity to accept all of the water pumped from the well, some water was discharged onto the ground approximately 500 ft southwest of the pumped well.

Data from the multiple-well aquifer test were analyzed using AquiferTest software developed by Waterloo Hydrogeologic, Inc. (Roenrich, not dated). On the basis of an analysis of the geohydrologic data collected in the study area and inspection of the aquifer-test data, a method of analysis described by Moench (1993 and 1995) was selected as the most appropriate. This method, which is based in part on Neuman's (1972 and 1974) method for partially penetrating pumping and observation wells in unconfined aquifers, also allows for delayed yield from the unsaturated zone that results as the water table is lowered. The assumptions for the use of Moench's analysis are

- The aquifer is infinite in extent, homogeneous, and isotropic.
- Drawdown is small compared to the saturated thickness of the aquifer.
- The water table is horizontal prior to pumping.
- The well is pumped at a constant rate.
- The diameter of the pumped well is small enough that well storage is negligible.

These conditions were met or approximated at the test site.

The method of Moench (1993) required water-level data from the pumped well and one or more observation wells; distances between wells; pumping rate; and well characteristics such as diameter, depth, and length of well screen. The AquiferTest software uses the input data to determine the appropriate type curve(s) for the analysis. The software calculates aquifer properties of transmissivity, horizontal and vertical hydraulic conductivity, and specific yield as the plotted water-level data are moved interactively on the computer screen to obtain the best fit between the type curve and the data.

Water-Level Measurements

Measurements of surface- and ground-water levels were made in monitoring wells and at selected well points within the study area to determine the altitude of the water surface, identify directions of flow, and characterize surface-water and ground-water interactions. Measurements were made approximately bimonthly from June 1997 through July 1998 and intermittently from May 1999 through August 2000. The measurements provide information about the seasonal fluctuations of water levels and whether changes in ground-water-flow directions may occur with fluctuations.

Water-level measurements were made with an electric tape and were referenced to the surveyed point on each well. Generally, two or more measurements were made to confirm the result. The altitude of the surface water at each well-point location also was determined by measuring from the reference point. Water-level measurements from the well points were used to determine the magnitude and direction of hydraulic gradients across the streambed of Crumpacker Ditch and the bottom sediments of a small pond.

Water levels were monitored continuously in the wells at sites MW-4 and MW-5 and in well LP-3 (locations shown on fig. 3) for approximately 3 months in summer 1997. Water levels were monitored by use of submersible pressure transducers, and data were recorded hourly. Precipitation, barometric pressure, and pumping from the municipal-supply well for the Town of Westville also were monitored. The data were used to investigate the possible influence of pumping on the contaminant plume. The summer months were selected for monitoring because water demand, and therefore pumping rates, generally are greatest during these months.

Streamflow and Seepage Measurements

Streamflow was measured at selected locations in Crumpacker Ditch, Wright Arm, Forbes Ditch, and Crooked Creek (fig. 5). The times of measurement correspond with ground-water-level measurements or sample collection. The same locations were not measured each time because some locations were dropped and new locations were added. Streamflow measurements were used to estimate the contribution of ground water to surface-water flow. If no rain occurs prior to the measurements and if other sources of inflow are considered, the difference between streamflow at two locations along a stream indicates the volume of water gained or lost in the intervening reach.

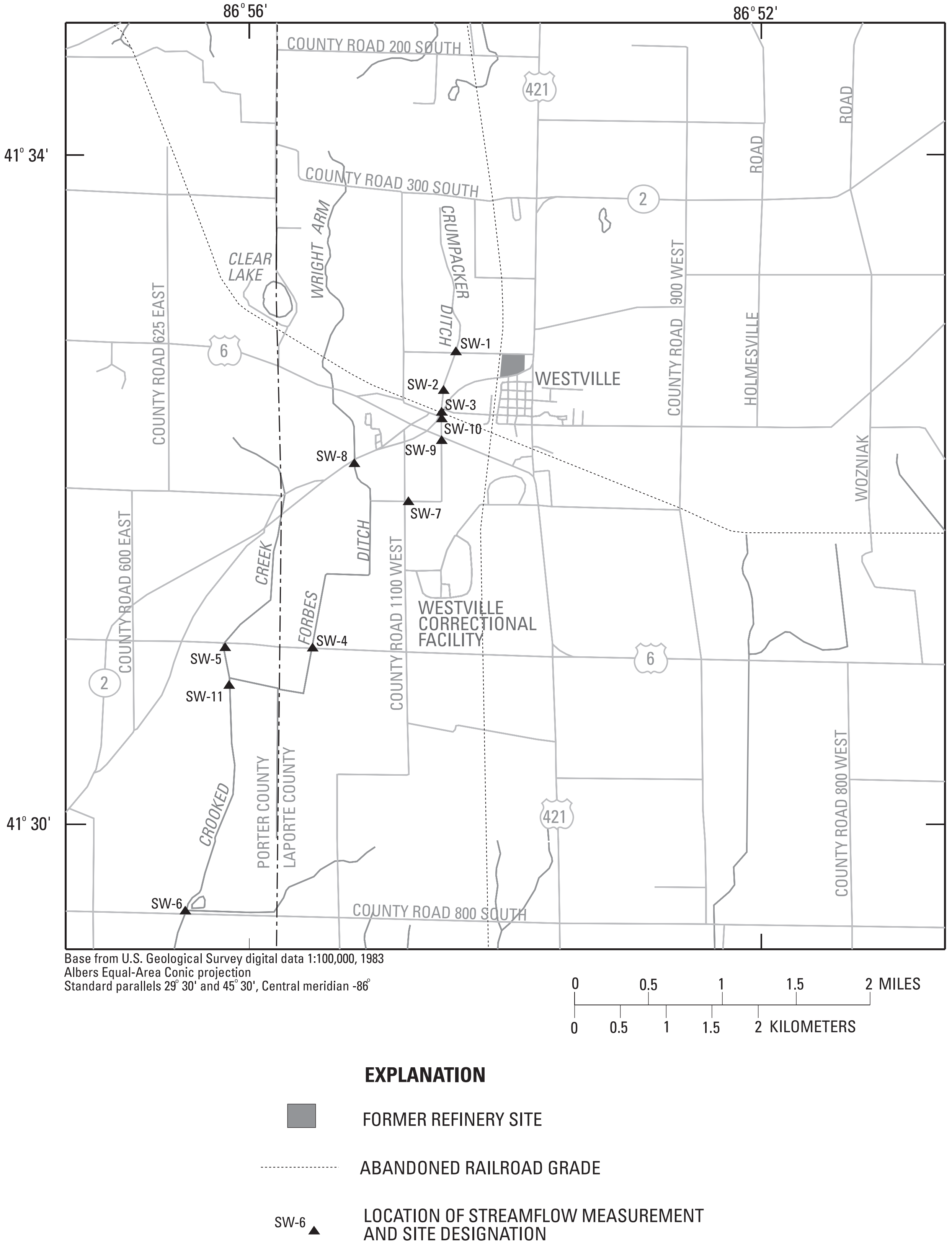
Streamflow measurements were made according to techniques described by Rantz and others (1982). Measurements were made with a standard Price pygmy or Price type AA current meter. The meter was connected to an AquaCalc computer that calculates the volume of flow based on the velocity from the meter and the cross-sectional area from measurements input by the hydrographer. During periods of very low flow, such as in August and December 1997, a Parshall flume was used at site SW-1 to determine streamflow according to methods described by Kilpatrick and Schneider (1983).

Seepage measurements were made near selected well points in Crumpacker Ditch, using seepage meters developed for this investigation. Measurements were made as part of the investigation of the relation between ground-water flow and Crumpacker Ditch; these measurements augment the streamflow data and water-level data collected from the well points. The measurements provide an estimate of the volume of ground water entering the stream at the location of the seepage meter.

Seepage meters were constructed of 8-in.-diameter, 16-in.-long PVC pipe. A nipple was connected to the pipe and extended through the outer wall so that plastic tubing could be attached. The seepage meter was pushed 3 to 4 in. into the streambed (fig. 6) to obtain a seal around the meter and to position the nipple below the water surface in the stream. Plastic tubing was attached to the nipple, and a plastic bag was attached to the tubing. Rocks were used as weights to hold the plastic bag beneath the water surface. For each measurement, the bag was allowed to collect water for approximately 24 hours. The volume of water in the bag was measured, and seepage into the stream was calculated based upon the elapsed time, the volume of water collected, and the cross-sectional area of the seepage meter.

Water-Quality Sample Collection and Analysis

Samples of ground water and surface water were collected and analyzed to document water-quality conditions in the vicinity of the refinery site. Ground-water samples were collected from monitoring wells, well points, and privately owned water-supply wells. Surface-water samples were



Base from U.S. Geological Survey digital data 1:100,000, 1983
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Figure 5. Locations of streamflow measurements near Westville, Indiana.

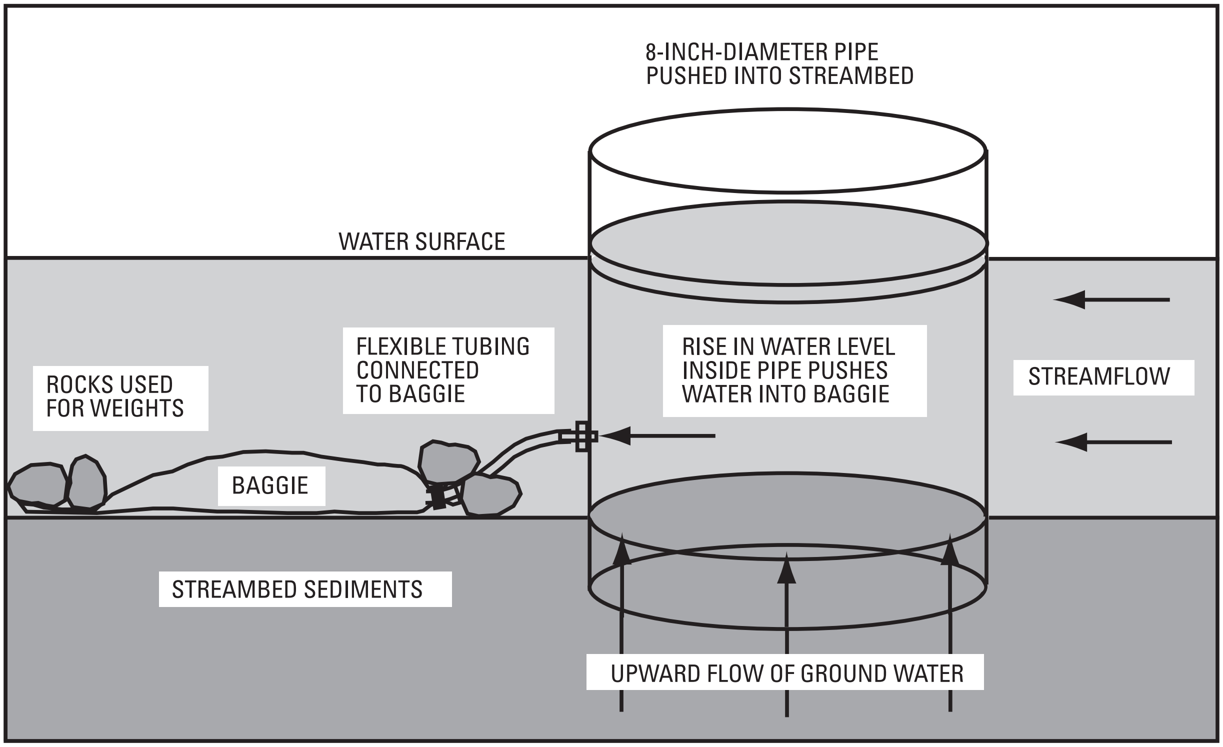


Figure 6. Diagram of seepage meter developed for the study of geohydrology and water quality near Westville, Indiana.

collected in selected locations from Crumpacker Ditch, Forbes Ditch, and Crooked Creek. Samples were collected by the USEPA, their contractors, and the USGS. All samples were analyzed either at the USEPA Region 5 Central Regional Laboratory or at a USEPA-contracted laboratory.

Quality Assurance

The sample collection followed quality-assurance and quality-control (QA/QC) protocols established in the Draft Sampling and Analysis Plan (SAP) (U.S. Environmental Protection Agency, written commun., 1997). The SAP specified bottle types, preservation, and holding times for the samples; equipment-decontamination procedures; and frequency for the collection of QA/QC samples, such as duplicate and blank samples. Each sample collection was recorded on field data sheets.

The contract laboratories provided narrative QA/QC documentation and data qualifiers with the reported analytical results. The results were reviewed to determine the suitability of the data for use, and the laboratory report was revised if necessary by the USEPA or their contractors. Analytical results reported by the USEPA Region 5 Central Regional Laboratory were reviewed internally by the USEPA.

Ground Water

Water samples were collected from 36 monitoring wells during April–June 1997, 45 wells during September 1997, 48 wells during December 1997, and 29 wells during May 1999. Samples collected during April–June 1997 were analyzed for selected major and minor inorganic constituents, VOC’s including 1,4-dioxane, and semi-volatile organic compounds (SVOC’s) including polychlorinated biphenyls (PCB’s) and pesticides. Samples were collected and analyzed for 1,4-dioxane during September 1997, December 1997, and May 1999. Samples collected in May 1999 were analyzed for

VOC's, including 1,4-dioxane, and SVOC's to monitor potential changes in water quality from clean-up activities at the refinery site and to monitor changes in the area of ground-water contamination.

Ground-water samples were collected by use of submersible, low-flow pumps. All pumps were positive displacement with controlled variable-flow rates and were constructed of Teflon and stainless-steel components. The pumps were equipped with Teflon discharge lines.

Prior to collection of each sample, the interior of the sampling pump was cleaned by placing the pump in a series of three PVC tubes containing soapy water, tap water, and distilled water. Approximately 3 gal of soapy water and 3 gal of tap water were run through the pump and discharge line, followed by 1 to 2 gal of distilled or deionized water. The exterior of the pump was cleaned with a soapy water spray and by scrubbing with a brush, a rinse of tap water, and a rinse of distilled water.

The water level in the well to be sampled was measured prior to placing the sampling pump in the well. The well was pumped at a rate of approximately 1 gal/min to remove stagnant water in the casing. The discharge line was connected to the flow-through cell of a multi-parameter water-quality meter. This allowed measurements of water temperature (T), pH, specific conductance (SC), dissolved oxygen (DO), and oxidation-reduction potential (ORP) to be recorded before the water came in contact with the atmosphere. Periodic measurements of turbidity were made with a portable turbidimeter.

Samples were collected after three consecutive measurements indicated stable conditions according to the following protocol:

T = ± 0.5°C,

pH = ± 0.25 pH units,

SC = ± 50 µS/cm,

DO = ± 10 percent,

ORP = ± 25 mV, and

turbidity = ± 10 percent,

or after a minimum of three casing volumes had been removed. Samples were collected after the pumping rate was slowed to minimize aeration of the sample while the bottles were filled. Samples were placed in coolers with ice for storage prior to shipment to the laboratories by overnight delivery.

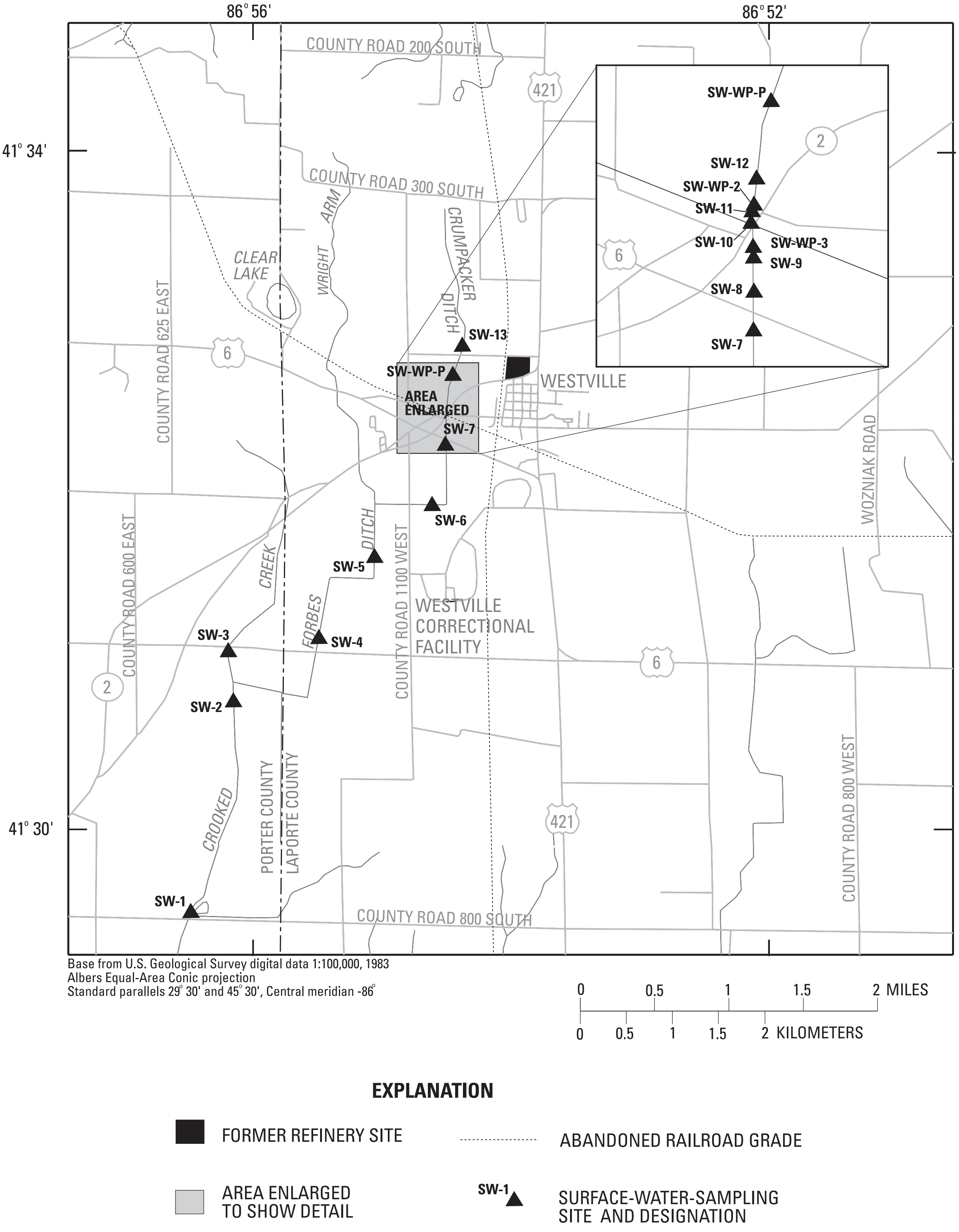
Privately owned, domestic water-supply wells in an area southwest of the site were sampled periodically for VOC's and 1,4-dioxane, beginning in April 1997. The majority of private water-supply wells are screened in the upper half of the glacial aquifer with many of the wells obtaining water from depths between 40 and 65 ft. Samples also were collected from the municipal well for the Town of Westville, supply wells for the Westville Correctional Facility, and from a well at a mobile-home park along Indiana Highway 2. In some cases, results of analyses of samples from water-supply wells guided the placement of new monitoring wells.

Most of the samples collected from water-supply wells were collected by USEPA personnel, although some samples were collected by the USGS or by USEPA contractors. Samples were collected as close as possible to the pump to avoid the effects of treatment and storage systems. Pumps were activated for a minimum of 10 minutes prior to collection of the sample. Sample preservation and handling were the same as procedures described previously for samples from the monitoring wells.

Surface Water

Surface-water samples were collected at locations in Crumpacker Ditch, Forbes Ditch, and Crooked Creek (fig. 7) during April–May 1997, August–September 1997, December 1997, and May 1999, to coincide with ground-water sampling. Samples collected April–May 1997 were analyzed for major and minor inorganic constituents, VOC's including 1,4-dioxane, and SVOC's including PCB's and pesticides. The remaining samples were analyzed only for 1,4-dioxane.

With the exception of samples collected in December 1997, samples were collected by submerging a closed sample bottle in the stream to a point approximately two-thirds of the distance from the water surface to the streambed. The bottle was



Base from U.S. Geological Survey digital data 1:100,000, 1983
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Figure 7. Locations of surface-water-sampling sites near Westville, Indiana.

opened and allowed to fill. The bottle was capped, brought to the surface, wiped clean, and placed in a cooler with ice for storage prior to shipment to the laboratory. Samples collected during December 1997 were collected with a Teflon bailer equipped with a bottom-control valve used to fill the sample bottles. Because 1,4-dioxane is not very soluble in water and is not very volatile, the use of a bailer should not bias the analytical results (U.S. Environmental Protection Agency, 1999). Field measurements of T, pH, SC, DO, ORP, and turbidity were recorded at the time of sample collection by submerging the multi-parameter water-quality meter in the center of flow.

Ground-Water-Flow Model

Ground-water flow was simulated with the USGS modular three-dimensional finite-difference ground-water-flow model developed by McDonald and Harbaugh (1988) and updated by Harbaugh and McDonald (1996). The digital model was based on a conceptualization of the aquifer geometry and geohydrology determined from data collected during installation, geophysical logging, and hydraulic testing of the monitoring wells. Particle tracking (Pollock, 1989 and 1994) was used to simulate the plume of 1,4-dioxane and to evaluate possible mechanisms of contaminant release, the effects of existing and planned ground-water pumping, and a potential method of remediation.

Well logs for privately owned water-supply wells in the study area were obtained from the Indiana Department of Natural Resources (IDNR) and provided lithologic data for parts of the study area where monitoring wells were not installed. The data allowed the boundaries of the model to be set far enough away from the refinery site and the contaminant plume to provide better definition of flow in these areas of the model. Records of ground-water pumpage for wells capable of producing 100,000 gal/d also were obtained from the IDNR for simulation by the model.

Geohydrology

A geologic description of the glacial sand aquifer underlying the study area was developed from the lithologic and geophysical logs. The subsurface sediments primarily are fine- to medium-grained sand intermixed and possibly layered with varying amounts of gravel, silt, and clay. Gravel and silt were reported at various depths throughout the aquifer, but clay, if present at all, generally was reported only for the upper 10 ft below land surface and at the base of the aquifer. Large gravel, cobbles, and boulders occasionally were reported, generally at depths less than 25 ft. At most of the drilling locations, an increase in sand grain size and a decrease in silt content with depth was observed. Lithologic logs for wells at sites MW-4, MW-7, MW-15, and MW-17 indicated an abundance of dark-gray to black shale gravel mixed with sand in lower parts of the aquifer.

The aquifer thickness in the vicinity of the refinery site ranges from 148 ft at site MW-9 to 215 ft at site MW-7. The sand is underlain by moderately hard to stiff grey or blue clay. The log for well TW-95A reported 8 ft of blue clay on top of shale bedrock.

Results of Geophysical Logging

The natural gamma logs, in general, show decreasing gamma radiation with depth (fig. 8). This interpretation supports the decrease in silt content with depth observed during drilling. A few layers that showed elevated gamma readings at depth in some wells do not appear to correlate among well locations. The elevated gamma readings may indicate small lenses of clay and/or silt that are thin and discontinuous within the study area. Although these lenses of clay can alter the flow of ground water locally, they probably do not substantially affect regional ground-water flow.

Electromagnetic conductivity logs generally correlate with the lithologic changes indicated by the NG logging, except for specific wells (MW-2XD, MW-4XD, MW-10XD, MW-14XD,

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GEOLOGIST'S LOG

DEPTH INTERVAL/ DESCRIPTION	
0-5/	DARK BROWN SILTY CLAY WITH SOME SAND AND GRAVEL
5-13/	BROWN SILTY SAND WITH TRACE OF CLAY, LARGE GRAVEL AT 12-13 FEET
13-21/	BROWN, SANDY, SILTY CLAY
21-24.5/	LARGE GRAVEL WITH SAND AND SILT, BOULDER AT 23.5 FEET
24.5-26/	DARK BROWN SILTY CLAY WITH SAND AND SMALL TO MEDIUM GRAVEL
26-32/	BROWN SANDY, SILTY CLAY
32-45/	VARIES FROM SANDY CLAY TO CLAYEY SAND
45-215/	BROWN TO GREY, FINE TO MEDIUM SAND WITH SMALL GRAVEL AND SHALE GRAVEL
215-217/	BLUE CLAY
217/	BOTTOM OF HOLE

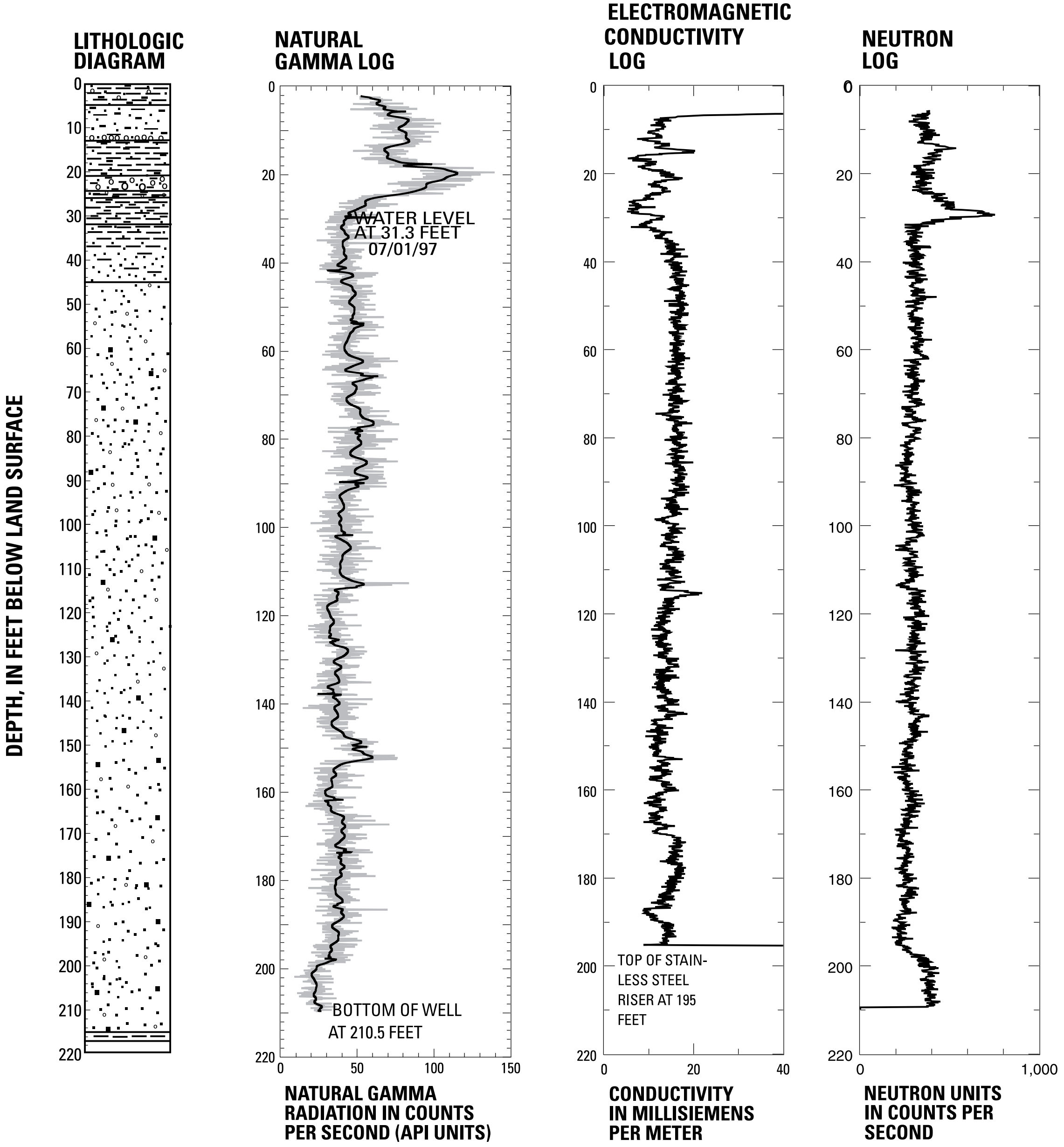


Figure 8. Geologist's log and geophysical logs for well MW-7XD near Westville, Indiana.

MW-15XD, and possibly MW-17XD) within the area of ground-water contamination. High values of SC, generally greater than 1,200 µS/cm, were measured in water from many of these wells compared to SC of water from wells not in the area of contamination that ranged from about 400 to 600 µS/cm. Concentrations of chloride ranged from 62 to 799 mg/L in water samples collected downgradient from the refinery site at well sites MW-2 and MW-4 during April–May 1997, compared to a range of 9 to 15 mg/L in water from upgradient wells at MW-7. The high EM response in wells within the plume of contamination probably is a result of high SC and chloride concentrations associated with the plume. Although a direct correlation between 1,4-dioxane and SC was not found, EM logs were used to determine vertical placement of the well screens for wells MW-15MD and MW-17MD.

With the exception of the bottom few feet of some wells, the neutron logs generally correlate well with the natural gamma logs. The change in neutron response near the bottom of the well is attributed to a difference in water content of the natural collapse/filter pack around the well screens compared to the bentonite grout above the screened interval. The bentonite grout has low permeability but also has high porosity and retains more water than the filter pack or aquifer material. The high water content of the bentonite results in low neutron readings because neutrons are absorbed by water.

Aquifer Hydraulic Properties

Single-well aquifer tests (slug tests) were completed to assess the spatial variability of horizontal hydraulic conductivity in the study area. A multiple-well aquifer test was done to determine the response of the aquifer to pumping and to provide additional estimates of hydraulic properties. Results of the single-well and multiple-well tests generally are in good agreement.

Results of the Single-Well Aquifer Tests

Slug tests were completed in 20 shallow wells, 6 D-series wells, 6 MD-series wells, and 16 XD-series wells. Results from slug tests at one MD-series wells and three XD-series wells were not analyzed because of erratic oscillations of the water level during recovery. Slug-test results for eight wells completed by the USEPA in 1994 were included in the analysis (table 2). In general, values of hydraulic conductivity obtained from the slug-test data indicate a large degree of variability. The average horizontal hydraulic conductivities determined at individual wells range from 0.6 ft/d at well MW-3D to 127 ft/d at well MW-17MD.

Results of the slug tests were grouped according to the depth of the well to evaluate vertical differences within the aquifer. The geometric mean of hydraulic conductivity was selected as the indicator of central tendency. Horizontal hydraulic conductivity for the S-series wells and other shallow wells ranged from 8.6 to 53.3 ft/d, and the geometric mean was 21.3 ft/d. Horizontal hydraulic conductivity for the D-series wells ranged from 0.6 to 62.4 ft/d, and the geometric mean was 12.2 ft/d. Horizontal hydraulic conductivity for the MD-series wells ranged from 46.8 to 127 ft/d, and the geometric mean was 89.9 ft/d. For the XD-series wells, horizontal hydraulic conductivity ranged from 9.7 to 118 ft/d, and the geometric mean was 64.4 ft/d.

Single-well aquifer-test results for the D-series wells indicate a bimodal distribution of hydraulic conductivity. Values of horizontal hydraulic conductivity obtained at wells MW-1D, MW-2D, MW-3D, and MW-14D were about two or more times smaller than the geometric mean; whereas, values of hydraulic conductivity for other D-series wells were about three or more times larger than the geometric mean. The D-series wells for which low values of horizontal hydraulic conductivity were determined are along the western edge of the former refinery site (wells MW-2D and MW-3D), south of the site (well MW-1D) and west of the site near Crumpacker Ditch (well MW-14D). The results may indicate an area of relatively low horizontal hydraulic conductivity in the aquifer west of the refinery site to Crumpacker Ditch at the 80-ft depth of the D-series wells. Values of horizontal hydraulic conductivity for the remaining D-series wells generally are similar to those obtained for wells in the MD and XD series.

There are several limitations to using slug-test results to develop hydraulic-conductivity estimates for aquifer sediments. Because of the small hydraulic stress imposed on the aquifer during a slug test, only the properties of the aquifer sediments in the immediate vicinity of the borehole (or well screen) are tested. At best, a slug test provides estimates of horizontal hydraulic conductivity for the materials within a few feet around the well, whereas a multiple-well aquifer test can provide a measure of hydraulic properties over a much larger volume of the aquifer. In addition, artifacts of well construction or ineffective well development can restrict flow of ground water between the well and the aquifer, resulting in incorrect estimates of horizontal hydraulic conductivity. In general, slug-test results have been shown to be consistent with results of multiple-well aquifer tests. In some cases, however, hydraulic conductivity values derived from results of slug tests can be three to five times smaller than values derived from data from multiple-well aquifer tests (Rovy and Cherkauer, 1995).

Table 2. Average values of horizontal hydraulic conductivity determined from single-well aquifer tests near Westville, Indiana

[ft/d, foot per day; test results analyzed by method of Bouwer and Rice (1976) except as noted]

Well name	Average horizontal hydraulic conductivity (ft/d)	Well name	Average horizontal hydraulic conductivity (ft/d)	Well name	Average horizontal hydraulic conductivity (ft/d)	Well name	Average horizontal hydraulic conductivity (ft/d)
B-4	12.5	MW-4XD	83.7	MW-12	22.1	MW-17XD	9.7
EP-2	27.4	MW-5XD	118	MW-13S	51.1	MW-18S	20.2
EP-3	34.6	MW-7S	15.8	MW-13D	32.8	MW-18XD[c]	104
LP-1[a]	17.2	MW-7D	62.4	MW-13XD	111	NDF-MW-1	34.6
LP-3[a]	53.3	MW-7XD	81.4	MW-14S	14.3	NDF-MW-2	7.85
MW-1S[a]	23.0	MW-8S	8.6	MW-14D	3.4	PZ-1S	18.0
MW-1D[a]	2.9	MW-8D	47.9	MW-14XD	50.4	PZ-1MD[c]	110
MW-2S[a]	21.6	MW-9S	14.9	MW-15S	37.4	PZ-1XD	not determined[b]
MW-2D[a]	7.2	MW-9XD	50.0	MW-15MD	46.8	PZ-2S	25.9
MW-2MD	not determined[b]	MW-10S	18.0	MW-15XD	85.7	PZ-2MD[c]	105
MW-2XD	29.3	MW-10XD	90.7	MW-16S	20.2	PZ-2XD[c]	79.8
MW-3S[a]	20.9	MW-11S	34.1	MW-16D	36.7	PZ-3S	13.4
MW-3D[a]	.6	MW-11D	38.1	MW-16XD	not determined[b]	PZ-3MD[c]	85.8
MW-4S	28.1	MW-11XD	not determined[b]	MW-17MD[c]	127	PZ-3XD[c]	79.5

[a] Well tested previously by the U.S. Environmental Protection Agency, August 2, 1994.

[b] Critically-damped response—test data not analyzed.

[c] Well for which data were analyzed by the method of van der Kamp (1976).

Results of the Multiple-Well Aquifer Test

A constant-discharge, multiple-well aquifer test was completed at the location of the Town of Westville's proposed well field. The test consisted of pumping well TW-95A and recording changes in water levels in the PZ-series wells (locations shown on fig. 3). Analysis of the test results provided estimates of horizontal and vertical hydraulic conductivity, transmissivity, and specific yield for the aquifer.

Water levels were monitored during 6 days prior to the aquifer test in wells LP-1; MW-7S, D, and XD; MW-5S and XD; and PZ-1S, MD, and XD. Precipitation data indicated about 0.6 to 0.8 in. of rain had fallen during April 8 and 9. The data show that ground-water levels rose steadily from April 10 through April 13 as a result of recharge from precipitation (fig. 9).

Well TW-95A was pumped at a rate of 86 gal/min for 3,048 minutes (approximately 2.1 days) beginning at 1:42 p.m., April 14, 1998. Prior to turning off the pump, 16 ft of drawdown was measured in the pumped well. Drawdown was observed in all the PZ wells, ranging from 0.079 ft in well PZ-1S to 0.29 ft in wells PZ-2MD and PZ-3MD. Water levels in the MD- and XD-series wells were lowered more by the pumping than were water levels in the S-series wells. This indicates that the lower part of the aquifer supplied most of the water pumped from the well. The pump was turned off at 4:30 p.m., April 16, and water levels were monitored in the wells for another 2,440 minutes (approximately 1.7 days). By that time, ground-water levels had recovered to or above their pre-test levels.

The water was pumped into two large tanks at the site. Most of the water then was pumped from the tanks to a town sewer approximately 1,000 ft away. After pumping for approximately 1,000 minutes, it was necessary to allow some excess water to drain intermittently from the tanks through a hose onto the ground approximately 500 ft southwest of well TW-95A. Based on a flow rate of 12 gal/min and the total amount of time that water was drained (825 minutes), the estimated volume of water discharged onto the ground is less than 10,000 gal, or 3.8 percent of the approximately 260,000 gal pumped. The discharged water did not appear to affect ground-water levels in the pumping or observation wells during the aquifer test.

Some discrepancies between drawdown measured by the pressure transducer and drawdown measured by electric tape were observed in the data. The discrepancies were determined to be caused by changes (drift) in the electrical current output from the pressure transducer over the time period of the aquifer test. These changes are not related to changes in water level but can be caused by changes in temperature and barometric pressure, stretching of the transducer cable, or electrical interference.

The water-level data were referenced to a common datum by subtracting the measured depth to water from the surveyed measuring point of the appropriate well. The results were plotted on graphs and inspected visually. Two types of corrections were made to the water-level data based on the inspections.

First, comparison of the manual measurements with data collected by the pressure transducers and data loggers indicated data from the transducers were subject to drift that resulted in small errors in the recorded water level. Generally, the manual measurements were considered more accurate than the transducer output; however, corrections were made only when differences of more than 0.01 ft were observed between data collected manually and data stored on the data loggers. Corrections for transducer drift were made on an individual basis as determined from the data.

Water levels also were corrected to account for ambient or background water-level conditions on the basis of water levels collected from wells at MW-7 and well LP-1. The changes in water levels measured in these wells include the effects of recharge and changes in barometric pressure. Assuming that water levels in wells at the test site would have similar responses, the background water levels can be used to correct for ambient water-level conditions. Data collected prior to the test (fig. 9) show nearly identical trends of rising water levels in these wells and in the wells at PZ-1 at the test site. Water levels in the wells at MW-7

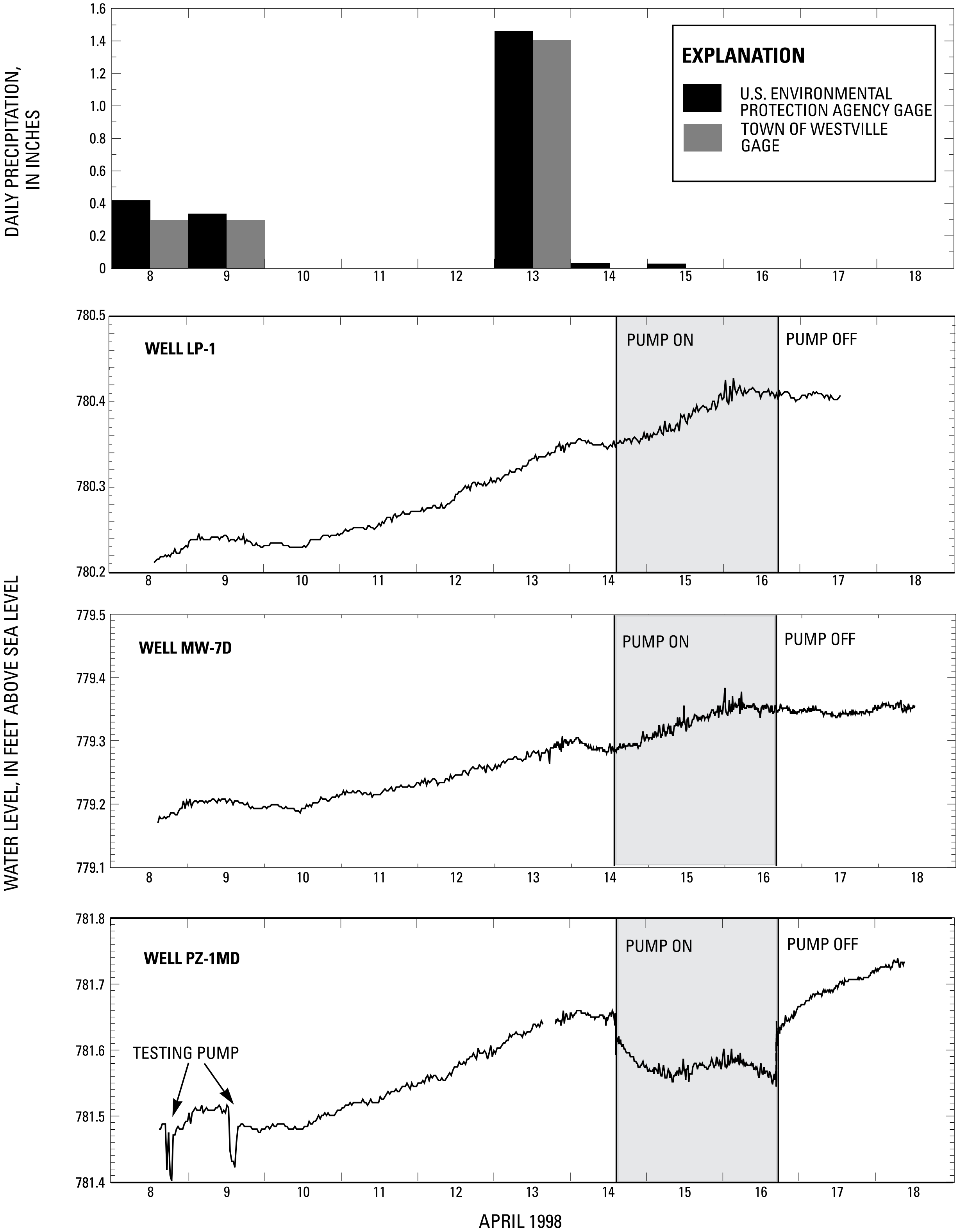


Figure 9. Precipitation amounts and water levels in wells LP-1, MW-7D, and PZ-1MD before and during the multiple-well aquifer test near Westville, Indiana, April 1998.

and well LP-1 continued to rise during the test as a result of recharge to the aquifer from almost 1.5 in. of rainfall that occurred on April 13. The water level in well MW-7D, an 80-ft-deep well west of the test site, rose 0.05 ft during pumping. It is assumed that water levels at the aquifer-test site also were rising during pumping, so drawdown measured during the test would be less than the drawdown that would have occurred without the recharge. Water-level data from the PZ wells and well TW-95A were corrected by prorating the rise in water levels measured at MW-7D with time during pumping and adding the results to the measured drawdown.

The method of Moench (1993) was used to analyze drawdown data from all of the PZ wells individually and in selected groups. Groups analyzed were (1) observation well site (PZ-1, PZ-2, or PZ-3) and (2) depth (S, MD, or XD). Drawdown data from all wells in the group were plotted together for these analyses. Water-level data from the recovery phase of the aquifer test were analyzed, using the same procedures used for the drawdown data. Data from the recovery phase were used to check and verify results obtained for the pumping phase.

The corrected data files were analyzed with the AquiferTest (Roenrich, not dated) analytical software. The shape of the type curve(s) generated by the software can be modified by specifying input variables for s, β, and the ratio between vertical and horizontal hydraulic conductivity (K_z/K_r). Moench (1993) defines s as S/Sy

where,

S = storativity
and Sy = specific yield,

and β as $K_z r^2/K_r b^2$,

where,

K_z = hydraulic conductivity in the vertical direction,
K_r = hydraulic conductivity in the horizontal direction,
r = radial distance from the center of the pumped well,
and b = initial saturated thickness of the aquifer.

Input values of s and K_z/K_r were adjusted to obtain the type curve that best matched the shape of the plotted data. The variable β had little or no effect on results of this analysis and was left at the default value (10^9).

The method of Moench (1993) provides an estimate of horizontal and vertical hydraulic conductivity, transmissivity, and specific yield (table 3). With the exception of results from well PZ-1S, the analysis of the aquifer-test data provided similar values of hydraulic conductivity. It is not clear why the results from well PZ-1S differ from the majority of analyses; however, well PZ-1S is the water-table well farthest from the pumping well, and it had the smallest measured drawdown. The lower value for hydraulic conductivity obtained for this well compared to the others may be related to an area of low permeability caused by an increase in silt content of the aquifer materials in the vicinity of the well, preferential flow paths within the aquifer, or error in measurement or analysis.

Results of analysis of data from individual wells (table 3) indicated average values of about 17,200 ft^2/d for transmissivity, 112 ft/d for horizontal hydraulic conductivity, 20 ft/d for vertical hydraulic conductivity, and 0.05 for specific yield. Individual values ranged from 7,400 to 20,800 ft^2/d for transmissivity, 48 to 136 ft/d for horizontal hydraulic conductivity, 4.8 to 36 ft/d for vertical hydraulic conductivity, and 0.01 to 0.08 for specific yield. The range of values are the result of differences in the composition of the aquifer, which changes mostly with depth but also areally to some extent. For most of the analyses for individual wells, data from the S-series wells produced lower values for all hydraulic parameters than data from the MD- and XD-series wells. Also, values obtained using data from observation wells at site PZ-3, southeast of the pumped well, were slightly higher than values from observation wells located northeast (well sites PZ-1 and PZ-2).

Results of analyses grouped by well site and by well depth were similar to those obtained from analysis of individual wells (table 3). With the exception of the group containing all wells at site PZ-1 that resulted in values slightly lower than the other groups, values for hydraulic parameters determined from grouped analysis were consistent among groups. The results of the analysis by groups probably provide the best estimates of aquifer properties because they take into account more of the data. Based on the grouped analysis, the aquifer transmissivity is 18,600 ft^2/d and horizontal hydraulic conductivity is 121 ft/d. Values for vertical hydraulic conductivity for each group ranged from 24 to 36 ft/d, and values for specific yield ranged from 0.05 to 0.08.

Drawdown data were plotted (fig. 10) to analyze the relative degree of anisotropy, or existence of preferential ground-water-flow directions, within the aquifer. The lack of a substantially elongated cone of drawdown indicates the aquifer is virtually isotropic in the horizontal direction. The plot of drawdown along a cross section from well TW-95A to well site PZ-1, however, illustrates that drawdown was greater in the lower part of the aquifer compared to drawdown at the water table. This indicates that most of the drawdown was transmitted horizontally and not vertically through the aquifer and is most likely the result of partial penetration of the pumped well (the well is not screened through the entire thickness of the aquifer). The small values of vertical hydraulic conductivity compared to horizontal hydraulic conductivity indicate that the aquifer is anisotropic with respect to vertical and horizontal flow.

Table 3. Hydraulic conductivity, transmissivity, and specific yield determined with drawdown data from individual wells and selected groups of wells from the multiple-well aquifer test near Westville, Indiana, April 1998

[ft/d, foot per day; ft^2/d, square foot per day]

Well or group name	Horizontal hydraulic conductivity (ft/d)	Vertical hydraulic conductivity (ft/d)	Ratio of horizontal to vertical hydraulic conductivity	Transmissivity (ft^2/d)	Specific yield (dimensionless)
PZ-1S	48	4.8	0.1	7,400	0.01
PZ-1MD	121	24	.2	18,600	.07
PZ-1XD	121	24	.2	18,600	.05
All wells at PZ-1	108	30	.3	16,600	.08
PZ-2S	108	10.8	.1	16,600	.03
PZ-2MD	121	24	.2	18,600	.08
PZ-2XD	108	21	.2	16,600	.08
All wells at PZ-2	121	36	.3	18,600	.06
PZ-3S	121	12	.1	18,600	.02
PZ-3MD	136	27	.2	20,800	.07
PZ-3XD	121	36	.3	18,600	.08
All wells at PZ-3	121	36	.3	18,600	.06
All S wells	121	24	.2	18,600	.05
All MD wells	121	24	.2	18,600	.06
All XD wells	121	36	.3	18,600	.06

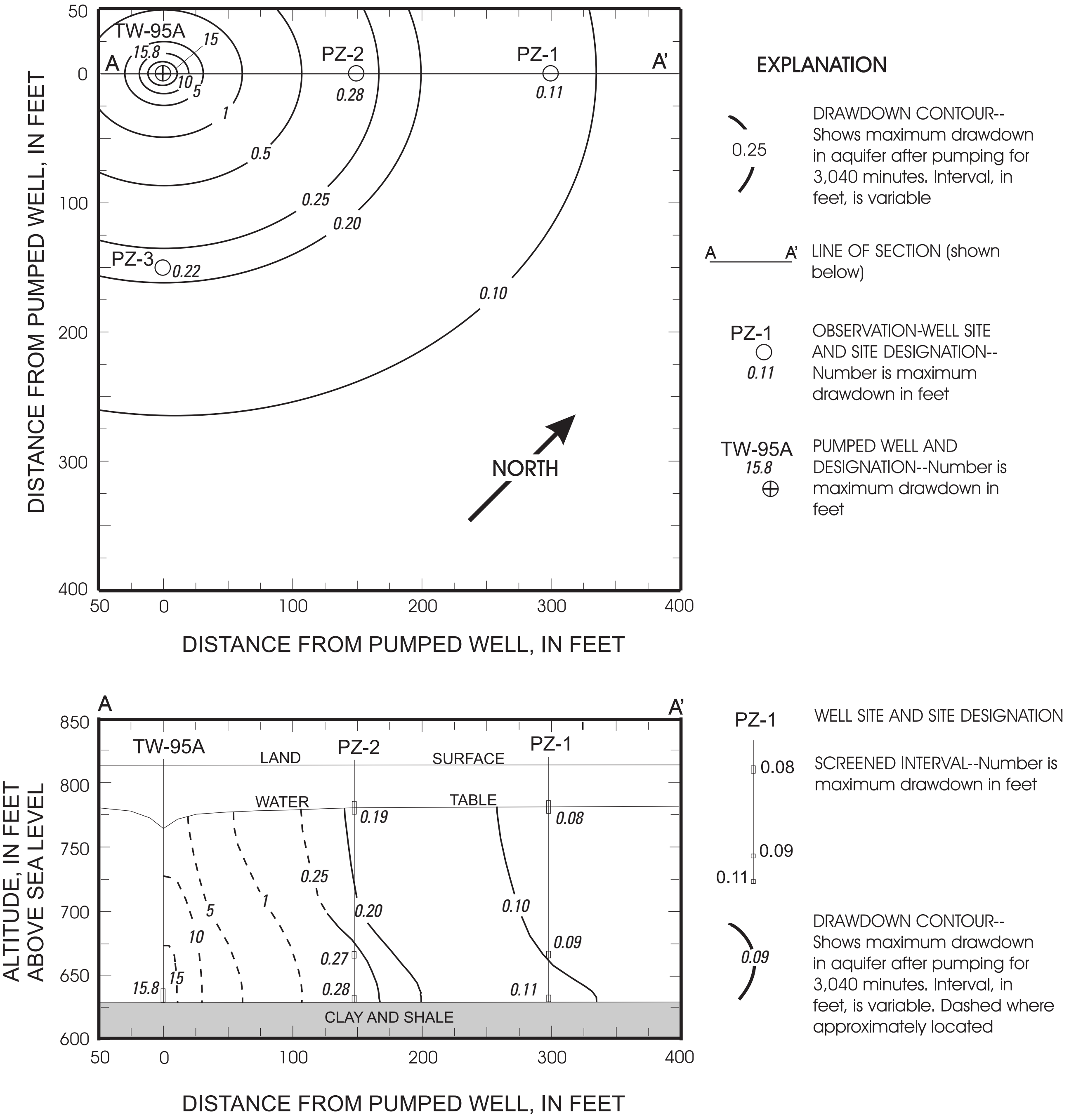


Figure 10. Map view (top) and section (below) of maximum drawdown measured during the multiple-well aquifer test near Westville, Indiana.

With the exception of wells PZ-2S and PZ-3S, the results of the multiple-well aquifer test (table 3) are in reasonable agreement with results of slug tests in the PZ wells (table 2). Both results indicate increased hydraulic conductivity with depth in the aquifer. The larger values of hydraulic conductivity obtained from the aquifer-test data compared to the slug tests are a result of the difference in scale of the two tests. The stress applied to the aquifer during a slug test is minor and tests only a small part of the aquifer near the open interval of a well. The small stress of the slug test results in estimates of hydraulic conductivity that are more conservative than estimates obtained from applying a larger stress to the aquifer by pumping.

The pumping rate of 86 gal/min maintained during the multiple-well aquifer test represents a small stress to the particular aquifer tested. The small amount of drawdown measured in the observation wells indicates that most of the water supplied to the pumped well was induced ground-water flow with a lesser amount obtained from storage. It is probable that the aquifer can sustain larger pumping rates with small increases in drawdown. Therefore, it is possible that the values for aquifer properties obtained from the aquifer-test analyses are conservative and underestimate the permeability of the aquifer.

Water Levels and Directions of Ground-Water Flow

The average depth to water measured in the monitoring wells ranged from about 3 ft below land surface in wells at sites MW-4 and MW-15 to about 36 ft below land surface in well LP-1. Depth below land surface is calculated by subtracting the altitude of the water surface (table A2 at the back of the report) from the land-surface altitude (table A1 at the back of the report). Beneath the refinery site, the average depth to water was about 30 ft below land surface at well B-1 on a high bank along the eastern edge of the site and about 16 ft below land surface at well MW-2MD on the abandoned railroad grade west of the site. The average depth to water in well B-2 near the center of the site was 17.5 ft for three measurements made during June through August 1997.

Ground water in the study area is recharged by direct infiltration of precipitation. Generally, water levels are highest in spring when precipitation is greatest and lowest in fall when precipitation is least. This pattern is observed in hydrographs for the wells at site MW-2 (fig. 11) for data collected from June 1997 through July 1998. Because of the variable frequency of data collection after July 1998, the extreme high and low water levels for this period probably were not measured. In addition, precipitation was below normal in 1999 and during the first part of 2000, and water levels declined during that time.

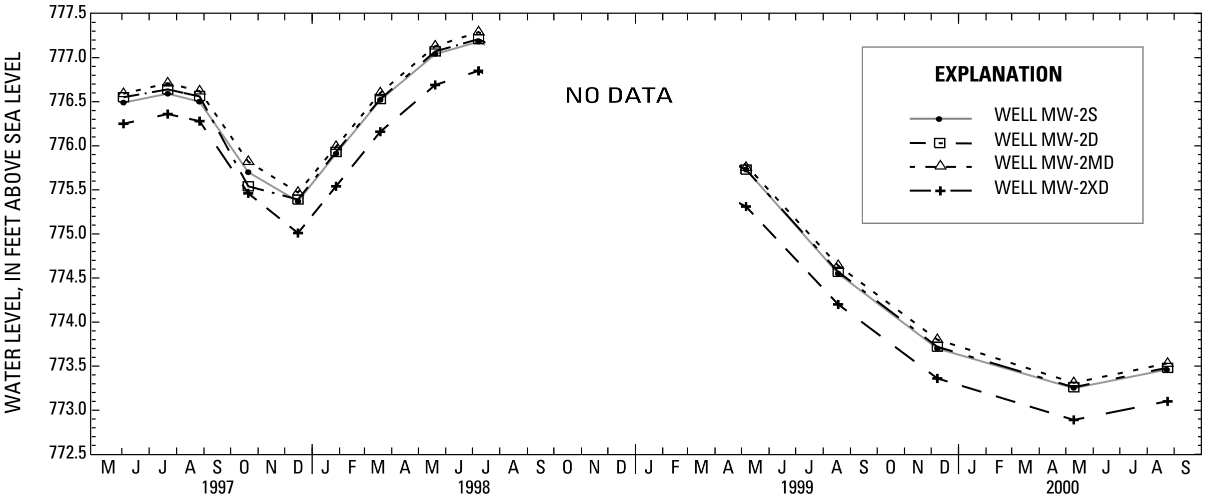


Figure 11. Water levels measured in monitoring wells at well site MW-2 near Westville, Indiana, 1997 through 2000.

Seasonal fluctuations of ground-water levels appear to be related to the location of the well in the study area. Water levels in wells near and northeast of the refinery site generally were highest in July 1998 and lowest in May 2000 (table A2 at the back of the report). Water levels in wells southwest of the site and near Crumpacker Ditch generally were highest in March 1998 and lowest in August 2000. Water levels in wells at sites LP-2, MW-11, and MW-12 were highest in May 1998 and lowest in December 1999. The observed pattern is most likely related to areas of ground-water recharge and discharge but also may be affected by the distribution of precipitation and resulting infiltration or areal differences in hydraulic properties of the aquifer.

Water-level fluctuations during the study ranged from about 5.6 ft in the PZ wells to about 2 ft in wells at site MW-9. The average fluctuation in wells near the refinery site was about 4.2 ft. The magnitude of the fluctuations measured in individual wells was related to the distance of the well from Crumpacker Ditch. Water-level fluctuations measured in wells near Crumpacker Ditch were less than those in wells farther away from the ditch. Water levels in deep wells had fluctuations similar to those in shallow wells at the same site.

Contour maps of water levels were prepared for the S-, D-, and XD-series wells (figs. 12, 13, and 14). Water levels measured in the B, EP, LP, and NDF wells were included with the S wells because these wells are screened across or near the water table. Water levels from wells that contained floating oil were not used in constructing the contour maps because the oil layer obscures the true water surface. Well MW-6S contained floating oil throughout the study, and floating oil entered well MW-1S between measurements made in July 1998 and May 1999. The source of the oil in these wells is assumed to be the refinery site, although additional wells are necessary to document the source and determine the extent of the oil. Water levels from the MD-series wells were not contoured because of the small number of wells in that series.

Inspection of the water-level-contour maps prepared for each set of measurements indicated no substantial change in directions of ground-water flow during the study; therefore, water levels measured on December 16, 1997, were selected as representative and to illustrate ground-water flow in the study area (figs. 12, 13, and 14). The highest measured ground-water altitudes in the study area are northeast of the refinery site and the lowest altitudes are southwest, indicating flow beneath the site is to the southwest. Water-level altitudes in shallow wells near Crumpacker Ditch are higher than the surface-water altitudes in the ditch, indicating a potential for ground water to discharge to the ditch.

Ground-water-flow directions are similar in the shallow (S wells), middle (D wells), and deep (XD wells) parts of the aquifer. Discharge of shallow ground water to Crumpacker Ditch is shown on figure 12 by contour lines that wrap around the ditch in the upstream direction. The potentiometric maps for the middle and deep parts of the aquifer (figs. 13 and 14) show a more generalized flow direction to the southwest. The potential for discharge of water from the middle and deep parts of the aquifer to Crumpacker Ditch is not obvious from inspection of figures 13 and 14, although water levels in the D- and XD-series wells (with the exception of well MW-14XD) are higher than the nearby surface-water levels.

Horizontal hydraulic gradients were determined from the contour maps of ground-water levels (table 4). Estimates of horizontal ground-water-flow velocities were determined by use of the Darcy flow equation:

$$V = \frac{K_h}{n} \cdot \frac{\Delta h}{\Delta l} , \qquad (1)$$

where,

V is the ground-water-flow velocity,

K_h is the horizontal hydraulic conductivity of the aquifer,

Δh is the difference between measured ground-water altitudes,

Δl is the distance between the two measuring points along the direction of flow, and

n is the effective porosity of the aquifer.

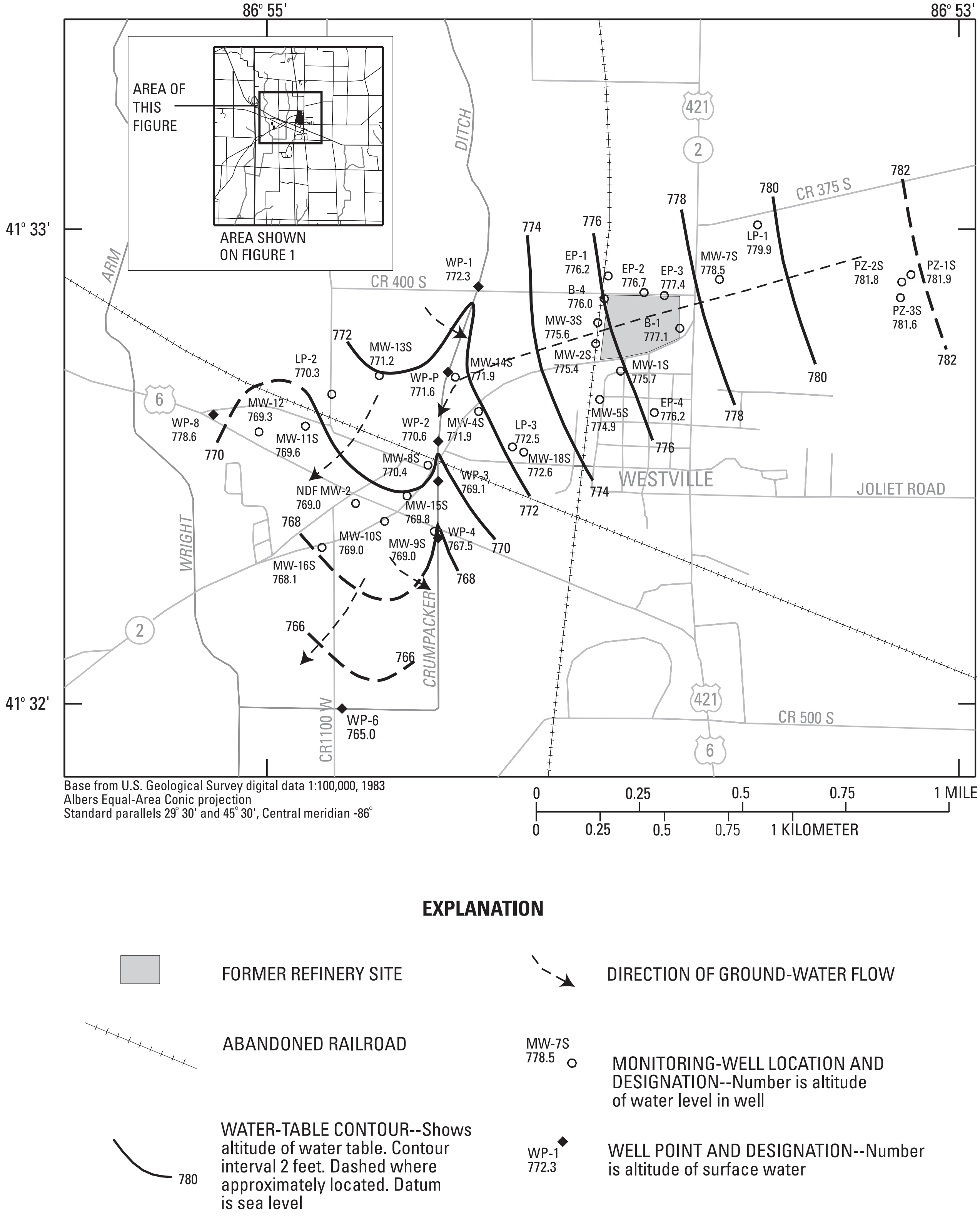


Figure 12. Altitude of water table measured December 16, 1997, near Westville, Indiana.

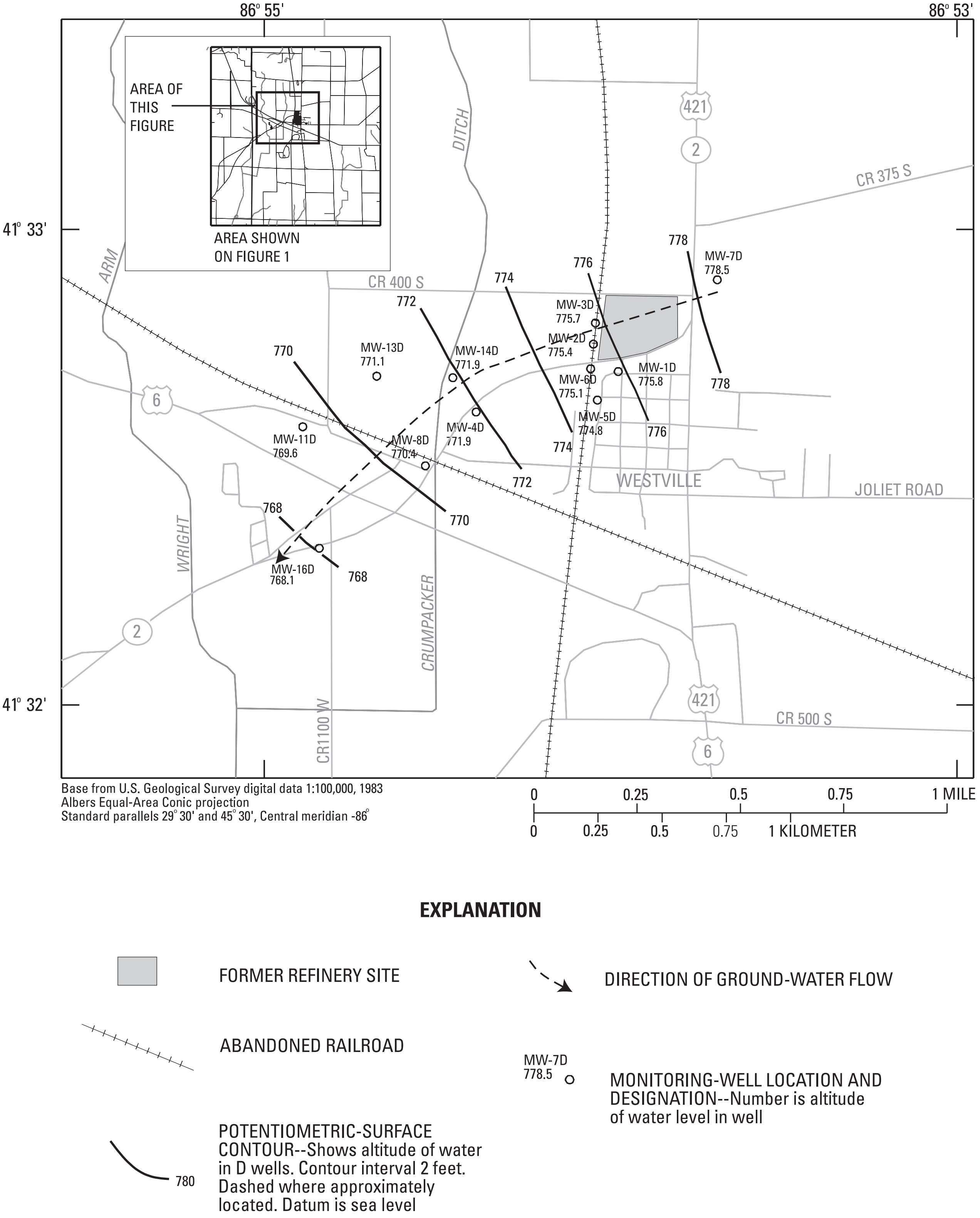
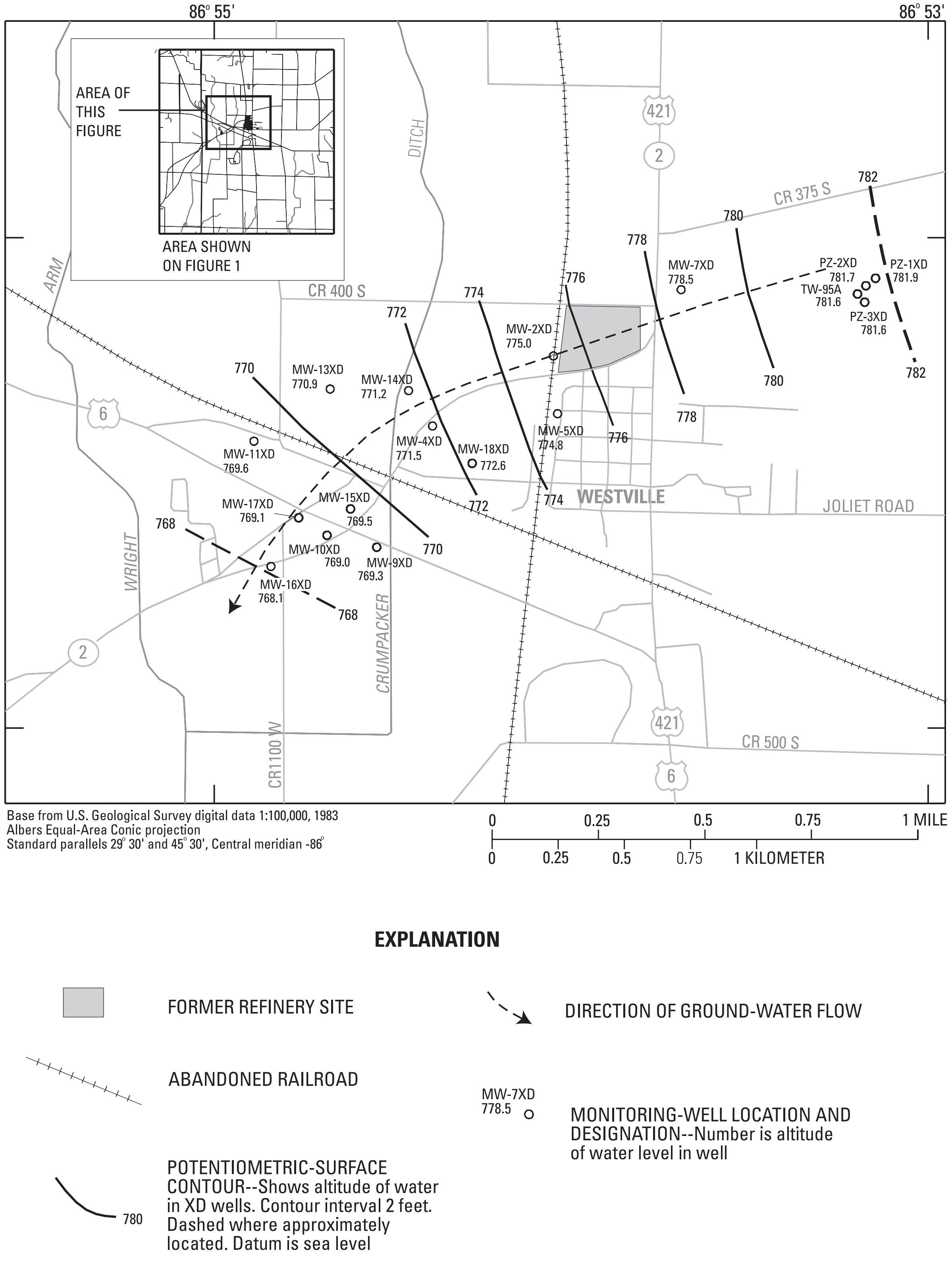


Figure 13. Altitude of potentiometric surface in the D-series wells measured December 16, 1997, near Westville, Indiana.



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

Figure 14. Altitude of potentiometric surface in the XD-series wells measured December 16, 1997, near Westville, Indiana.

Table 4. Horizontal gradients and calculated ground-water-flow velocities at and near the former refinery site near Westville, Indiana

[ft/d, foot per day; ft, foot; ft/ft, foot per foot]

Calculation zone	Horizontal hydraulic conductivity (ft/day)	Difference between ground-water altitudes (ft)	Distance between measuring points (ft)	Horizontal gradient (ft/ft)	Flow velocity (ft/day)
Water table—southwest of site	21.3	2	1,478	0.00135	0.12
Water table—at site	21.3	2	1,109	.00180	.15
Middle—west of site	12.2	2	1,035	.00193	.09
Deep—at site	64.0	2	1,109	.00180	.46
Deep—southwest of site	64.0	2	1,214	.00165	.42

The geometric-mean values for horizontal hydraulic conductivity determined from the single-well aquifer tests were used for the calculations. The difference in water-level altitudes and the distance between measuring points were determined from figures 12, 13, and 14. The effective porosity was not determined during this study; however, the neutron logs showed little variation in porosity with depth. Therefore, effective porosity was estimated to be 25 percent, based upon literature values for similar geologic materials (Fetter, 1995).

Horizontal-flow velocities were calculated for ground water beneath, south, and west of the refinery site and for shallow, middle, and deep parts of the aquifer (table 4). The results indicate that velocities are similar, between 0.09 and 0.15 ft/d, in the shallow and middle parts of the aquifer. Velocities calculated for the deep part of the aquifer averaged 0.44 ft/d, which is about three to five times faster than velocities determined for the shallow and middle parts of the aquifer.

Water-level data from sites having wells screened at different depths were compared to determine vertical gradients and directions of vertical flow in the aquifer. Vertical gradients (table 5) were calculated for selected well pairs, using water levels obtained at four different times to represent seasonal variability. Vertical gradients calculated from the data were variable, ranging from an average of 0.0016 ft/ft between wells MW-2D and MW-2MD to -0.0085 ft/ft between wells MW-2MD and MW-2XD. A positive vertical gradient indicates potential for upward flow, and a negative gradient indicates potential for downward flow. Positive gradients were determined consistently between well pairs MW-2S and MW-2D, MW-2D and MW-2MD, and MW-14S and MW-14D. Results for wells at MW-7 and PZ-1 indicate very small or no vertical gradients between those wells.

The largest vertical gradients were calculated from ground- and surface-water-level data collected at well point WP-2. Vertical gradients at WP-2 averaged 0.22 ft/ft. The positive gradient indicates the potential for ground water to flow upward to Crumpacker Ditch. The relatively large gradient, however, also suggests that the fine-grained materials in the streambed have lower hydraulic conductivity compared to that of the glacial sand aquifer.

A cross section, roughly along the flow path of ground water, was constructed to illustrate vertical ground-water flow (fig. 15). Directions of flow determined from the contours in the cross section suggest that flow in the glacial aquifer may be separated into a shallow, local flow system that discharges to Crumpacker Ditch and a deep, regional flow system that flows beneath the ditch. Vertical gradients calculated for the wells at site MW-2 (table 5) illustrate the two flow systems.

Water-level altitudes in wells MW-2S, MW-2D, and MW-2MD indicate an upward component of flow; the data for wells MW-2MD and MW-2XD indicate a downward component of flow in the aquifer between the screened intervals of these wells. This pattern of vertical flow also was determined from water-level altitudes in wells at site MW-14 near Crumpacker Ditch.

Table 5. Vertical hydraulic gradients for selected pairs of monitoring wells near Westville, Indiana, December 1997 through July 1998

[Differences in water levels are calculated by subtracting the water-level altitude in the second well from the water-level altitude of the first well; well locations shown on figure 3]

Well pair	Vertical distance between mid-point of well screens (feet)	Difference in water-level altitude, December 1997 (feet)	Vertical hydraulic gradient, December 1997 (feet/foot)	Difference in water-level altitude, March 1998 (feet)	Vertical hydraulic gradient, March 1998 (feet/foot)	Difference in water-level altitude, May 1998 (feet)	Vertical hydraulic gradient, May 1998 (feet/foot)	Difference in water-level altitude, July 1998 (feet)	Vertical hydraulic gradient, July 1998 (feet/foot)
MW-2S-MW-2D	57.2	+ 0.02	+ 0.00035	+ 0.01	+ 0.00018	+ 0.03	+ 0.00052	+ 0.03	+ 0.00052
MW-2D-MW-2MD	47.4	+ .08	+ .0017	+ .07	+ .0015	+ .06	+ .0013	+ .08	+ .0017
MW-2MD-MW-2XD	52.5	- .46	- .0088	- .44	- .0084	- .44	- .0084	- .44	- .0084
MW-7S-MW-7D	variable[a]	0	0	0	0	- .01	- .00022	0	0
MW-7D-MW7XD	130.6	0	0	0	0	+ .01	+ .00008	- .01	- .00008
MW-14S-MW-14D	variable[b]	+ .02	+ .00029	+ .05	+ .00071	+ .07	+ .00010	+ .06	+ .00086
MW-14D-MW-14XD	81.1	- .74	- .0091	- .37	- .0046	- .30	- .0037	- .29	- .0036
MW-15S-MW-15MD	88.9	- .10	- .0011	- .13	- .0014	- .11	- .0012	- .13	- .0015
MW-15MD-MW-15XD	56.1	- .21	- .0037	- .20	- .0036	- .18	- .0032	- .18	- .0032
PZ-1S-PZ-1MD	variable[c]	- .01	- .00009	0	0	0	0	- .01	- .00009
PZ-1MD-PZ-1XD	35	- .02	- .00057	- .01	- .00029	- .01	- .00029	- .01	- .00029
WP-2 inside-WP-2 outside	variable[d]	+ .30	+ .09	+ 1.06	+ .301	+ .82	+ .218	+ .89	+ .284

[a] Vertical distance between mid-point of saturated parts of well screens was 44.1 in December 1997 and March 1998, 44.8 in May 1998, and 44.9 in July 1998.

[b] Vertical distance between mid-point of saturated parts of well screens was 69.6 in December 1997 and 70.1 in March 1998, May 1998, and July 1998.

[c] Vertical distance between mid-point of saturated parts of well screens was 111.9 in December 1997, 111.6 in March 1998, 112.3 in May 1998, and 112.7 in July 1998.

[d] Vertical distance between mid-point of saturated parts of well screens was 3.33 in December 1997, 3.52 in March 1998, 3.77 in May 1998, and 3.13 in July 1998.

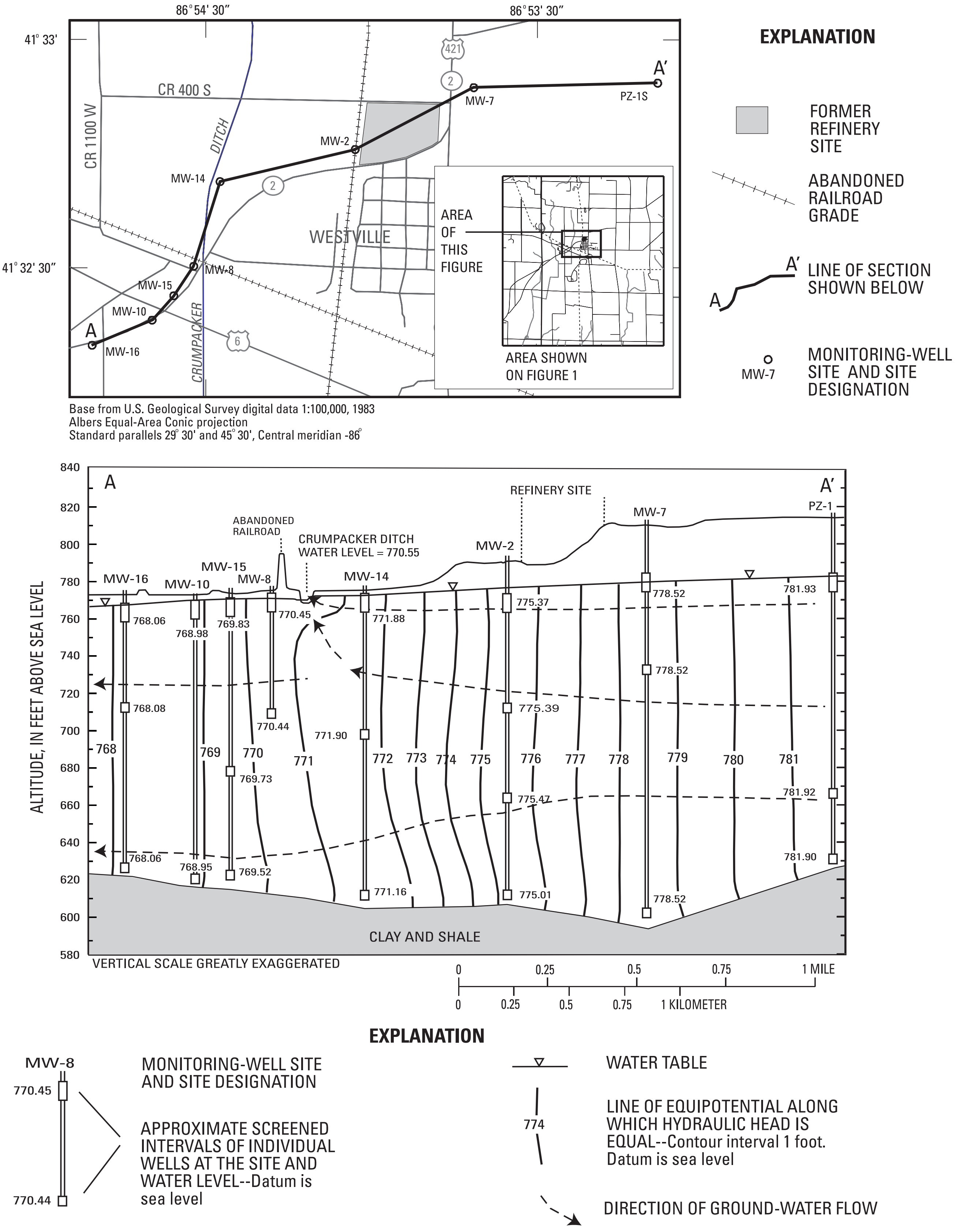


Figure 15. Ground-water levels along a section from well site PZ-1 to well site MW-16 near Westville, Indiana, December 16, 1997.

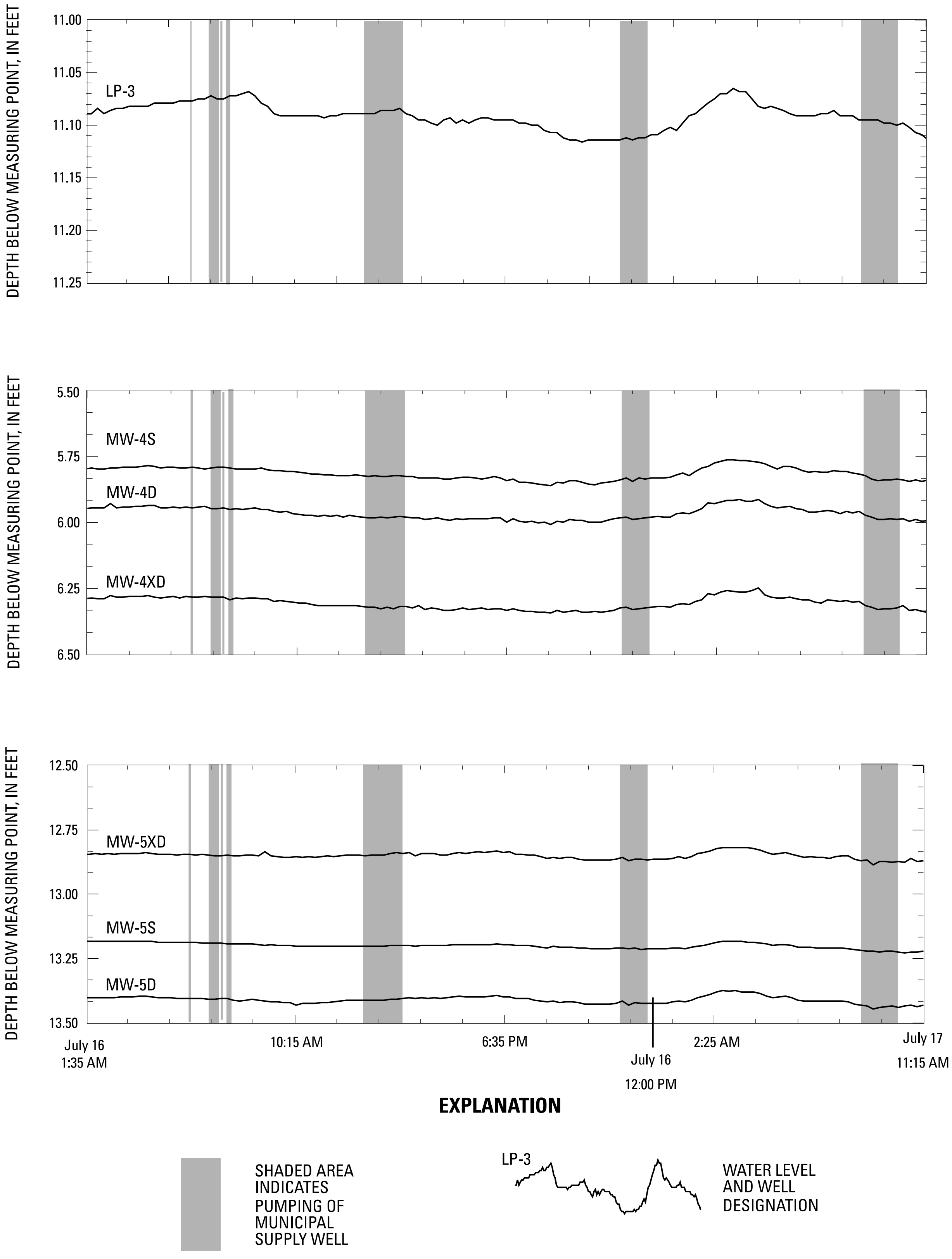


Figure 16. Water levels in monitoring wells at sites LP-3, MW-4, and MW-5 during pumping of the municipal supply well at Westville, Indiana, July 16–17, 1997.

Pumping at the municipal well for the Town of Westville has the potential to affect directions of ground-water flow within the area of influence, or cone of depression. To determine the area of influence, water levels in wells at sites MW-4 and MW-5 and well LP-3, along with rainfall and barometric pressure, were monitored continuously for approximately 3 months during summer 1997. Pumping was determined by recording when the municipal-well pump turned on and off.

Selected data for July 16–17 are shown on figure 16. During the time of monitoring, no changes in water levels in the monitored wells were observed that correspond clearly to pumping. Therefore, the area influenced by pumping does not extend to that part of the aquifer monitored by wells at sites MW-4, MW-5, and LP-3 and cannot be defined by the monitoring wells. One limitation to this interpretation is that water demand was not as large as expected because of the wet summer during 1997. The extent of the cone of depression caused by pumping the municipal well would be expected to be seasonally and annually variable.

Ground-Water/Surface-Water Interactions

In addition to analysis of water levels, two methods were used to examine the interaction between ground water and surface water in the study area. The first method used streamflow measurements at selected locations to estimate the contribution of ground water to surface-water flow. The second method used seepage meters to measure ground-water discharge into Crumpacker Ditch.

Measurements of flow along Crumpacker and Forbes Ditches and Crooked Creek (table 6) ranged from no flow to 3.8 ft^3/s at the upstream site SW-1

Table 6. Measurements of flow in Crumpacker and Forbes Ditches and Crooked Creek near Westville, Indiana, April 1997 through August 1999

[Streamflow is in cubic feet per second; --, not measured]

Measuring station[a]	April 1997	June 1997	August 1997	December 1997	March 1998	July 1998	May 1999	August 1999
SW-1	0.04	0.13	0.05	0.02	3.83	0.33	0.06	0
SW-2	.51	.89	.38	.27	4.59	.91	.26	.03
SW-3	.76	--	.73	.62	6.32	1.04	.63	.41
SW-10	--	.95	--	.56	6.38	1.06	.78	--
SW-9	1.45	1.35	1.02	.75	8.00	1.77	1.09	.51
SW-7	3.35	3.92	3.77	2.56	13.8	5.59	3.22	1.72
SW-8[b]	0	.41	0	0	20.0	.15	.01	0
SW-4	5.00	7.43	5.49	3.08	30.8	9.85	5.14	2.37
SW-5[b]	2.71	3.33	2.43	1.41	11.4	3.57	2.81	.94
SW-11	--	--	8.37	6.74	41.2	17.6	9.60	2.94
SW-6	16.8	25.6	16.6	14.2	66.5	29.1	18.6	9.94

[a] Locations of measuring stations shown on figure 5.

[b] Measuring station is an upstream location on a tributary to the principal stream of interest.

and from 9.9 to 66.5 ft^3/s at the downstream site SW-6 (locations shown on fig. 5). According to local residents, Crumpacker Ditch often is dry upstream from the Town of Westville's treated-sewage outfall (near streamflow-measurement site SW-3) during summer. This condition was observed in August 1999. The largest streamflows were measured during March 1998.

For most of the measurements, streamflow consistently increased from upstream to downstream-measurement stations. No rain occurred prior to measurements made during April, August, and December 1997 and May and August 1999; therefore, the increase in streamflow generally is attributed to discharge of ground water. Substantial ground-water discharge occurs between specific measurement stations but is seasonally variable. For example, an increase of 0.69 ft^3/s was measured between stations SW-3 and SW-9 in April 1997. Between the same two measurement stations in August 1999, the measured increase was 0.1 ft^3/s. Streamflow measurements in December 1997 at stations SW-3 and SW-10 indicate a decrease in flow; however, these results are within the margin of error for streamflow measurements (usually about 5 percent).

Not all of the increase in streamflow between measurement stations is the result of ground-water discharge. The outfall from the wastewater-treatment plant for the Town of Westville is between measurement stations SW-2 and SW-3, and the outfall from the Westville Correctional Facility wastewater-treatment plant is between measurement stations SW-9 and SW-7. Numerous drainage-tile outfalls from farm fields also discharge to the stream system in the study area. The drainage tiles intercept ground-water recharge and bypass the natural flow system by routing the water to the streams.

Data from the seepage meters were used to estimate the vertical hydraulic conductivity of streambed sediments, using the following form of the Darcy equation:

$$K_v = \frac{Q}{A \times (\Delta h / \Delta l)} , \qquad (2)$$

where,

K_v is the vertical hydraulic conductivity,

Q is the ground-water discharge,

A is the cross-sectional area of flow, and

$\Delta h/\Delta l$ is the vertical hydraulic gradient or change in water level (Δh) over distance (Δl).

Water collected by the seepage meter represents the discharge (Q) through the streambed within the cross-sectional area of the seepage meter (A)—in this case, 0.340 ft^2. Discharge is equal to the volume of water collected divided by the length of time for collection. For these calculations, the hydraulic gradient ($\Delta h/\Delta l$) was assumed to equal the vertical gradients measured at well points near the seepage meters.

Seepage measurements were made near well points WP-1,WP-2, WP-3, and WP-P (table 7). At well points WP-2 and WP-P, different values of vertical hydraulic conductivity were calculated for different dates of measurement. The difference probably results from the seepage meters not being placed in exactly the same location for both measurements and the variability of the streambed materials which range from sand to silt.

Results of the seepage measurements indicate that vertical hydraulic conductivities of the streambed sediments are two or more orders of magnitude less than horizontal hydraulic conductivities for the glacial aquifer determined from the single-well and multiple-well aquifer tests. The largest streambed vertical conductivity, nearly 2 ft/d, was determined from data collected near well point WP-1, where the streambed is sand. Between well points WP-P and WP-3, the streambed is mostly silt, and vertical conductivity values averaged 0.25 ft/d. The results of the seepage measurements substantiate the water-level and streamflow measurements and indicate that ground water is discharged to Crumpacker Ditch.

Table 7. Discharge and vertical hydraulic conductivity determined from measurements of seepage in Crumpacker Ditch near Westville, Indiana, August–September 1997 and July 1998

[ft^3/d, cubic foot per day; ft/d, foot per day]

Location of measurement[a]	Date of measurement	Discharge (ft^3/d)	Vertical hydraulic gradient	Vertical hydraulic conductivity (ft/d)
WP-1	09/10/97	0.115	0.173	1.96
WP-2	07/07/98	.0238	.59	.119
WP-2	08/26/97	.0118	.41	.085
WP-3	08/27/97	.0151	.235	.189
WP-P	09/10/97	.0108	.25	.127
WP-P	07/08/98	.102	.404	.745

[a] Locations of measuring stations shown on figure 5.

Water Quality

A description of water quality in the study area was determined from analytical results of selected ground-water and surface-water samples collected for the USEPA field investigation. Samples were collected April–June, August–September, and December 1997 and May 1999. Based on previous environmental studies, the primary contaminant of concern for this study is 1,4-dioxane. Water samples also were collected and analyzed for inorganic constituents and organic compounds, and on-site measurements of selected water properties were made.

Results of Quality Assurance

The USEPA quality-control data-assurance review indicated that the analytical results reported by the laboratories were acceptable for use with respect to the applicable data qualifiers. One general exception was the analysis of 1,4-dioxane for samples collected April–June 1997. At that time, the laboratory was developing the analytical methods for 1,4-dioxane and the results for many of these analyses were qualified as unusable. Additional discussion of quality-assurance results and results of analyses are provided in appendix B.

Ground-Water Quality

Ground-water samples collected for the USEPA investigation were analyzed for major ions, minor elements, VOC's, SVOC's, pesticides, and PCB's. SVOC's, pesticides, and PCB's generally were not detected in ground-water samples (U.S. Environmental Protection Agency, 1999) and are not discussed in this report. The primary delineation of ground-water quality is based on four rounds of sample collection from the monitoring wells. Water samples also were collected from 27 private-supply wells during the USEPA investigation.

General Ground-Water Chemistry

The pH of ground water in the study area generally ranged from 6.0 to 8.0 (table C1 at the back of the report). Wells MW-12 and MW-14XD produced water with pH values less than 6.0, and well MW-14S produced water with a pH value less than 5.0. The pH of water from wells at B-4, MW-2, MW-3, and MW-6, along the western (downgradient) edge of the refinery site, ranged from 6.0 to 7.5, compared to a range of 7.0 to 7.9 for water from wells at B-1, EP-3, and MW-7, east (upgradient) of the site. This difference suggests that ground-water conditions at the site are lowering the pH. No trends in pH with depth were apparent.

Except for well MW-3D and several shallow monitoring wells, concentrations of dissolved oxygen (DO) in ground water in the study area were less than 2.0 mg/L (table C1 at the back of the report). Concentrations of DO in water from well MW-3D ranged from 3.5 to 5.8 mg/L; however, water from this well was reported to effervesce during sample collection. The effervescence likely was caused by degassing of the water resulting from pressure changes during pumping, and the degassing probably affected the measurements of DO. The largest DO concentration, 9.3 mg/L, was measured in water from well PZ-1S. The larger concentrations of DO in water from the shallow wells compared to those in deeper wells may indicate that the shallow ground water is recharged recently to the aquifer through infiltration of precipitation containing large concentrations of DO. In addition, the water table is in contact with the atmosphere, which allows mixing of oxygen with ground water.

The oxidation-reduction potential (ORP) measures whether conditions in the aquifer are chemically oxidizing or chemically reducing and commonly is related to the concentration of DO. Chemical reactions in which an element loses electrons are referred to as oxidations, while those in which electrons are gained are referred to as reductions (Hem, 1985, p. 20). Measurements of ORP are made to determine relative potentials. A positive value indicates oxidizing conditions; a negative value indicates reducing conditions; and the magnitude of the value indicates the relative potential. Measurements of ORP in ground water indicated relatively reducing conditions through most of the deep part the aquifer. Wells MW-5D and MW-5XD were the only deep wells that produced water with consistently positive values of ORP. Measurements of ORP in water from most of the shallow wells indicated the potential for oxidizing conditions in the shallow part of the aquifer, although water from shallow wells B-1, B-2, B-4, MW-6S, MW-9S, and MW-10S consistently had negative values of ORP.

Specific conductance (SC) is a measure of the fluid electrical conductivity. Although not a direct relation, small and large values of SC generally equate to small and large concentrations of dissolved constituents. Measurements of SC ranged from 330 µS/cm in water from well MW-9XD to 3,870 µS/cm in water from well MW-15XD. An increase in SC was observed downgradient from the refinery site, indicating that materials at the site are being dissolved and transported in ground water. SC ranged from 437 to 1,030 µS/cm in water from wells upgradient from the refinery site and from 330 to 3,780 µS/cm in water from downgradient wells. In addition, SC measurements upgradient from the site indicated little or no difference in SC related to depth in the aquifer; whereas, downgradient from the site, SC values were variable with depth. For example, at the upgradient well site MW-7, SC ranged from 504 to 652 µS/cm in water from well MW-7S; 520 to 605 µS/cm in water from well MW-7D; and 437 to 541 µS/cm in water from well MW-7XD. Downgradient from the site, SC ranged from 630 to 1,160 µS/cm in water from well MW-2S; 1,010 to 1,450 µS/cm in water from well MW-2D; 481 to 528 µS/cm in water from well MW-2MD; and 3,450 to 3,780 µS/cm in water from well MW-2XD.

Major ions are abundant, naturally occurring substances that readily dissolve in water and therefore constitute the majority of the dissolved constituents found in natural water. Ions that have a positive electrical charge are known as cations; ions that have a negative charge are known as anions. To determine the relative abundance of specific ions, the concentrations in milligrams per liter were converted to milliequivalents per liter. Milliequivalents per liter account for differences in atomic weight and ionic charge of the ions considered in the analysis (Hem, 1985, p. 55–56). The total concentration of cations and anions in a sample can be calculated, and concentrations of specific ions can be expressed as percentages of the total. The charge balance between cations and anions indicates whether the ions selected for the analysis include the majority of dissolved constituents in the sample. Ideally, the cations and anions are combined and their ionic charges are canceled, resulting in a charge balance of zero. A small charge balance is acceptable, because of the range of error in chemical analyses; however, a large charge balance can indicate an error in the chemical analysis or that not all of the major constituents were included in the calculations. A charge balance of ± 10 percent was considered acceptable for this study.

Calculations were made for samples that had sufficient analyses to determine the charge balance (table 8). Cations included in the calculations are calcium, magnesium, potassium, sodium, and iron; anions are bicarbonate, chloride, and sulfate (tables C2 and C3 at the back of the report). The cation-anion charge balances are less than ± 10 percent for samples from 13 of the 27 wells. Charge balances for samples from wells EP-1, MW-2XD, MW-5S, MW-5D, MW-6D, and MW-8D exceeded ± 25 percent—indicating that the calculations do not account for all of the ions for these samples.

The calculations for major ions indicated that ground water in the study area generally is a calcium-bicarbonate type. Ions were considered dominant if they accounted for 50 percent or more of the positive or negative charge. Calcium was the dominant cation in 21 of the 27 samples, accounting for 50.3 to 66.6 percent of the cations. Bicarbonate was the dominant anion in 20 samples and accounted for 50.3 to 91.7 percent of the anions. The analyses of samples from wells MW-5D and MW-8D indicated magnesium was the dominant cation; samples from wells MW-4D, MW-5S, MW-6D, and MW-8D indicated chloride was the dominant anion. The analysis of samples from wells B-1, MW-1D, MW-4D, and MW-6D indicated no dominant cation; analysis of samples from wells MW-1D, MW-3D, and MW-7D indicated no dominant anion.

Calculations that resulted in charge balances greater than ± 10 percent are considered inconclusive to determine water type. Generally, samples with the largest charge-balance discrepancies also had data qualifiers of less than or greater than the reported value used for the calculations. The lack of a charge balance also may result from the presence of ions that were not analyzed or changes in some ion concentrations (such as alkalinity) caused by biological processes. In addition, calculations for the duplicate sample from well MW-4XD (not shown in table 8) indicated a calcium-sulfate water type; whereas, the original sample indicated a calcium-bicarbonate type.

Minor Elements

Ground-water samples collected April–June 1997 were analyzed for concentrations of minor elements (table C3 at the back of the report). The minor elements principally are metals or elements that chemically act as metals, such as arsenic. These elements are naturally occurring, have various solubilities, and often are detected in natural water. In ground water, the variety and abundance of minor elements often is indicative of the composition of the geologic materials in the aquifer. For example, iron and manganese commonly are detected in ground water in glacial aquifers as a result of the abundance of minerals in the glacial sediments that contain these elements.

Barium, iron, and manganese were detected in samples from all of the monitoring wells. Concentrations of barium ranged from 13.0 µg/L in water from well MW-7D to 498 µg/L in water from well MW-10D. Iron was detected in the largest concentrations compared to the other minor elements and was included in the calculations for major ions; in these calculations, iron accounted for 0.04 to 16 percent of the cations in the samples. Concentrations of iron ranged from an estimated 31.5 µg/L in water from well MW-5XD to 69,300 µg/L in water from well MW-6S and exceeded 1,000 µg/L in 29 of 36 samples. Concentrations of manganese ranged from 7.8 µg/L in water from well MW-7S to 3,500 µg/L in water from well MW-2S. Concentrations of manganese greater than 1,000 µg/L were reported for water from two other wells, B-2 and EP-2.

Nickel and zinc were detected in all but four samples. Detected concentrations of nickel ranged from 1.1 µg/L in water from well MW-7S to 182 µg/L in water from well MW-2S. Detected concentrations of zinc ranged from an estimated 2.6 µg/L in water from well MW-1D to an estimated 503 µg/L in water from well MW-2S. Antimony was detected at estimated concentrations, ranging from 2.1 to 9.1 µg/L in all but nine samples. Concentrations of antimony exceeded the USEPA Primary Drinking Water Standard of 6 µg/L (U.S. Environmental Protection Agency,

Table 8. Results of calculations for major ions and water type for ground-water samples collected near Westville, Indiana, April–June 1997

[meq/L, milliequivalents per liter; cations are calcium, magnesium, potassium, sodium, and iron; anions are bicarbonate, chloride, and sulfate; a positive charge balance indicates excess cations; a negative charge balance indicates excess anions]

Well	Sum of cations (meq/L)	Sum of anions (meq/L)	Charge balance (percent)	Water type
B-1	10.3023	-8.6396	8.78	Low calcium-bicarbonate
B-4	14.7734	-16.3717	-5.13	Calcium-bicarbonate
EP-1	5.8000	-3.2148	28.7	Calcium-bicarbonate[a]
EP-2	8.5363	-6.6516	12.4	Calcium-bicarbonate[a]
LP-2	6.7936	-4.9575	15.6	Calcium-bicarbonate[a]
LP-3	7.4034	-6.2036	8.82	Calcium-bicarbonate
MW-1S	8.3117	-6.9291	9.07	Calcium-bicarbonate
MW-1D	10.0450	-11.6983	-7.60	Low sodium-low chloride
MW-2S	9.9386	-10.0665	-.64	Calcium-bicarbonate
MW-2D	14.3821	-14.8187	-1.50	Calcium-bicarbonate
MW-2MD	6.0647	-5.5371	4.55	Calcium-bicarbonate
MW-2XD	46.9240	-25.4940	29.6	Calcium-bicarbonate[a]
MW-3S	17.1186	-16.8844	.69	Calcium-bicarbonate
MW-3D	14.6453	-15.3766	-2.44	Calcium-low bicarbonate
MW-4S	9.1523	-8.1809	5.60	Calcium-bicarbonate
MW-4D	21.6711	-30.0870	-16.3	Low calcium-chloride[a]
MW-4XD	48.5502	-32.8411	19.3	Calcium-bicarbonate[a]
MW-5S	4.5961	-17.7077	-58.8	Calcium-chloride[a]
MW-5D	37.6266	-9.1154	61.0	Magnesium-bicarbonate[a]
MW-5XD	5.5953	-7.1668	-12.3	Calcium-bicarbonate[a]
MW-6D	7.5053	-17.7077	-40.5	Low calcium-chloride[a]
MW-7S	7.0391	-4.5573	21.4	Calcium-bicarbonate[a]
MW-7D	6.8055	-6.1987	4.67	Calcium-low bicarbonate
MW-7XD	5.7438	-4.3806	13.5	Calcium-bicarbonate[a]
MW-8D	59.0717	-16.8644	55.6	Magnesium-chloride[a]
MW-9S	8.2225	-7.0205	7.89	Calcium-bicarbonate
MW-9XD	6.5221	-4.8417	14.8	Calcium-bicarbonate[a]

[a] Results inconclusive for water type; charge balance exceeds 10 percent.

2001) in water from wells MW-2D, MW-10D, and MW-11D.

Aluminum and copper were detected in all but 10 samples, and cobalt was detected in all but 11 samples. Detected concentrations ranged from 9 to 1,230 µg/L for aluminum, 1.1 to 38.5 µg/L for copper, and 1.2 to 113 µg/L for cobalt. Arsenic was detected in all but 13 samples; detected concentrations ranged from 2.1 µg/L in water from well LP-2 to 29.4 µg/L in water from well MW-6S. Concentrations of chromium ranged from an estimated 1.2 to 63.4 µg/L.

The remaining minor elements were detected in less than half of the samples and in concentrations less than 10 µg/L. Thallium was detected in 16 samples, 15 of which contained concentrations exceeding the USEPA Primary Drinking Water Standard of 2 µg/L (U.S. Environmental Protection Agency, 2001). Vanadium was detected in seven samples, lead was detected in three samples, and silver was detected in two samples. Beryllium, cadmium, mercury, and selenium were detected in only one sample each (table C3 at the back of the report). The concentration of cadmium reported for the sample from well MW-2S exceeds the USEPA Primary Drinking Water Standard of 5 µg/L (U.S. Environmental Protection Agency, 2001).

No relation between the detection of minor elements with respect to ground-water flow and the refinery site, or with depth, is readily apparent. The largest concentrations of cadmium, cobalt, manganese, and nickel were detected in water from well MW-2S at the western edge of the site. The largest concentrations of aluminum, copper, lead, vanadium, and zinc were detected in water from well MW-11S, approximately 0.75 mi southwest of the site.

Organic Compounds

VOC's were detected in ground-water samples during each round of sample collection, although more compounds were detected during the first round (table C4 at the back of the report). Water from 12 of 36 wells sampled April–June 1997 contained one or more VOC's; whereas, samples from 9 of 46 wells collected September 1997, 3 of 41 wells collected December 1997, and 12 of 15 wells collected May 1999 contained VOC's. Fifteen different VOC's were detected during April–June 1997, compared to 13 VOC's detected during September 1997 and 12 VOC's detected during December 1997 and May 1999.

VOC's generally were detected in samples collected from wells at or near the refinery site. Well B-2, the only well sampled on the refinery site, was vandalized prior to sample collection in December 1997; seven VOC's were detected in water from this well collected during April 1997, and nine VOC's were detected during September 1997. Although the compounds and concentrations detected in samples from well B-2 are variable between sampling rounds, vinyl chloride, chloroethane, 1,1-dichloroethane, benzene, and trichloroethene were detected at similar concentrations in samples from both rounds.

The average concentrations in water from well B-2 for the two rounds of sampling are 54 µg/L for vinyl chloride, 7.5 µg/L for chloroethane, 150 µg/L for 1,1-dichloroethane, 5 µg/L for benzene, and 30.5 µg/L for trichloroethene. In addition, a concentration of 1,500 µg/L of total 1,2-dichloroethene was reported for the first sampling round, while concentrations of 20 µg/L of trans-1,2-dichloroethene and 1,400 µg/L of cis-1,2-dichloroethene were reported for round two.

Shallow wells west and south of the refinery site (wells B-4, MW-1S, MW-2S, MW-3S, and MW-6S) also provided samples in which VOC's consistently were detected. Chloroethane was detected in the four samples collected from well B-4, three of four samples from well MW-2S, and in two of four samples from well MW-1S. Concentrations of chloroethane in these samples averaged 442 µg/L for well B-4, 82 µg/L for well MW-2S, and 2 µg/L for well MW-1S. Based on four samples, the average concentration of 1,1-dichloroethane was 115 µg/L for well B-4 and 68 µg/L for well MW-1S. This compound was detected in only one of three samples collected from well MW-3S at an estimated concentration of 15 µg/L. The average concentration of trichloro-ethene in four samples from well MW-1S was 13 µg/L. Concentrations of benzene averaged 122 µg/L for well B-4, 7 µg/L for well MW-1S, 16 µg/L for well MW-2S, and 4 µg/L for well MW-3S.

Other VOC's also were detected in water from shallow wells near the former refinery site. Toluene, ethylbenzene, and xylenes were detected consistently in samples from well B-4 in concentrations of 7 µg/L or less. Toluene also was detected in samples from well MW-2S in concentrations of 1 µg/L or less, and similar concentrations of xylenes were detected in samples collected from well MW-6S during September 1997. Methylene chloride was detected in four samples from wells B-4 and MW-2S in concentrations ranging from 4 to 90 µg/L. Water from well MW-1S contained an average concentration of 93 µg/L of 1,1,1-trichloroethane, based on three samples.

Detections of VOC's in ground water primarily were limited to shallow wells on or near the refinery site. One exception is well MW-14S, approximately 0.4 mi southwest of the former refinery, that produced a sample in which methylene chloride was detected at a concentration of 1 µg/L during the December 1997 sampling. Methylene chloride was detected consistently at concentrations ranging from 4 to 7 µg/L in samples from wells B-4 and MW-2S along the western refinery boundary; therefore, the detection in water from a well farther downgradient may indicate that some VOC's are being transported in the direction of ground-water flow. Well MW-14S was installed during November 1997 and was not available for sampling during the first two rounds of sample collection. No other samples were collected from this well to determine whether methylene chloride is persistent in the ground water at this location.

The detected VOC's generally are classified as chlorinated solvents, such as chloroethane, 1,1-dichloroethane, and trichloroethane, or aromatic hydrocarbons, such as benzene, toluene, and xylene. Chlorinated solvents were detected with greater frequency and in the larger concentrations (as much as 1,500 µg/L of 1,2-dichloroethene from well B-2) than the aromatic hydrocarbons (as much as 140 µg/L of benzene from well B-4). Chlorinated solvents are used as cleaners and de-greasers; aromatic hydrocarbons are components of oil and gasoline.

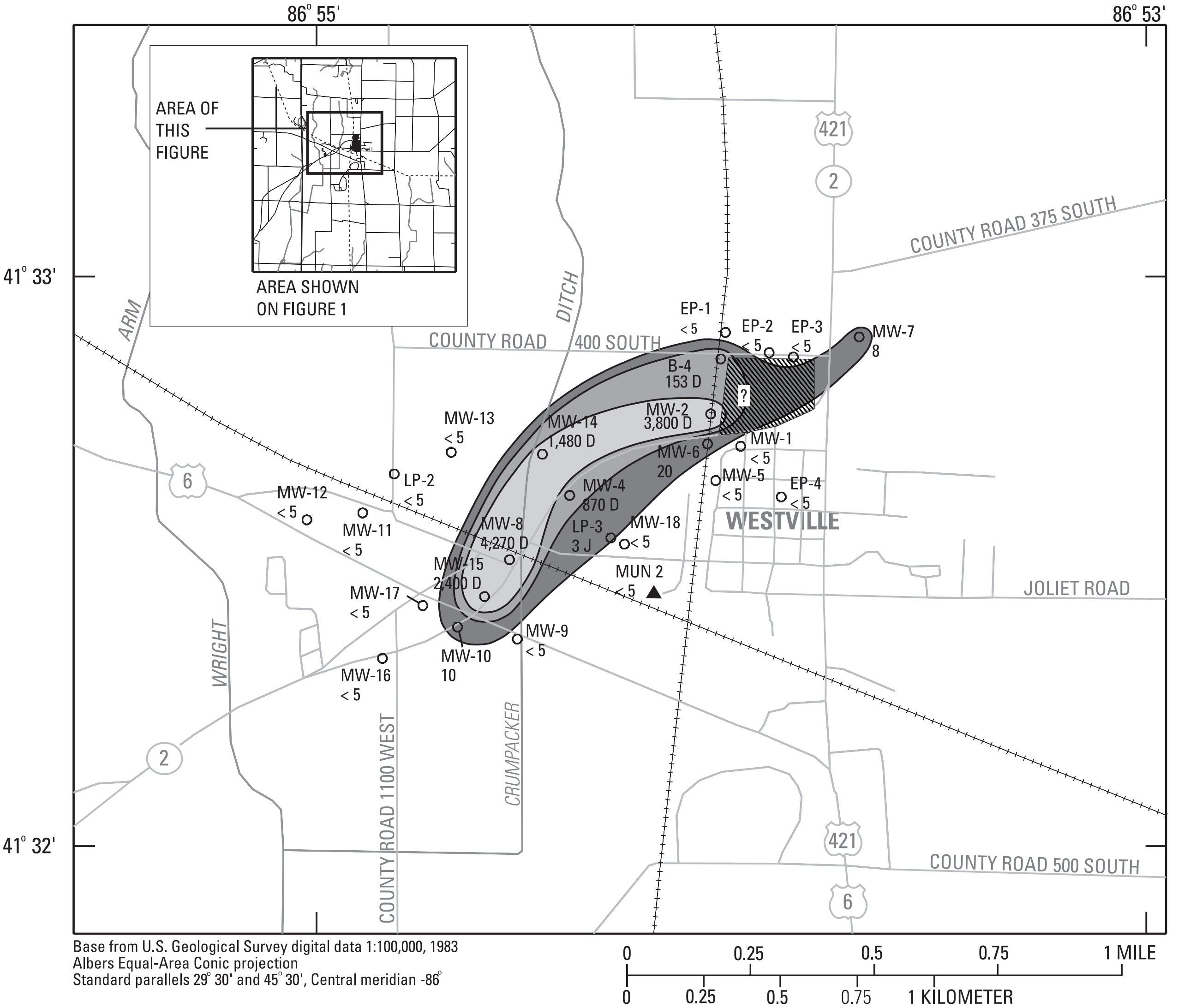
1,4-Dioxane in Ground Water

Samples for analysis of 1,4-dioxane were collected during all rounds of sample collection (table C5 at the back of the report). The most complete sample collection was during December 1997, based on the number of wells sampled; therefore, the description of the extent of 1,4-dioxane is primarily based on results of that sample collection.

Concentrations of 1,4 dioxane were detected in water from 20 of 48 wells and 1 of 3 well points in Crumpacker Ditch sampled during December 1997. Samples containing 1,4-dioxane were collected from wells along the western boundary of the refinery site and from wells southwest of the site along the direction of ground-water flow that roughly parallels State Road 2 (fig. 17). Concentrations ranged from 3 µg/L in water from well LP-3 to 4,270 µg/L in water from well MW-8D. Water from wells MW-10S and MW-10XD, approximately 0.8 mi southwest of the site, contained concentrations of 1,4 dioxane of 7 and 10 µg/L.

Along the western (downgradient) boundary of the refinery site, concentrations ranged from 20 µg/L in water from well MW-6D to 3,800 µg/L in water from well MW-2D for samples collected during December 1997. During September 1997, the laboratory estimated a concentration of 11,000 µg/L in water from well MW-2D. Although not sampled during December 1997, samples collected during September 1997 from well B-2 on the refinery site and well MW-3D along the western boundary contained 1,4-dioxane, ranging from 220 µg/L at well B-2 to 1,600 µg/L at well MW-3D.

Concentrations of 1,4-dioxane varied not only horizontally but also vertically in the aquifer (fig. 18). The vertical distribution is affected by vertical flow paths and the heterogeneity of aquifer materials and hydraulic properties. At site MW-2, the largest concentration of 1,4-dioxane was 3,800 µg/L in the sample from the 80-ft-deep well, MW-2D. The smallest concentration was 380 µg/L in the sample from the 130-ft-deep well,



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

EXPLANATION

▨ FORMER REFINERY SITE

■ AREA IN WHICH 1,4-DIOXANE WAS DETECTED

▩ AREA IN WHICH CONCENTRATIONS OF 1,4-DIOXANE EXCEEDED 100 MICROGRAMS PER LITER

□ AREA IN WHICH CONCENTRATIONS OF 1,4-DIOXANE EXCEEDED 1,000 MICROGRAMS PER LITER

○ MW-7 8 — MONITORING-WELL LOCATION AND DESIGNATION--Number is maximum concentration of 1,4-dioxane in micrograms per liter in wells at site, < denotes less than concentration shown, J denotes an estimated concentration, D denotes a sample that was diluted

MUN-2 < 5 ▲ — MUNICIPAL SUPPLY WELL AND DESIGNATION--Number is concentration of 1,4-dioxane in micrograms per liter

Figure 17. Maximum concentrations of 1,4-dioxane in ground water near Westville, Indiana, December 1997.

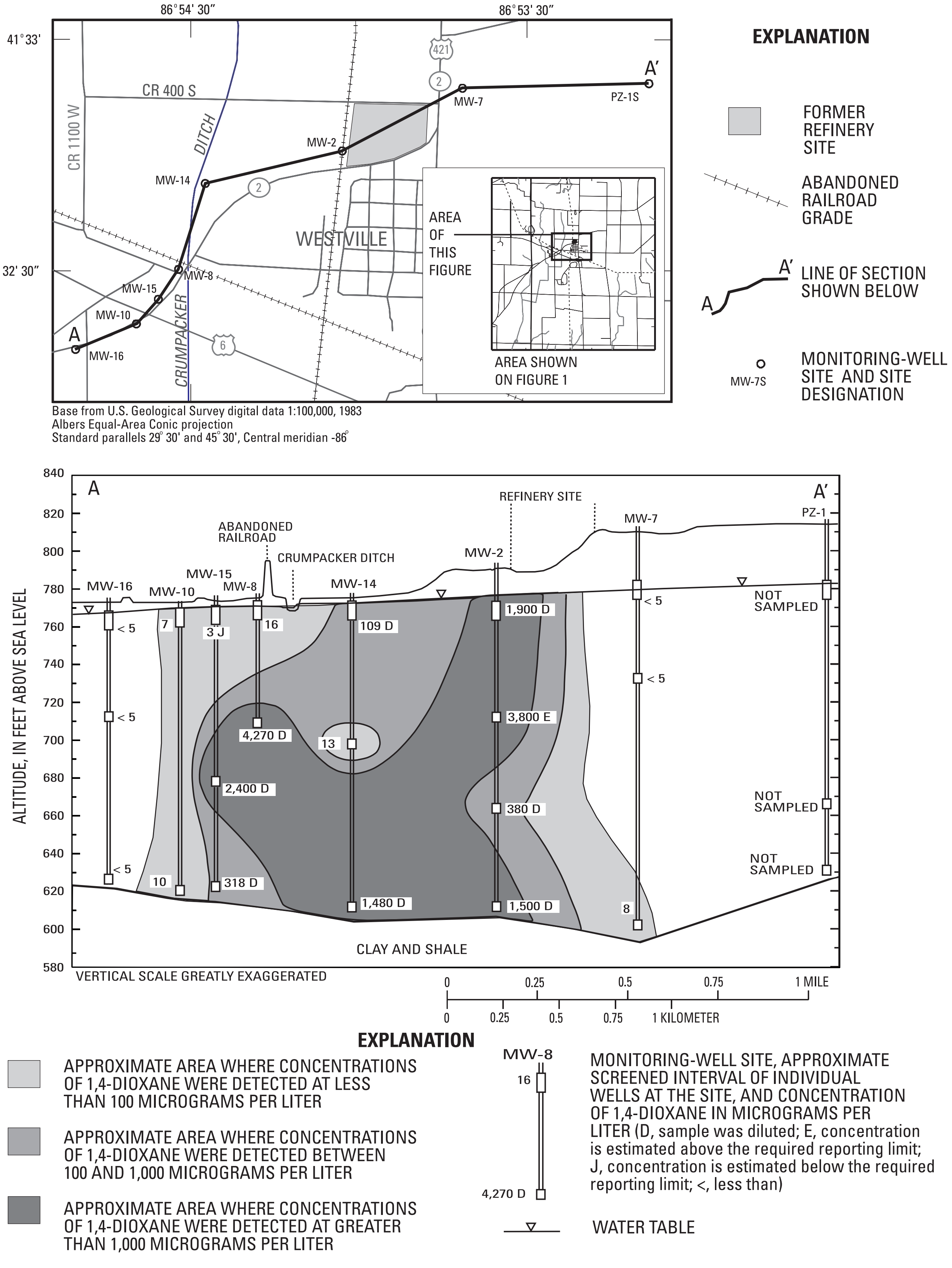


Figure 18. Concentrations of 1,4-dioxane in ground water along a section from well site PZ-1 to well site MW-16 near Westville, Indiana, December 1997.

MW-2MD. Concentrations of 1,4-dioxane were 1,900 µg/L in the sample from well MW-2S, screened across the water table, and 1,500 µg/L in the sample from well MW-2XD, screened at 182 ft, the bottom of the aquifer. Similar patterns of concentration with depth were observed for results of the samples collected from this well during the other rounds of sampling.

Downgradient from the site, the largest concentrations of 1,4-dioxane generally were detected in samples from the deep wells (fig. 18). At sites MW-4, MW-10, and MW-14, the largest concentrations of 1,4-dioxane were detected in samples from wells screened at the bottom of the aquifer. At site MW-15, the largest concentration was reported for the sample from the 100-ft-deep well MW-15MD and at site MW-8, the largest concentration was in the sample from the 65-ft-deep well MW-8D. Well MW-8D is the deepest well at this site; therefore, the concentration of 1,4-dioxane at greater depth at this site is not known.

The sample collected from well point WP-P during December 1997 contained 160 µg/L of 1,4-dioxane. Although 1,4-dioxane was not detected in samples from well points WP-2 and WP-3 collected during December, it was detected in samples from well points WP-P (180 µg/L) and WP-2 (5 µg/L) collected during September 1997. The detection of 1,4-dioxane in the well points and the previously discussed discharge of ground water to Crumpacker Ditch indicate the potential for 1,4-dioxane to be entering surface water along this part of the ditch.

Water collected during December 1997 from well MW-7XD, approximately 0.1 mi upgradient from the site, also contained 1,4-dioxane. The concentration was low, 8 µg/L, but is above the method-detection limit and the result was not qualified by the USEPA quality review. During September 1997 or May 1999, 1,4-dioxane was not detected in samples collected from this well; however, it was reported at a similar concentration for the sample collected during May 1997 (table C5 at the back of the report). The detection of 1,4-dioxane in water from an upgradient well is not easily explained and the possibility of sample contamination, or laboratory error is acknowledged. The specific density of 1,4-dioxane at 20°C relative to the density of water at 4°C is about 1.03; therefore, 1,4-dioxane would not be expected to sink in the aquifer unless it was mixed with other, more dense, compounds. It is possible that natural flow gradients were altered by former lagoons at the site that created downward vertical gradients and radial flow off site.

Samples from 3 of the 27 private water-supply wells sampled contained 1,4-dioxane (U.S. Environmental Protection Agency, 1999). Two of these wells are in the area where 1,4-dioxane was detected in samples from the monitoring wells, and the concentrations are comparable. The third water-supply well, near monitoring well MW-12, is west of the area where 1,4-dioxane was detected. Concentrations of 1,4-dioxane in samples from this well ranged from 4 to 34 µg/L (U.S. Environmental Protection Agency, 1999). Samples from nearby well MW-12 or from wells LP-2, MW-13, and MW-11 that are between well MW-12 and the area of 1,4-dioxane contamination did not contain 1,4-dioxane. The geographical distribution of detection and nondetection suggests that the water-supply well may be affected by a source of 1,4-dioxane other than the refinery site.

The pattern of 1,4-dioxane concentrations in ground water defines a plume that extends from the vicinity of the former refinery site to the southwest along State Road 2 approximately 0.8 mi (fig. 17). Detectable concentrations of 1,4-dioxane are present in ground water beneath the refinery site (well B-2) and throughout the thickness of the aquifer at the western boundary (site MW-2). This compound is miscible in water and not easily sorbed onto aquifer materials (U.S. Environmental Protection Agency, 1999), indicating that it is easily transported in ground water. In addition, because 1,4-dioxane does not degrade easily and has low volatility, the only processes that may be decreasing the concentration of 1,4-dioxane in the ground water are dilution from precipitation recharging the aquifer, mixing due to dispersion, and diffusion with uncontaminated ground water (U.S. Environmental Protection Agency, 1999). The large concentrations throughout the plume, however, indicate the relative dilution rates are not large.

The plume of 1,4-dioxane is only roughly defined by the monitoring-well network. The width of the plume is about 0.17 mi at the western boundary of the refinery and increases to at least 0.25 mi between well point WP-P and well LP-3. In addition, because concentrations of 1,4-dioxane vary with depth, it is possible that contaminants may be present at depths where the monitoring wells are not screened. For example, large concentrations of 1,4-dioxane were detected in water from 65- to 100-ft-deep wells at sites MW-8 and MW-15; whereas, sites MW-9 and MW-10 have no wells screened at intermediate depths.

Surface-Water Quality

Surface-water samples collected April–May 1997 were analyzed for selected major ions, metals, VOC's, SVOC's, pesticides, PCB's, and 1,4-dioxane. Organic compounds (including VOC's, SVOC's, pesticides, and PCB's) generally were not detected in surface-water samples (U.S. Environmental Protection Agency, 1999) and are not discussed in this report. After the initial sample collection, sampling focused on the part of Crumpacker Ditch that was receiving ground water from the contaminant plume; samples of surface water collected during August and December 1997 and May 1999 were analyzed for 1,4-dioxane.

General Surface-Water Chemistry

Measurements of pH at surface-water-sampling sites ranged from 4.5 to 8.3 (table C6 at the back of the report). Most pH values were between 7.0 and 8.0, with the exception of measurements made December 1997; three of four measurements at that time indicated a pH of about 4.5. During December 1997, a pH of 4.8 was measured in water from well MW-14S near Crumpacker Ditch in the area where the surface-water samples were collected; however, a pH of 6.7 was measured in surface water near well point WP-P and adjacent to well site MW-14 (see fig. 3 for location). Streamflows reported for December 1997 were among the lowest measured during the study. It is not known whether the low pH values measured in surface water during December 1997 reflect the quality of water discharged to the ditch during low-flow conditions or are the result of measurement error.

Concentrations of dissolved oxygen in surface-water samples ranged from 0.2 to 13.6 mg/L and typically were larger than 5 mg/L (table C6 at the back of the report). Measurements of ORP ranged from -196 to 464 millivolts. Most measurements indicated relatively oxidizing conditions in the surface water, except for measurements made during August 1997 when relatively reducing conditions were measured at 10 of 13 sites. The SC of surface water ranged from 371 to 1,350 µS/cm. Some of the largest values of SC were measured at sites SW-7, SW-8, and SW-11, where values consistently exceeded 1,000 µS/cm. SC values also were larger than 1,000 µS/cm at least once during sampling at sites SW-9, SW-10, SW-13, SW-WP-2, SW-WP-3, and SW-WP-P.

Calculations were made to determine the cation-anion charge balance for surface-water samples collected during April–May 1997 (table C7 at the back of the report). The charge balances are less than ± 10 percent for all of the analyses (table 9), indicating the constituents included in the analysis account for the majority of the ions in the samples. The results indicate that the surface water is generally a calcium-low bicarbonate water type. Water at sampling sites SW-8, SW-9, and SW-11 is a low-calcium low-chloride type. These sites are downstream from the outfall for treated sewage from the Town of Westville. In addition, they are near a point where a state highway crosses Crumpacker Ditch. Concentrations of chloride in the treated effluent or runoff of highway-deicing chemicals could explain the increase in chloride concentration and the large values of SC measured at these sites. Additional samples of surface water were not collected for analysis of major ions, and it is unknown whether this condition is normal or persistent.

Minor Elements

Aluminum, barium, iron, manganese, and zinc were the only minor elements detected in concentrations greater than 10 µg/L (table C8 at the back of the report). Concentrations of aluminum ranged from estimates of 9 to 590 µg/L, and concentrations of barium ranged from about 32 to 74 µg/L.

Table 9. Results of calculations for major ions and water type for surface-water samples collected near Westville, Indiana, April–May 1997

[meq/L, milliequivalents per liter; cations are calcium, magnesium, potassium, sodium, and iron; anions are bicarbonate, chloride, and sulfate; a positive charge balance indicates excess cations; a negative charge balance indicates excess anions]

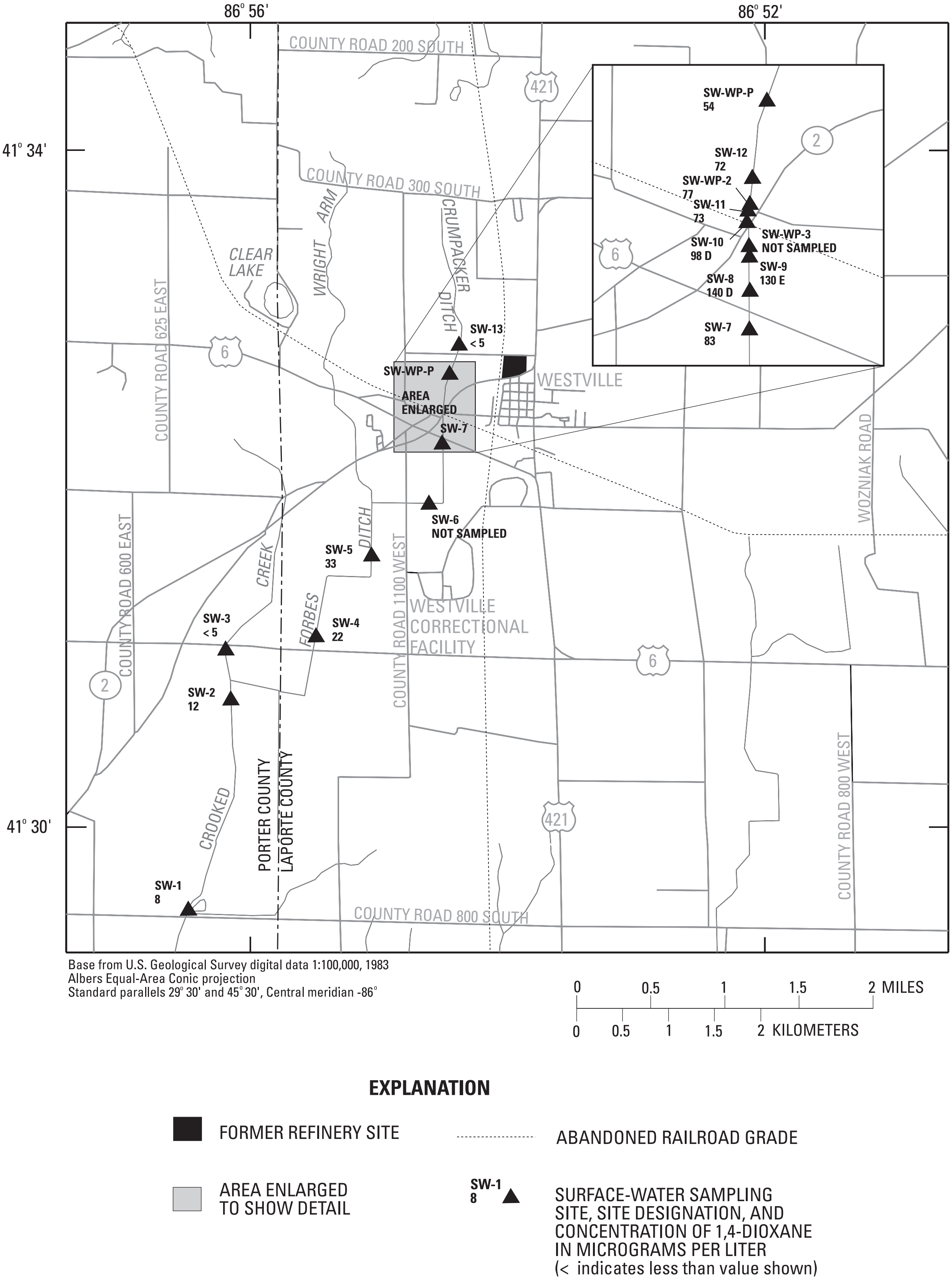
Surface-water site	Sum of cations (meq/L)	Sum of anions (meq/L)	Charge balance (percent)	Water type
SW-1	9.9583	-8.4838	8.0	Calcium-low bicarbonate
SW-2	8.9869	-8.6348	2.0	Calcium-low bicarbonate
SW-3	8.9845	-8.5978	2.2	Calcium-low bicarbonate
SW-4	9.6885	-9.1242	3.0	Calcium-low bicarbonate
SW-5	9.1536	-8.7400	2.3	Calcium-low bicarbonate
SW-6	9.5506	-9.8737	-1.7	Low calcium-low bicarbonate
SW-7	10.3506	-8.9015	7.5	Low calcium-low bicarbonate
SW-8	10.8741	-12.2882	-6.1	Low calcium-low chloride
SW-9	11.0590	-11.3404	-1.3	Low calcium-low chloride
SW-11	11.6653	-9.7538	8.9	Low calcium-low chloride
SW-12	8.0166	-7.9189	.6	Calcium-bicarbonate
SW-13	5.8924	-5.5144	3.31	Calcium-bicarbonate

Iron was detected in the largest concentrations, compared to the other minor elements. Iron was included in the calculations for major ions, where it accounted for 0.2 to 1.7 percent of the cations in the surface-water samples. Concentrations of iron ranged from 723 to 4,680 µg/L and exceeded 1,000 µg/L in 10 of the 12 samples. Concentrations of manganese ranged from 62.4 to 1,200 µg/L; estimated concentrations of zinc ranged from 3.1 to 121 µg/L.

Cobalt was detected in all samples of surface water collected April–May 1997 at estimated concentrations ranging from 1.2 to 2.6 µg/L. Beryllium, copper, nickel, and thallium were detected in 11 of 12 samples, with detected concentrations ranging from estimates of 1 to 1.8 µg/L for beryllium, 1.2 to 8.4 µg/L for copper, 1.1 to 3 µg/L for nickel, and estimates of 2.3 to 4 µg/L for thallium. Antimony, chromium, and vanadium were detected in five or fewer samples. The remaining minor elements were not detected in surface-water samples.

1,4-Dioxane in Surface Water

Samples of surface water for analysis of 1,4-dioxane were collected during all rounds of sample collection (table C9 at the back of the report). Samples collected in August 1997 are used to illustrate the detection of 1,4-dioxane in surface water (fig. 19). With two exceptions, 1,4-dioxane was detected in all surface-water samples collected in August 1997. The exceptions are site SW-13, the most upstream location on Crumpacker Ditch, and site SW-3 on Crooked Creek, upstream from the confluence with Forbes Ditch. A concentration of 54 µg/L of 1,4-dioxane was detected in water from Crumpacker Ditch collected at site SW-WP-P, near well point WP-P. Concentrations of 1,4-dioxane increased downstream at each location from site SW-WP-P to a maximum concentration of 140 µg/L at site SW-8, north of U.S. Highway 6. Concentrations of 1,4-dioxane were detected in samples downstream from site SW-8 in Crumpacker Ditch, Forbes Ditch, and Crooked Creek.



Base from U.S. Geological Survey digital data 1:100,000, 1983
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Standard parallels 29° 30' and 45° 30', Central meridian -86°

Figure 19. Concentrations of 1,4-dioxane in surface-water samples collected near Westville, Indiana, August 1997.

The sample from site SW-1, the farthest downstream location sampled, contained 8 µg/L of 1,4-dioxane.

Concentrations of 1,4-dioxane in surface-water samples collected in August 1997 were evaluated with concurrent streamflow measurements to assess which mechanisms (dilution, volatilization, or degradation) might be affecting the concentrations of 1,4-dioxane in surface water. If dilution were the only mechanism affecting concentrations of 1,4-dioxane, the concentrations should decrease downstream proportionally to the increase in flow. If the concentrations of 1,4-dioxane decreased at a rate greater than that, then another mechanism (such as volatilization) might be affecting the concentrations.

The data suggest that 1,4-dioxane is entering Crumpacker Ditch in ground-water discharge between sample-collection sites SW-WP-P and SW-8, with the largest concentration, 140 µg/L, in the sample from site SW-8. Streamflow was not measured at site SW-8 but is estimated from streamflow measurements at sites SW-3 and SW-9 (locations shown on fig. 5). Streamflow at these sites was 0.73 and 1.02 ft^3/s. By interpolating between these two measurement points, a flow of 0.85 ft^3/s was assigned for the SW-8 sampling location.

At surface-water-sampling site SW-2, approximately 3 mi downstream from site SW-8, the measured streamflow was 8.37 ft^3/s (streamflow-measuring site SW-11); at sampling site SW-1, the most downstream site, the measured streamflow was 16.6 ft^3/s (streamflow-measuring site SW-6). The estimated streamflow for SW-8 (0.85 ft^3/s) accounts for 10.1 percent of the streamflow at site SW-2 and 5.1 percent of the streamflow at site SW-1. If dilution were the only mechanism acting to reduce the concentration of 1,4-dioxane between these sampling sites, a concentration of about 14 µg/L would be expected at site SW-2 and a concentration of about 7 µg/L would be expected at site SW-1. Concentrations of 1,4-dioxane in samples collected at sites SW-2 and SW-1 were 12 and 8 µg/L.

Simulation of Ground-Water Flow

Ground-water flow was simulated by use of the USGS modular three-dimensional finite-difference ground-water-flow model developed by McDonald and Harbaugh (1988). The digital model was based on a conceptualization of the aquifer geometry and geohydrology developed from data collected during installation, geophysical logging, and hydraulic testing of the monitoring wells. The model was used to investigate the effects of existing and planned ground-water pumping, the possible mechanisms of contaminant release, the interaction between the contaminant plume and Crumpacker Ditch, and potential methods of aquifer remediation.

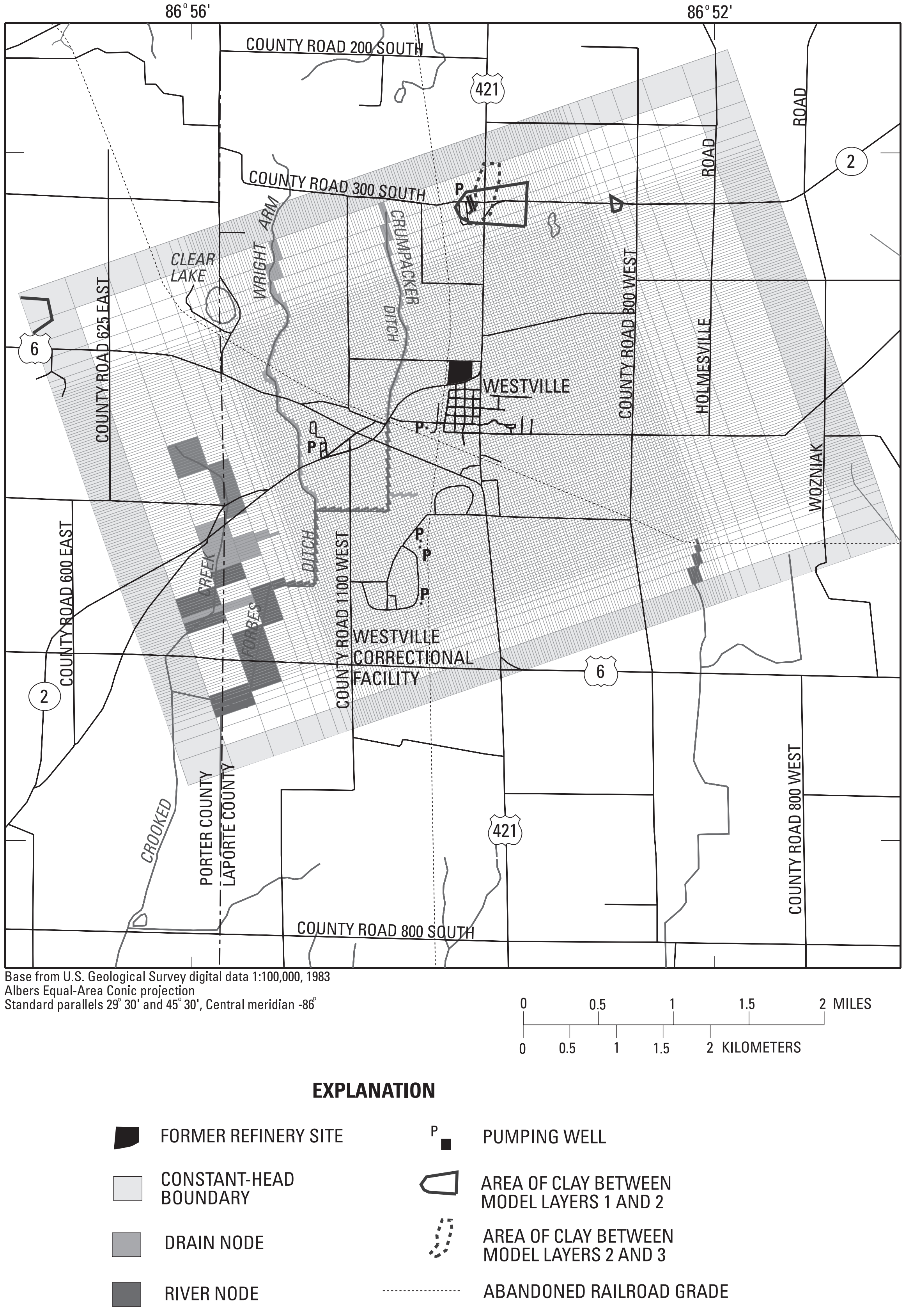
Simplifying Assumptions

The following assumptions were made for the geometry, hydraulic properties, and other characteristics of the ground-water-flow system in the study area:

- The sand and gravel deposits define the principal aquifer in the study area.
- The base of the aquifer is an impermeable boundary formed by the underlying clay and shale.
- Horizontal hydraulic conductivity varies with depth but is uniform in each model layer. Vertical hydraulic conductivity is 0.2 times the value for horizontal conductivity.
- The simulated value of streambed vertical hydraulic conductivity is based upon a streambed thickness of 1 ft.
- The ground-water-flow system is in dynamic equilibrium. Dynamic equilibrium is defined as water levels fluctuating above or below a long-term average water level. The starting water levels are assumed to be at steady state.

Model Design

The digital model is based on a rectangular block-centered-grid network that covers 17.4 mi^2 of the study area (fig. 20). The grid is 5.0 mi by



Base from U.S. Geological Survey digital data 1:100,000, 1983
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Figure 20. Model grid used to simulate ground-water flow near Westville, Indiana.

3.48 mi, with the longest distance along the northeast to southwest. The grid contains 20,636 blocks (134 rows by 154 columns) that range in size from about 100 ft by 100 ft in the central part of the model to almost 1,710 ft by 1,140 ft at the corners of the model. The 100-ft by 100-ft block size was used to provide detail in the principal area of interest—the former refinery and the 1,4-dioxane plume.

Ground-water flow was simulated by four model layers determined from the vertical positions of the well screens of the monitoring wells (fig. 21). The four model layers allowed the simulation of differences in horizontal hydraulic conductivity with depth determined from the single-well aquifer tests. Wells were screened at four general depths; the tops and bottoms of the layers were calculated to be the vertical midpoints between the well screens. In areas without data from monitoring wells to calculate the tops and bottoms, the aquifer was divided into layers that represent the same percentage of the total aquifer thickness as was calculated for the monitoring wells. For example, if 25 percent of the total aquifer thickness was represented by layer 2 at the monitoring wells, then 25 percent of the total thickness was used to represent layer 2 at other locations. The total thickness of the aquifer was determined from available well logs and by use of a 1:500,000-scale map of bedrock-surface altitude (Gray, 1982). To account for the thickness of clay above the bedrock, the bottom of the aquifer was assumed to be 8 ft above the bedrock surface, as reported on the geologic log for well TW-95A.

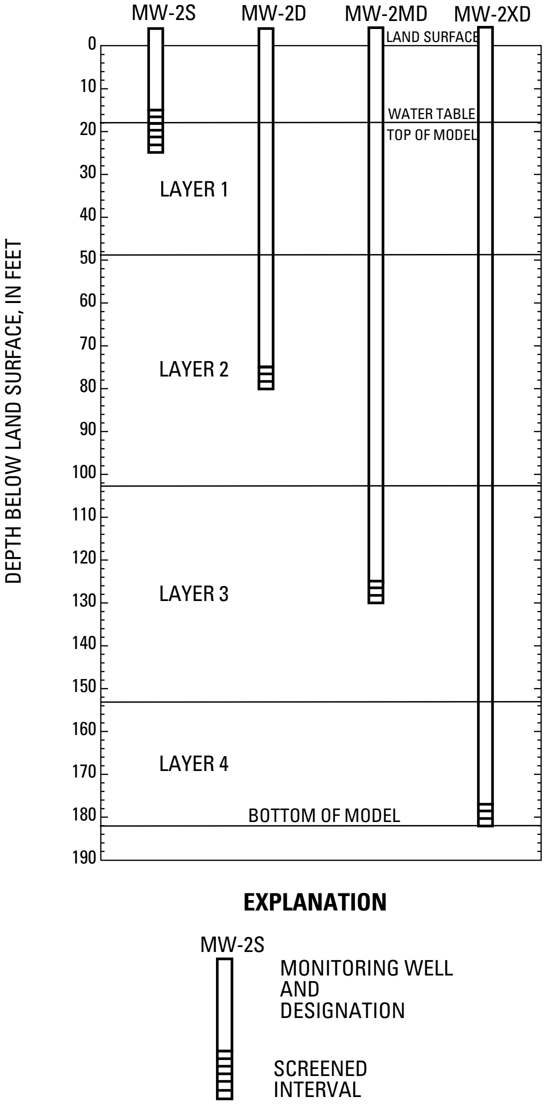


Figure 21. Diagram showing subdivision of aquifer into model layers at well site MW-2 near Westville, Indiana.

Boundary conditions in the ground-water model were selected so the location and type of the boundary would have a minimal effect on model simulations in the area of interest. Boundaries were placed far from major ground-water pumpage so the boundary condition would have minimal effect on the simulated response of the ground-water system to pumping in the area of interest. Constant-head boundaries were placed on each of the four sides of each model layer. Generally, constant-head nodes are useful to simulate flow across the model boundary and to help stabilize the iterative solution process. A no-flow boundary was assumed at the bottom of the model because of the presence of low-permeability clay and shale beneath the aquifer. The upper surface of the model was simulated as a free-surface boundary to represent the water table.

Lithologic data for two privately owned wells within the modeled area showed clay and silt in the upper part of the unconsolidated sediments, indicating that the aquifer may not be present in layer 1 in this area. Both wells are in boundary nodes along the northern edge of the model. One was too far away from other points of data to confirm or deny its validity; the other was near several other points of data that indicated sand at similar depths. Therefore, layer 1 was simulated everywhere as an aquifer.

One data point, also near the northern boundary, indicated the aquifer was not present in layer 2 of the model; however, two other points of data within 600 ft of this point showed the aquifer was present. Therefore, layer 2 was simulated everywhere as an aquifer.

The lithologic data indicated clay and silt between layer 1 and layer 2 in several areas in the northwestern and north-central parts of the model (fig. 20). A small area of clay and silt, defined by data from four wells, was mapped between layers 2 and 3 in the north-central part of the model. None of the lithologic data indicated clay or silt between layers 3 and 4. The thickness of clay and silt deposits was not included in the calculation of thickness of sand and gravel for each layer.

Layer 1 is simulated under unconfined (or water-table conditions) in most of the modeled area; it is simulated as confined in parts of the model along the northern and western boundaries where clay and silt are at land surface. Layers 2, 3, and 4 are simulated under confined conditions. Horizontal hydraulic conductivities were assigned to each layer, based on the geometric-mean values determined from the single-well aquifer tests. Vertical hydraulic conductivities of the layers were set at 0.2 times the value for horizontal conductivity. For areas where confining beds were mapped between layers, vertical leakance between aquifers was calculated using a value of 0.001 ft/d for the vertical hydraulic conductivity of the confining bed based on a range of values reported for silt and clay (Morris and Johnson, 1967, p. D21).

A total of 179 river nodes were used to simulate parts of Crumpacker Ditch, Wright Arm, Forbes Ditch, and Crooked Creek. River nodes represent large streams that can supply water to the aquifer when the water table declines below the bottom of the stream. Drain nodes represent small streams that cease to flow when the water table declines below the bottom of the streambed. Drain nodes receive ground-water discharge but do not recharge the aquifer. A total of 273 drain nodes were used to simulate the upstream parts of the streams where they were shown as intermittent on USGS 7.5-minute topographic maps or where streamflow data indicated the stream went dry. There were two exceptions to this convention—Crumpacker Ditch was simulated by river nodes south of State Road 2 where perennial flow was observed, and Wright Arm, north of State Road 2, was simulated by drain nodes because no flow was observed at that location on several occasions. For the initial model simulations, streambed thickness was assumed to be 1 ft and vertical hydraulic conductivity was assumed to be 1 ft/d. Lakes and ponds were not simulated in the model.

Data for ground-water pumpage, obtained from the Indiana Department of Natural Resources and from the Westville Correctional Facility, showed four locations of substantial pumpage—the correctional facility (three wells), the Town of Westville (one well), and two mobile-home parks (three wells) (fig. 20). Individual wells were simulated in the appropriate model node (based on the location information) and the appropriate model layer (based on the screened interval of the well). The well for the Town of Westville and wells at the northernmost mobile-home park obtain water from model layer 3. The remaining simulated wells obtain water from model layer 2. Monthly pumpage for each of these wells reported for 1997 were totaled and then averaged to obtain a rate of pumpage in cubic feet per second for input to the model. Average rates of pumpage ranged from 0.9 ft^3/s (581,400 gal/d) at one of the wells at the correctional facility to 0.02 ft^3/s (12,920 gal/d) for one of the mobile-home parks. The total rate of pumpage simulated by the model is 1.54 ft^3/s (994,840 gal/d).

Recharge from precipitation was applied to the simulated water table in layer 1. The rate of recharge was dependent on the surficial geology. Initial rates of recharge were estimated on the basis of values used for model simulations of similar geologic materials in Indiana (Bergeron, 1981; Imbrigiotta and Martin, 1981; Arihood, 1982; and Duwelius and Greeman, 1989). Three rates of recharge were applied—a rate of 3 in/yr was applied to areas of the model where the geologic map indicated clay and silt (glacial till) at the land surface (see fig. 2); a rate of 8 in/yr was applied in areas mapped as muck, peat, or marl less than 5 ft thick overlying sand and gravel; and a rate of 12 in/yr was applied to areas of sand and gravel (glacial outwash).

Model Calibration

The model was calibrated to match ground-water-level and streamflow data collected December 16, 1997. Calibration consisted of adjusting the values of model parameters (such as water levels at the boundaries and horizontal hydraulic conductivity) until model-simulated ground-water levels and ground-water discharge to streams agreed as closely as possible to measured values. The data collected during December 1997 were assumed to represent steady-state-flow conditions. A total of 63 ground-water-level measurements and 10 streamflow measurements were used for the calibration. The final calibrated parameter values are listed with the initial values in table 10.

The choice of water levels around the boundary of the model had some effect on the simulated water levels in the center of the model. Boundary water levels were changed by as much as 5 ft from original estimates, which caused simulated water levels in the center of the model to change by as much as 0.2 ft. A maximum change of 5 ft was considered acceptable because it is within the range of error for the method used to estimate the original boundary water levels. Changes were made to initial water levels along the northern and western model boundaries to improve the match between simulated and measured water levels in the western part of the model after all other reasonable model-parameter changes had been made.

Initial values of horizontal hydraulic conductivity were increased by 25 percent during calibration to improve simulated water levels near Crumpacker Ditch. The final values used in the model are within the range of horizontal hydraulic conductivities determined from the hydraulic tests.

Table 10. Initial and calibrated values of hydraulic parameters for the model used to simulate ground-water flow near Westville, Indiana

[ft/d, foot per day; in/yr, inches per year]

Model parameter	Initial values used for model		Calibrated values used for model	
Horizontal hydraulic conductivity of layer 1	21.3	ft/d	26.6	ft/d
Horizontal hydraulic conductivity of layer 2	12.2	ft/d	15.2	ft/d
Horizontal hydraulic conductivity of layer 3	89.9	ft/d	112.4	ft/d
Horizontal hydraulic conductivity of layer 4	64.4	ft/d	105.5	ft/d
Vertical hydraulic conductivity of clay semi-confining units	.001	ft/d	.001	ft/d
Recharge rate to clay and silt (glacial till)	3	in/yr	3	in/yr
Recharge rate to muck, peat, or marl overlying sand and gravel	8	in/yr	4	in/yr
Recharge rate to sand and gravel (glacial outwash)	12	in/yr	8.8	in/yr
Streambed hydraulic conductivity	1	ft/d	.1–50	ft/d

Vertical hydraulic-conductivity values for the streambed were changed from the initial estimate of 1 ft/d; this helped to match observed seepage determined from streamflow measurements and streambed conductivity determined with the seepage meters. Data from the seepage meters were available for the portion of Crumpacker Ditch that appears to be intercepting part of the plume of 1,4-dioxane. Although the data indicate the potential for large variability in vertical hydraulic conductivity, the average measured value was about 0.1 ft/d; therefore, this value was used along that part of the ditch. Other parts of Crumpacker Ditch and the other streams simulated in the model were assigned values of streambed hydraulic conductivity of 1 to 50 ft/d, depending on the need to increase or decrease simulated seepage to match measured streamflow.

Recharge to the model generally was decreased from initial estimates in order to lower simulated water levels. Recharge to areas of surficial sand and gravel (glacial outwash) was reduced to 8.8 in/yr and recharge to muck, peat, or marl overlying sand and gravel was reduced to 4 in/yr. The recharge rate to clay and silt (glacial till) was not changed.

During calibration of the model, differences between simulated and measured ground-water levels are minimized. The determination of the differences is based on the mean absolute error, bias, the percent mean absolute error, percent bias, and the standard deviation of the differences. The first four of these terms are defined below:

$$\text{Mean absolute error} = \frac{\Sigma\left|\text{simulated water levels - measured water levels}\right|}{\text{total number of observations}}$$

$$\text{Bias} = \frac{\Sigma\ (\text{simulated water levels - measured water levels})}{\text{total number of observations}}$$

$$\text{Percent mean absolute error} = \frac{\text{Mean absolute error}}{\text{maximum - minimum measured water level}}$$

$$\text{Percent bias} = \frac{\text{Bias}}{\text{maximum - minimum measured water level}}$$

The determinations of error terms resulting from calibration of the model to ground-water levels measured during December 1997 are listed in table 11. The mean absolute error ranges from 0.09 ft in layer 3 to 0.17 ft in layer 2. The percent mean absolute error is 1 percent and the standard deviation of the differences is 0.22 ft for all model layers. The results indicate the model provides a reasonable simulation of ground-water flow in the study area.

Table 11. Measurements of error in water levels simulated by the ground-water-flow model and water levels measured December 16, 1997, near Westville, Indiana

Model layer	Number of measured water levels	Mean absolute error (feet)	Percent mean absolute error	Bias (feet)	Percent bias	Standard deviation (feet)
1	29	0.16	1	-0.01	0	0.24
2	12	.17	1	-.06	0	.23
3	6	.09	1	.02	0	.11
4	16	.15	1	.03	0	.22
All	63	.15	1	-.01	0	.22

Model Sensitivity

A sensitivity analysis was completed following calibration of the model to determine which model-input parameters most affect the simulated water levels. Parameters that have a large effect on model simulations must be accurate if the results of model simulations are to be considered reliable. The input parameters included in the analysis were the horizontal and vertical hydraulic conductivities of the aquifer, the vertical hydraulic conductivity of the streambed, and recharge.

Model sensitivity was analyzed by varying one input parameter while all other parameters remained constant. Each parameter was varied from 0.2 to 2.4 times its calibrated value in increments of 0.2. Sensitivity was determined by observing changes in the mean absolute error and bias of the resulting simulated water levels (fig. 22).

The sensitivity analysis indicates that simulated water levels are most sensitive to changes in recharge and horizontal hydraulic conductivity (fig. 22). Increases and decreases in the rate of recharge caused similar errors in simulated water levels, while decreases in horizontal hydraulic conductivity caused larger errors than increases in this model parameter. Changes to vertical hydraulic conductivity of the aquifer or the streambed did not result in substantial changes to simulated water levels.

Because recharge and horizontal hydraulic conductivity are critical input parameters for the model, it is important that reliable information is used to determine or estimate these parameters. Recharge was not measured directly, and initial rates of recharge were estimated based on values used for model simulations of similar geologic materials. Although recharge rates for the glacial outwash and for muck, peat, and marl overlying sand and gravel were reduced during calibration, the values of recharge in the calibrated model are within the range of values used in the other model simulations. Initial values of horizontal hydraulic conductivity were estimated from results of the single-well aquifer tests and were increased during calibration. The calibrated values are in general agreement with those obtained from the multiple-well aquifer test.

Simulated Water Levels and Flow Budget

Simulated water levels for layer 1 and ground-water levels measured in the shallow wells on December 16, 1997, are shown on figure 23. The simulated and measured values are in reasonable agreement and have a maximum absolute difference of 0.83 ft in layer 1 near Crumpacker Ditch at well MW-14S. Simulated water levels in layers 2 through 4 are nearly identical to those in layer 1; the maximum absolute difference between simulated and measured water levels is 0.60 ft at well MW-14D for layer 2, 0.17 ft at well MW-15MD for layer 3, and 0.59 at well MW-2XD for layer 4. In general, simulated water levels were slightly higher than measured water levels in the vicinity of the refinery site and were slightly lower than measured water levels near and west of Crumpacker Ditch.

Simulated discharge to selected stream segments and streamflow attributed to ground-water discharge based on measurements during December 9 and 10, 1997, is shown on figure 24. Estimates of the volume of treated wastewater discharged to Crumpacker Ditch from the Town of Westville (0.25 ft^3/s) and the Westville Correctional Facility (1 ft^3/s) were subtracted from the measured streamflow to determine streamflow attributed to ground-water discharge. The total simulated ground-water discharge to streams is 2.57 ft^3/s compared to the measured increase in streamflow of 3.23 ft^3/s, indicating that the model accounts for about 79 percent of the actual streamflow. Additional discharge to the streams occurs through field-drainage tiles, which may account for the larger measured streamflow compared to the simulated discharge. Also, streamflow measurements commonly are subject to error, depending on channel geometry and flow conditions.

The model simulates three sources of water—recharge, inflow across model boundaries, and leakage from streams. There are three options for discharge—outflow across model boundaries, discharge to streams, and pumpage from wells. A water budget was used to determine rates and volumes of flow (table 12).

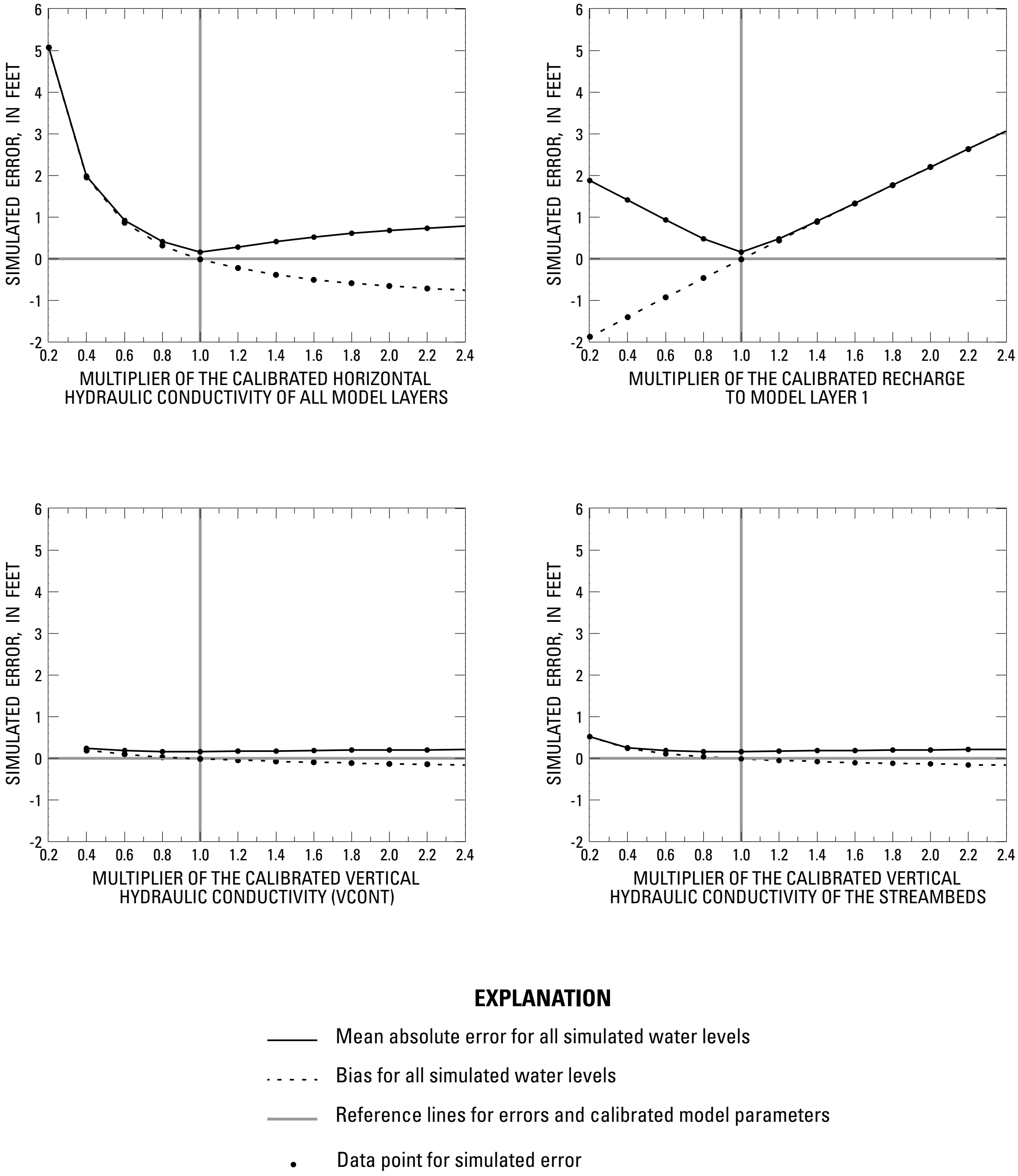
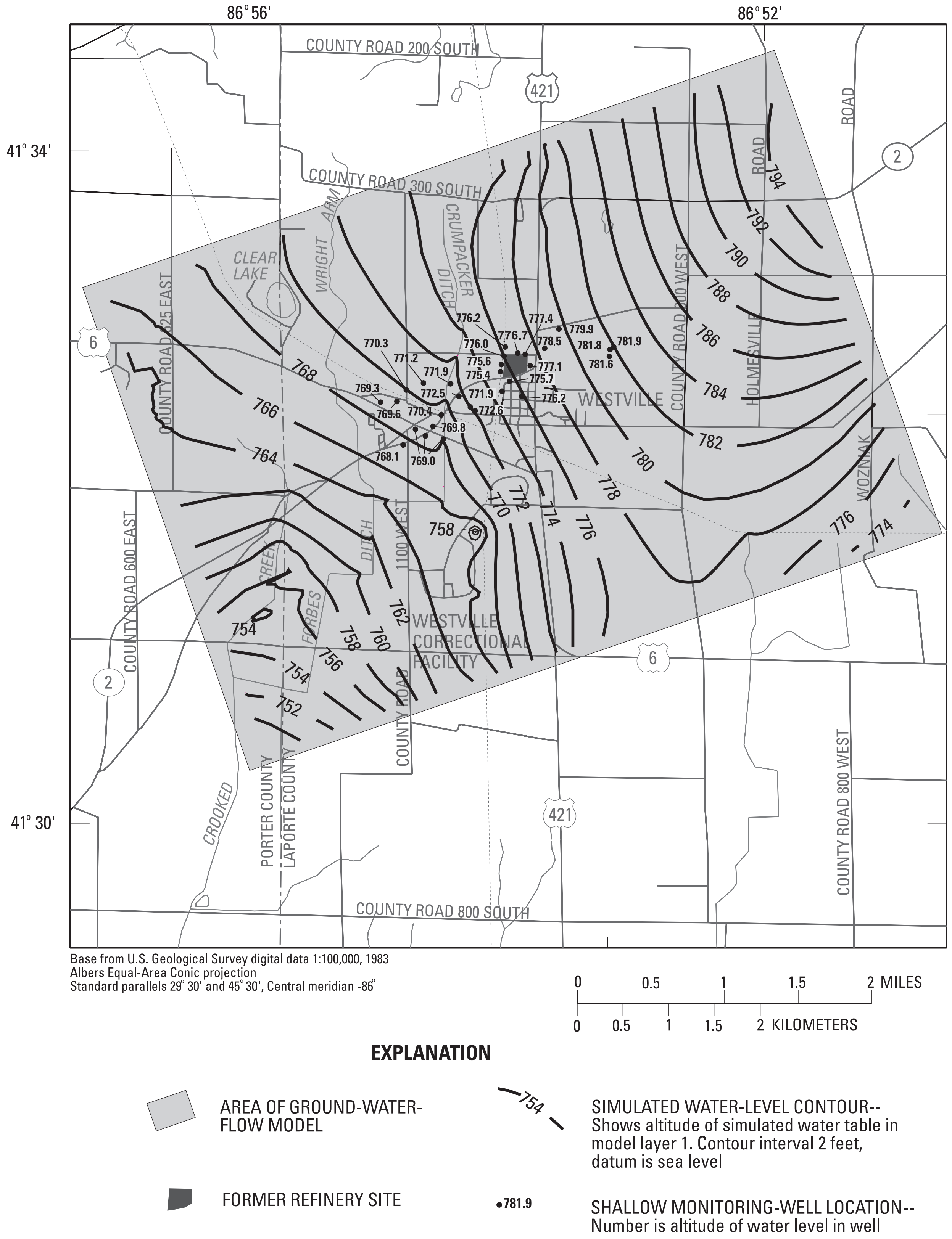


Figure 22. Relation between simulated error in water levels and changes in the value of model parameters.



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

Figure 23. Simulated water levels in model layer 1 and ground-water levels measured December 16, 1997, near Westville, Indiana.

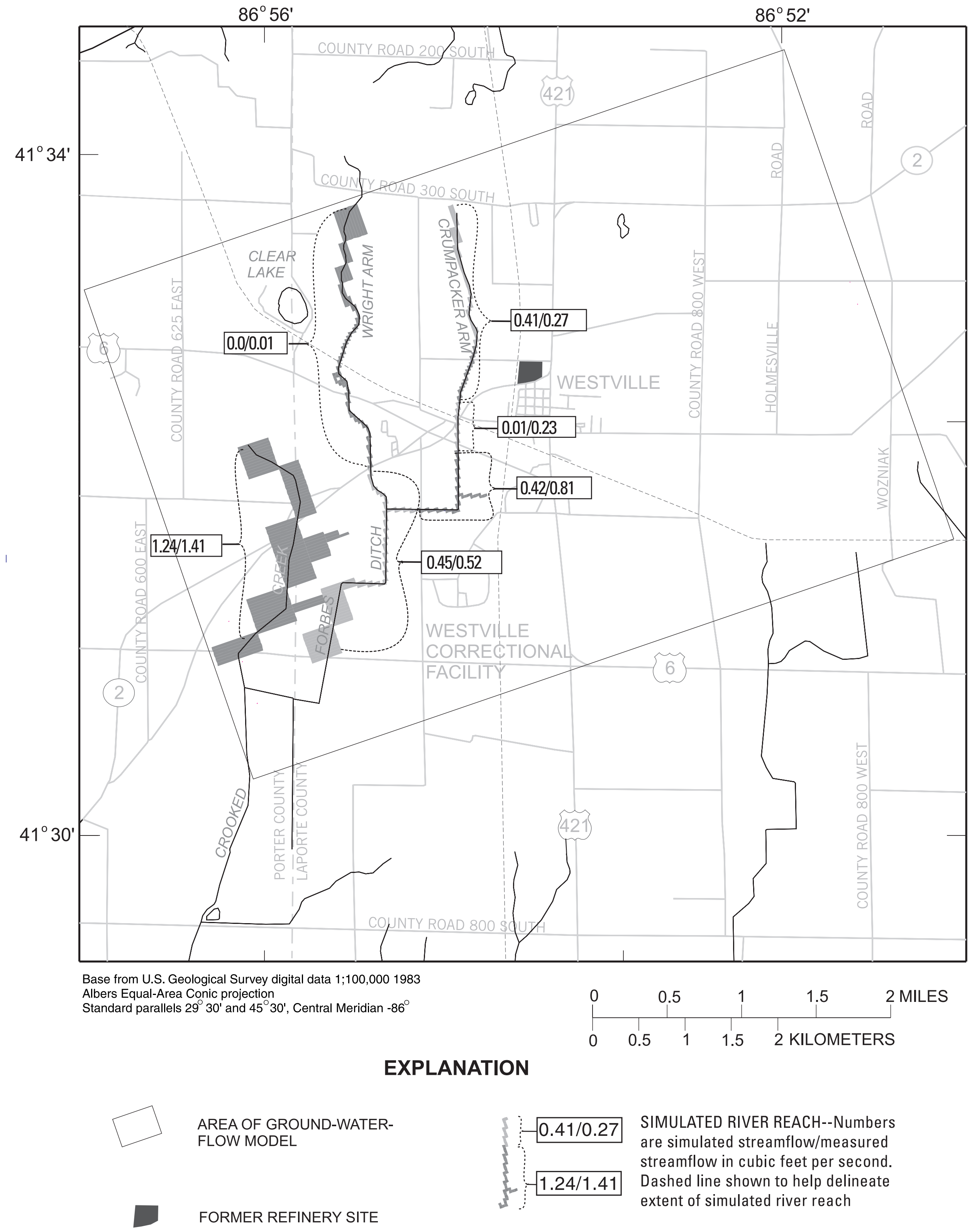


Figure 24. Simulated streamflow and streamflow measured December 1997 near Westville, Indiana.

Total simulated ground-water flow in the steady-state model is 8.61 ft^3/s (5.56 Mgal/d). About 75 percent of the total inflow is from recharge; about 25 percent is inflow across the model boundaries; less than 1 percent is leakage from streams. Outflow from the model is about 45 percent across model boundaries, about 37 percent leakage to streams, and about 18 percent pumpage from wells. Because the constant-head boundary can add or subtract water, the model budget may not represent the actual ratio between recharge and boundary flux. Because the model is calibrated to measured streamflow, the simulated volume of flow probably is reasonable.

The total inflow across model boundaries (boundary flux) is 2.13 ft^3/s (table 12), of which 73 percent is across the eastern boundary, 16 percent across the northern boundary, 8 percent across the southern boundary, and 3 percent across the western boundary. Outflow across model boundaries is 3.88 ft^3/s, of which 37 percent is across the southern boundary, 25 percent across the northern boundary, 23 percent across the western boundary, and 15 percent across the eastern boundary.

The model budget indicates that the largest volumes of horizontal ground-water flow are in layers 1 and 3. Horizontal flow was determined by summing the components of outflow for each layer, with the exception of leakage across layer boundaries. Horizontal flow is 3.51 ft^3/s in layer 1, 1.62 ft^3/s in layer 2, 2.55 ft^3/s in layer 3, and 0.92 ft^3/s in layer 4. The large volume of flow in layer 1 is related to recharge that is applied to this layer in the model. The large volume of flow in layer 3 results from this layer having larger horizontal hydraulic conductivity than the other model layers.

Recharge applied to layer 1 also provides water to the rest of the model through vertical leakage between layers (table 12). Downward flow of ground water, mostly from recharge, is 5.74 ft^3/s from layer 1 to layer 2, 5.06 ft^3/s from layer 2 to 3, and 1.45 ft^3/s from layer 3 to 4. Ground water flows downward primarily in areas away from the streams. Upward flow of ground water is 1.04 ft^3/s from layer 4 to layer 3, 3.38 ft^3/s from layer 3 to 2, and 2.61 ft^3/s from layer 2 to 1. Upward flow of ground water occurs near streams.

Results of Model Simulations

The calibrated model was used to simulate (1) the plume of 1,4-dioxane, (2) two possible mechanisms of contaminant release at the refinery site, (3) the effect of additional pumping from existing water-supply wells and pumping at the proposed well field for the Town of Westville, and (4) the capability of pumping at the leading edge of the plume to capture the contaminants.

Contaminant Plume

The plume of 1,4-dioxane was simulated by use of the MODPATH particle-tracking program (Pollock, 1989 and 1994) and the MODTOOLS program for translating data from MODPATH into geographic information system files (Orzol, 1997). The location and movement of the plume were visualized by placing particles in the four layers on the downgradient side of model cells along the western edge of the refinery site. When the model is run, the MODPATH program traces the movement of particles along the simulated flow path to provide a “picture” of the simulated contaminant plume (fig. 25). This technique assumes a conservative contaminant (such as 1,4-dioxane) that moves at the rate of ground-water flow and is not affected by dilution, sorption, biodegradation, or other mechanisms that may control movement of contaminants in ground water.

The location of the simulated plume approximates that mapped from results of ground-water sampling (compare figs. 17 and 25). In addition, the model simulates discharge of some particles to Crumpacker Ditch and flow of other particles beneath the ditch. Because the model simulates steady-state-flow conditions, the plume extends farther downgradient than has been documented by the water-quality sampling. As the plume continues southwest, particles are discharged to streams at locations where the streams intersect the plume. At steady state, the plume extends to Crooked Creek.

Table 12. Water budget for the ground-water-flow model determined by steady-state simulation

[ft^3/s, cubic foot per second; <, less than]

Inflow	Rate (ft^3/s)	Percentage of total	Outflow	Rate (ft^3/s)	Percentage of total
		Layer 1			
Recharge	6.45	70	Boundary flux	0.32	3
Boundary flux	.16	2	Leakage to layer 2	5.74	62
Leakage from layer 2	2.61	28	Leakage to streams	3.19	34
Leakage from streams	.03	< 1			
Total inflow, layer 1	9.25	100	Total outflow, layer 1	9.25	100
		Layer 2			
Boundary flux	.18	2	Boundary flux	.32	3
Leakage from layer 1	5.74	62	Pumpage from wells	1.30	14
Leakage from layer 3	3.38	36	Leakage to layer 1	2.61	28
			Leakage to layer 3	5.06	54
Total inflow, layer 2	9.29	100	Total outflow, layer 2	9.29	100
		Layer 3			
Boundary flux	1.28	17	Boundary flux	2.31	31
Leakage from layer 2	5.06	69	Pumpage from wells	.24	3
Leakage from layer 4	1.04	14	Leakage to layer 2	3.38	46
			Leakage to layer 4	1.45	20
Total inflow, layer 3	7.38	100	Total outflow, layer 3	7.38	100
		Layer 4			
Boundary flux	.51	26	Boundary flux	.92	47
Leakage from layer 3	1.45	74	Leakage to layer 3	1.04	53
Total inflow, layer 4	1.96	100	Total outflow, layer 4	1.96	100
		All layers			
Recharge	6.45	75	Boundary flux	3.88	45
Boundary flux	2.13	25	Leakage to streams	3.19	37
Leakage from streams	.03	< 1	Pumpage from wells	1.54	18
Total inflow, all layers	8.61	100	Total outflow, all layers	8.61	100

Possible Mechanisms of Contaminant Release

Two possible mechanisms of contaminant release—leakage from lagoons and injection by pumping into a disposal well—were simulated to determine if these mechanisms could account for movement of 1,4-dioxane into the deep part of the aquifer. The two mechanisms selected for simulation may not be the only possible mechanisms to explain the distribution of contaminants. The particle-tracking program, MODPATH (Pollock, 1989 and 1994), was used to visualize ground-water flow for these simulations. The simulations were run at steady state.

An aerial photographic analysis of the refinery site by the Environmental Sciences Division of USEPA (Kartman, 1999) showed that the number of lagoons increased from 3 in 1939 to 12 in 1958. From 1958 until about 1980, smaller lagoons were joined to make larger lagoons. The lagoons were in various stages of use, with some having standing liquids and others showing staining. The number of lagoons was reduced to three in 1987, and no lagoons were visible on photographs of the site taken in 1992 (Kartman, 1999).

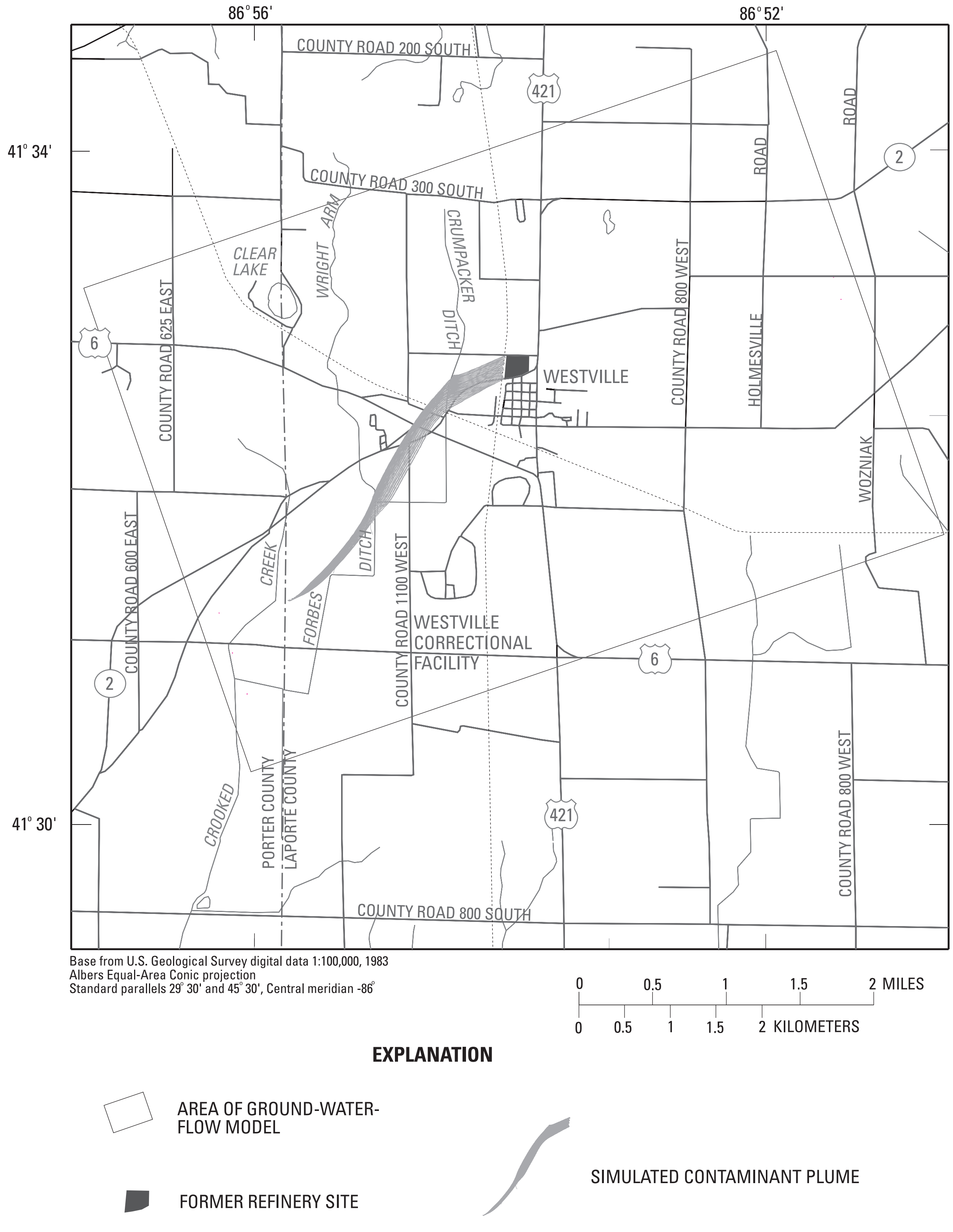
Leakage from two lagoons along the northern boundary and from one lagoon in the southwest corner of the site was simulated by assigning values of constant head and vertical hydraulic conductivity to the appropriate model cells in layer 1. The constant heads were set equal to the land-surface altitude, and vertical hydraulic conductivity was varied over a range from 0.1 to 10 ft/d. Based upon these simulations, a vertical hydraulic conductivity of 0.2 ft/d for the lagoon beds was required to move contaminants into layer 4 of the model and 0.4 ft/d was required to push contaminants to the bottom of the aquifer. All of the simulations showed mounding and radial flow of ground water beneath the lagoons. Simulations using 0.4 ft/d or more for vertical hydraulic conductivity of the lagoon beds resulted in the contaminant plume spreading to the vicinity of the water-supply well for the Town of Westville. Analyses of samples from the water-supply well indicate this has not occurred. At these rates of leakage, the simulations also show water from the lagoons would reach Crumpacker Ditch within 10 years.

Flow budgets for the simulations indicate that the rate of leakage is about 195 gal/min when the vertical hydraulic conductivity of the lagoon beds is 0.4 ft/d and about 98 gal/min when the vertical hydraulic conductivity is 0.2 ft/d. Although the actual rate of leakage is not known, the simulated rates appear to be too large because they imply a constant rate of leakage and, therefore, a continuous source of liquid during the operation of the refinery. At 98 gal/min, the annual leakage rate is about 51.5 Mgal.

The second simulated mechanism for movement of 1,4-dioxane was injection by pumping into a disposal well. During the site investigation, a consultant for the group of industries that brought materials to the refinery found and restored a 6-in.-diameter well on the refinery site (well OSW). The well is about 135 ft deep. For the model simulations, an injection well was included that added water to layer 3 of the model.

The simulations indicated an injection rate of 50 gal/min was required to spread contaminants to the bottom of the aquifer. At that rate, most of the injected water moves horizontally through layer 3, then vertically upward to discharge in Crumpacker Ditch. Some of the injected water also moves upward into layer 2 near the source of the injection. The simulations also show that water injected into layer 3 can spread into layers 2 and 4 and reach Crumpacker Ditch within 10 years.

The simulations of the two possible mechanisms for release of contaminants indicate that either, or both, mechanisms could spread contaminants throughout the thickness of the aquifer. The disposal well requires about half of the water needed to spread the plume throughout the aquifer as that needed for the lagoons to do so. The location of the plume determined by the particle tracking varies slightly, depending on the source of the water.



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

Figure 25. Contaminant plume simulated at steady state by particle tracking from the western edge of the former refinery site near Westville, Indiana.

Pumping from Supply Wells

The model was used to simulate pumping from existing supply wells for the Town of Westville and the Westville Correctional Facility. Pumping rates were increased above the average rates for these wells to investigate whether additional pumpage could draw water from the plume of 1,4-dioxane. Pumping also was simulated for the new well field for the Town of Westville to estimate the pumpage required to begin drawing water from the refinery site. The simulations of pumping were completed separately for each well. The combined effect of increased pumpage from all wells was not simulated.

Table 13 lists the average ground-water pumpage based on reported withdrawals for 1997 and the simulated pumpage required to possibly draw water from the contaminant plume. The model simulations indicate that a pumping rate of about 300 gal/min (more than 500 percent of the average pumpage) is required to possibly draw water from the plume toward the existing water-supply well for the Town of Westville. Simulated pumpage at the correctional facility was 1,000 gal/min (174 percent of the average pumpage). For the new well field for the Town of Westville, a model-simulated pumping rate of 1,000 gal/min caused drawdown extending to the refinery site and possible contribution of ground water from the eastern edge of the site. The final pumping rates cause simulated flow paths to pass sufficiently near the plume or refinery site so that contaminants may be induced into the supply well. In addition, the rates selected were round numbers, such as 1,000 gal/min. It is possible that a simulated pumping rate of 980 gal/min, for example, also could induce contaminants into the well.

Pumping from Capture Wells

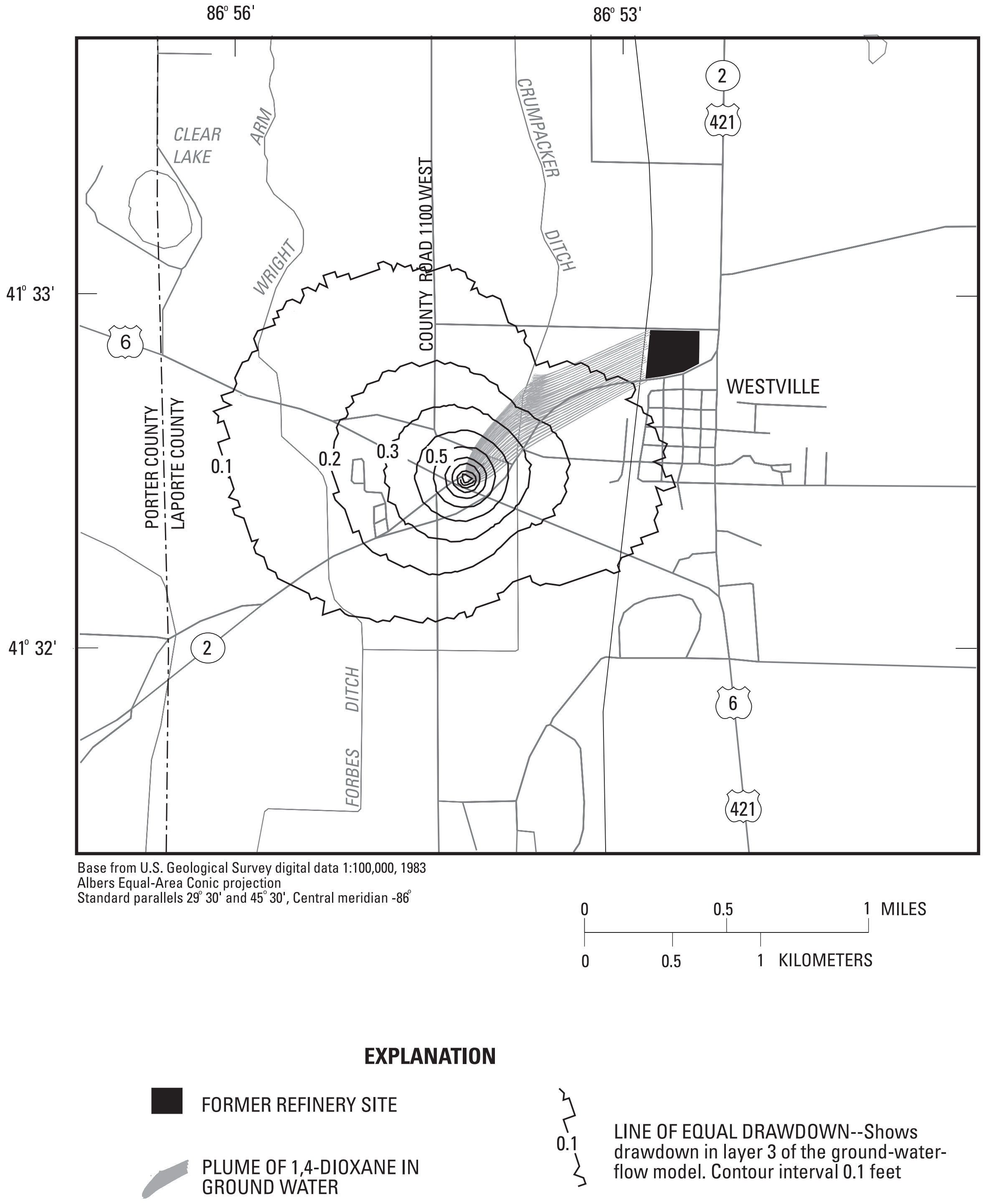
Pumping from wells at the leading edge of the contaminant plume was simulated to determine the rate of pumping required to capture water from the plume horizontally and vertically. For these simulations, the locations of pumped wells and rates of pumping were varied to achieve complete capture with the least pumpage. The plume of 1,4-dioxane was simulated by particle tracking from the western edge of the former refinery site.

Table 13. Average ground-water pumpage in 1997 and model-simulated pumpage possibly required to draw water from the contaminant plume near Westville, Indiana

[gal/min, gallon per minute; -- no data]

Pumpage center	Average pumpage in 1997 (gal/min)	Approximate pumpage required to intercept contaminant plume[a] (gal/min)	Percent of average pumpage
Town of Westville, existing well	58	300	517
Correctional facility	575	1,000	174
Town of Westville, new well field	--	1,000	--

[a] Simulation of increased pumpage was done separately for each well. The combined effect of increased pumpage was not simulated.



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

Figure 26. Simulated drawdown for three wells, each pumping at a rate of 25 gallons per minute, at the leading edge of the plume of 1,4-dioxane.

To completely capture the plume simulated by the particle tracking, three wells were placed in adjacent model cells at the leading edge of the plume west of Crumpacker Ditch and near the intersection of U.S. Highway 6 and State Road 2 (fig. 26). Water was pumped from layer 3 at a combined rate of 75 gal/min—25 gal/min for each well. Reducing the pumping rate below 75 gal/min resulted in some of the particle plume bypassing the capture wells.

Model Limitations

The capacity of ground-water-flow models to simulate actual field conditions is limited by the amount of input data available to define aquifer characteristics, water levels, flow rates, and the geometry of the flow system. The ground-water-flow model constructed for this study was based on data from 65 monitoring wells installed in the vicinity of the former refinery site and from logs for more than 50 privately owned wells throughout the study area. This information provides adequate data for construction of the model, and the calibration statistics indicate close agreement between simulated and measured water levels (mean absolute error is 0.15 ft). In addition, comparison of measured and simulated ground-water discharge to streams provides assurance that flow quantities are reasonable. Therefore, it is likely that the simulation of flow quantity and direction in the area of the monitoring wells is a reasonable representation of field conditions. The greatest uncertainty is in predictions of flow directions in areas of the model away from the monitoring wells. Water-level data outside the area of monitoring wells are only estimates derived from water levels recorded by drillers of the privately owned wells. The trends in flow directions predicted by the model, however, appear reasonable because ground water tends to flow toward the major local streams.

Summary and Conclusions

A study of the geohydrology and water quality at a Superfund site—a former waste-oil refinery near Westville, Ind.—was completed as part of environmental investigations by the U.S. Environmental Protection Agency at the site. The refinery was in operation from the mid-1930's until about 1987. By 1996, several geotechnical and environmental studies had documented contaminants in soil at the site, and 1,4-dioxane was found in off-site ground water.

The site of the former refinery is underlain by approximately 150 ft of glacial deposits on top of shale and lacustrine clay. The glacial deposits include clayey till, silt and sand of the Valparaiso Moraine in the northern part of the study area, and silty sand and gravel of the Kankakee Outwash in the central and southern parts of the study area. An increase in sand grain size and a decrease in silt content with depth were observed during installation of monitoring wells. This observation was substantiated by natural-gamma and electromagnetic-conductivity logging completed in the monitoring wells and by single-well and multiple-well hydraulic testing. The well testing generally indicated an increase in hydraulic conductivity with depth. The average horizontal hydraulic conductivity determined from the multiple-well aquifer test was 121 ft/d, and the aquifer transmissivity was about 18,600 ft^2/d. Values of vertical hydraulic conductivity ranged from 24 to 36 ft/d, and specific yield ranged from 0.05 to 0.08.

Ground water generally flows from northeast to southwest in the study area. The depth to water ranges from about 36 feet below land surface northwest of the refinery site to about 3 feet below land surface southwest of the site. Horizontal gradients average about 0.001 ft/ft; estimated horizontal ground-water-flow velocities average about 0.1 ft/d in the upper and middle parts of the glacial aquifer and about 0.4 ft/d near the bottom of the aquifer. Ground-water levels near Crumpacker Ditch, about one-half mile west of the site, are higher than water levels in the ditch, indicating discharge of ground water to the ditch. Streamflow measurements showed an increase in flow along the ditch and along other streams in the study area. Seepage meters installed in the ditch measured a range of ground-water discharge from about 0.01 to 0.12 ft^3/d, and the data were used to estimate a range of vertical hydraulic conductivity for the streambed of about 0.1 to 2 ft/d.

Based upon the analysis of ground-water levels, several conclusions can be made about flow in the glacial aquifer:

- Ground-water flows predominantly from northeast to southwest in the study area.
- Flow in the aquifer is predominantly horizontal.
- Flow in the shallow part of the aquifer discharges to Crumpacker Ditch. Flow in the middle part of the aquifer may discharge to Crumpacker Ditch or may be a part of a regional flow system.
- Flow in the deep part of the aquifer is part of a regional flow system that probably does not discharge to Crumpacker Ditch. Ground water in the regional system flows beneath Crumpacker Ditch and may discharge to Forbes Ditch or to Crooked Creek.
- Ground-water-flow velocities are three or more times faster in the deep part of the aquifer, compared to the shallow and middle parts of the aquifer.

A description of the water quality in the study area was determined from analytical results of selected ground-water and surface-water samples collected for the USEPA investigation. These results show the ground water generally is a calcium-bicarbonate type with a nearly neutral pH. Specific conductivity ranged from 437 to 1,030 µS/cm in water from wells upgradient from the refinery site and 330 to 3,780 µS/cm in water from downgradient wells. Barium, iron, manganese, nickel, and zinc commonly were detected in ground-water samples.

Although semi-volatile organic compounds (including pesticides and polychlorinated biphenyls) generally were not detected consistently or in large concentrations in ground-water samples, shallow wells near the boundaries of the refinery site provided samples in which volatile organic compounds consistently were detected. The compounds detected generally are classified as chlorinated solvents such as chloroethane, 1,1-dichloroethane, 1,2-dichloroethene, and trichloroethane or aromatic hydrocarbons such as benzene, ethylbenzene, toluene, and xylenes. Chlorinated solvents were detected with greater frequency and in larger concentrations (as much as 1,500 µg/L of 1, 2-dichloroethene) than the aromatic hydrocarbons (as much as 140 µg/L of benzene).

Detected concentrations of 1,4-dioxane ranged from 3 µg/L to more than 4,000 µg/L in wells screened at different depths in the glacial aquifer. The detections of 1,4-dioxane define a plume of ground-water contamination that extends from the refinery site to approximately 0.8 mi southwest along the direction of ground-water flow. Downgradient from the site, the largest concentrations generally were found in the lower half of the aquifer. Ground water containing 1,4-dioxane is discharged to Crumpacker Ditch, as evidenced by detections of 1,4-dioxane in samples of surface water. Concentrations of 1,4-dioxane detected in surface water ranged from 8 to 140 µg/L; 1,4-dioxane also is transported in ground water beneath the ditch.

A three-dimensional ground-water-flow model was constructed based upon the aquifer geometry and hydrologic properties determined from the collected data. The model simulates flow in four layers defined by the depths of the monitoring wells. The model was calibrated to match ground-water levels and surface-water flow measured in December 1997.

The plume of 1,4-dioxane was simulated by tracking particles placed in all model layers along the western boundary of the site. Possible mechanisms for release of contaminants were investigated by simulating leaking lagoons and a disposal well. Based on the simulation of three lagoons, a vertical hydraulic conductivity of 0.2 ft/d was required to move contaminants into the bottom layer of the model at a constant leakage rate of about 98 gal/min. The simulations of a disposal well indicated an injection rate of 50 gal/min was necessary to spread contaminants vertically in the aquifer.

The ground-water-flow model also was used to estimate rates of pumping required for drinking-water-supply wells at the Town of Westville and the Westville Correctional Facility to draw the contaminant plume toward the wells. Pumping at the new well field for the Town of Westville also was simulated. The simulations indicated that a rate of about 300 gal/min (more than 500 percent of the average pumpage) was required for the supply well at the Town of Westville to possibly begin drawing water from the plume. The rate of pumping at the correctional facility would have to be approximately 1,000 gal/min (174 percent of the average pumpage). A pumping rate of 1,000 gal/min also was required to draw water from beneath the refinery site toward the new well field.

Pumping from wells at the leading edge of the contaminant plume was simulated with the ground-water-flow model to determine a rate of pumping that would capture water from the plume horizontally and vertically. For these simulations, the plume was generated by placing particles in all model layers along the western edge of the refinery site. The simulations indicated that three wells, each pumping 25 gal/min from model layer 3, would completely capture the contaminant plume.

References

Arihood, L.D., 1982, Ground-water resources of the White River Basin, Hamilton and Tipton Counties, Indiana: U.S. Geological Survey Water-Resources Investigations Report 82-48, 69 p.

ATEC Associates, Inc., 1985, Ground water study Cam-Or facility Westville, Indiana: ATEC Associates, Inc., Indianapolis, Ind., variously paginated.

Bergeron, M.P., 1981, Effect of irrigation pumping on the ground-water system in Newton and Jasper Counties, Indiana: U.S. Geological Survey Water-Resources Investigations Report 81-38, 73 p.

Bleuer, N.K., and Woodfield, M.C., 1993, Glacial terrain, sequences, and aquifer sensitivity, Porter County, Indiana: Indiana Geological Survey Open File Report 93-2, variously paginated.

Bouwer, Herman, and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: Water Resources Research, v. 12, no. 3, p. 423–428.

Bouwer, Herman, 1989, The Bouwer and Rice slug test—An update: Groundwater, v. 27, no. 3, p. 303–309.

Dames and Moore, Inc., 1996, On-site source characterization and off-site groundwater investigation—Westville, Indiana: Dames and Moore, Inc., Indianapolis, Ind., variously paginated.

Duwelius, R.F., and Greeman, T.K., 1989, Geohydrology, simulation of ground-water flow, and ground-water quality at two landfills, Marion County, Indiana: U.S. Geological Survey Water-Resources Investigations Report 89-4100, 135 p.

EMES, Inc., 1992, Monitoring well installation phase I—Imperial Oil Company Next Door Food Store, April 8, 1992: Lansing, Mich., Environmental Management and Engineering Services, variously paginated.

Fenelon, J.M., Bobay, K.E., and others, 1994, Hydrologic atlas of aquifers in Indiana: U.S. Geological Survey Water-Resources Investigations Report 92-4142, 197 p.

Fetter, C.W., 1995, Applied hydrogeology (3d ed.): New York, McMillian Publishing Co., 691 p.

Fraser, G.S., and Bleuer, N.K., 1991a, Geologic framework of the aquifers of the Valparaiso Moraine: Indiana Department of Natural Resources Geological Survey Occasional Paper 59, 8 p.

———1991b, Geologic framework of the aquifers in the Kankakee River Lowland: Indiana Department of Natural Resources Geological Survey Occasional Paper 60, 10 p.

Gray, H.H., 1982, Map of Indiana showing topography of the bedrock surface: Indiana Department of Natural Resources Geological Survey Miscellaneous Map 35, 1:500,000.

———1989, Quarternary geologic map of Indiana: Indiana Department of Natural Resources Geological Survey Miscellaneous Map 49, 1:500,000.

Harbaugh, A.W., and McDonald, M.G., 1996, Programmer's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 96-486, 56 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Imbrigiotta, T.E., and Martin, Angel, Jr., 1981, Hydrologic and chemical evaluation of the ground-water resources of northwest Elkhart County, Indiana: U.S. Geological Survey Water-Resources Investigations 81-53, 140 p.

Indiana Department of Natural Resources, 1990, Water resource availability in the Kankakee River Basin, Indiana: Indiana Department of Natural Resources Division of Water, Water Resources Assessment 90-3, 247 p.

Kartman, A.S., 1999, Aerial photographic analysis Cam-Or site Westville, Indiana: U.S. Environmental Protection Agency, Environmental Services Division, TS-PIC-9905554S, 59 p.

Keys, W.S., and MacCary, L.M., 1971, Application of borehole geophysics to water-resources investigations: U.S. Geological Survey Techniques of Water-Resources Investigations of the United States Geological Survey, book 2, chap. E1, 124 p.

Kilpatrick, F.A., and Schneider, V.R., 1983, Use of flumes in measuring discharge: Techniques of Water-Resources Investigations of the United States Geological Survey, book 3, chap. A14, 46 p.

References—Continued

Lapham, W.W., Wilde, F.D., and Koterba, M.T., 1997, Guidelines and standard procedures for studies of ground-water quality—Selection and installation of wells and supporting documentation: U.S. Geological Survey Water-Resources Investigations Report 96-4233, 110 p.

Mack, T.J., 1993, Detection of contaminant plumes by borehole geophysical logging: Ground Water Monitoring and Remediation, vol. 13, no. 1, p. 107–114.

Malott, C.A., 1922, The physiography of Indiana, *in* Logan, N.W., and others, Handbook of Indiana geology: Indiana Department of Conservation, Division of Geology, Publication 21, p. 112–124.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1, 586 p.

Midwestern Climate Center, 2001, Historical climate summaries, Indiana, LaPorte and Valparaiso: Accessed June 26, 2001, at URL http:/mcc.sws.uiuc.edu/index.html.

Moench, A.F., 1993, Computation of type curves for flow to partially penetrating wells in water-table aquifers: Ground Water, vol. 31, no. 6, p. 966–971.

———1995, Combining the Neuman and Boulton models for flow to a well in an unconfined aquifer: Ground Water, vol. 33, no. 3, p. 378–384.

Montgomery, J.H., 1991, Groundwater chemicals field guide: Wall, N.J., Lewis Publishers, 320 p.

Montgomery, J.H., and Welkom, 1990, Groundwater chemicals desk reference, Volume 1: Wall, N.J., Lewis Publishers, 1,348 p.

Morris, D.A., and Johnson, A.I., 1967, Summary of hydrologic and physical properties of rock and soil materials, as analyzed by the hydrologic laboratory of the U.S. Geological Survey 1948–60: U.S. Geological Survey Water-Supply Paper 1839-D, 39 p.

Neuman, S.P., 1972, Theory of flow in unconfined aquifers considering delayed response of the water table: Water Resources Research, vol. 8, no. 4, p. 1,031–1,045.

———1974, Effects of partial penetration on flow in unconfined aquifers considering delayed aquifer response: Water Resources Research, vol. 10, no. 2, p. 303–312.

Orzol, L.L., 1997, User's guide for MODTOOLS—Computer programs for translating data of MODFLOW and MODPATH into geographic information system files: U.S. Geological Survey Open-File Report 97-240, 86 p.

Peerless-Midwest, Inc., 1996, Test well 95A test drilling results, pumping test analysis, permanent well recommendations, water plant site—City of Westville, Indiana, February 8, 1996.

Pollock, D.W., 1989, Documentation of computer programs to compute and display pathlines using results from the U.S. Geological Survey modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 89-381, 188 p.

———1994, User's guide for MODPATH/MODPATH-PLOT, Version 3—A particle tracking post-processing package for MODFLOW, the U.S. Geological Survey finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 94-464, variously paginated.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow—Volume 1, Measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, 284 p.

Roenrich, T., not dated, AquiferTest©: Waterloo, Ontario, Canada, Waterloo Hydrologic, Inc., version 2.53.

Rovy II, C.W., and Cherkauer, D.S., 1995, Scale dependency of hydraulic conductivity measurements: Ground Water, vol. 33, no. 5, p. 769–780.

Shaver, R.H., Ault, C.H., Burger, A.M., Carr, D.D., Droste, D.L., Eggert, D.L., Gray, H.H., Harper, D., Hasenmueller, N.R., Hasenmueller, W.A., Horowitz, A.S., Hutchison, H.C., Keith, B.D., Keller, S.J., Patton, J.B., Rexroad, C.B., and Wier, C.E., 1986, Compendium of Paleozoic rock-unit stratigraphy in Indiana—A revision: Indiana Department of Natural Resources Geological Survey Bulletin 59, 203 p.

Sepulveda, Nicasio, 1992, Computer algorithm for the analysis of underdamped and overdamped water-level responses in slug tests: U.S. Geological Survey Water-Resources Investigations Report 91-4162, 20 p.

U.S. Department of Agriculture, 1982, Soil survey of LaPorte County, Indiana: U.S. Department of Agriculture Soil Conservation Service, 162 p.

References—Continued

U.S. Environmental Protection Agency, 1989, Preparing perfect project plans—A pocket guide for the preparation of quality assurance project plans: U.S. Environmental Protection Agency, EPA/600/9-89/087, 62 p.

———1992, Standard operating safety guides: U.S. Environmental Protection Agency Publication 9285.1-03 PB92-963414, 182 p.

———1993a, Use of airborne, surface, and borehole geophysical techniques at contaminated sites: U.S. Environmental Protection Agency EPA/625/R-92/007, variously paginated.

———1993b, Subsurface characterization and monitoring techniques—A desk reference guide, vol. I, Solids and ground water, Appendices A and B: U.S. Environmental Protection Agency, EPA/625/R-93/003a, variously paginated.

———1993c, Subsurface characterization and monitoring techniques—A desk reference guide, Vol. II, The vadose zone and field screening, Appendices C and D: U.S. Environmental Protection Agency, EPA/625/R-93/003b, variously paginated.

———1999, Field Investigation Report for Cam-Or, Westville, Indiana, U.S. Environmental Protection Agency, Region 5, Chicago, variously paginated.

———2001, Current Drinking Water Standards: Accessed June 13, 2001 at URL http:/www.epa.gov/safewater/mcl.html.

U.S. Geological Survey, 1969, Topographic map of Westville, Ind.: U.S. Geological Survey 7.5-Minute Series Topographic Maps, scale 1:24,000.

van der Kamp, Garth, 1976, Determining aquifer transmissivity by means of well response tests—The underdamped case: Water Resources Research, vol. 12, no. 1, p. 71–77.

Wilde, F.D., Radtke, D.B., Gibs, Jacob, and Iwatsubo, R.T, eds., 1998, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations Book 9, Handbooks for water-resources investigations, variously paginated.

Appendix A.
Supplemental Data Tables

Table A1. Selected characteristics of monitoring wells and well points used to monitor ground-water flow and quality near Westville, Indiana

[USGS, U.S. Geological Survey; ID, identification; --, no data; ?, unknown]

Well name	Date installed	Latitude/ longitude	USGS site ID number	Land-surface altitude (feet above sea level)	Measuring-point altitude (feet above sea level)	Inside diameter of well casing and screen (inches)	Screened interval (feet below land surface)
B-1	03/08/85	413245/865353	413245086535301	806.3	808.51	2	26 - 42
B-2	03/11/85	413248/865359	413248086535901	795.0	796.18	2	13 - 23
B-4	03/12/85	413251/865406	413251086540501	796.7	797.50[a]	2	17 - 27
EP-1	1987	413254/865405	413254086540501	798.2	800.13	2	18 - 28
EP-2	1987	413251/865359	413251086535901	796.7	798.12	2	24 - 32[b]
EP-3	1987	413251/865354	413251086535401	802.0	802.35	2	31 - 39[b]
EP-4	1987	413237/865356	413237086535601	805.7	807.30	2	27 - 37[b]
LP-1	1986	413301/865337	413301086533701	815.7	816.99	2	33 - 43
LP-2	1986	413238/865450	413238086545001	785.6	786.98	2	14 - 24
LP-3	1986	413233/865421	413233086542101	783.2	784.12	2	9 - 19
MW-1S	1993	413242/865402	413242086540201	790.2	792.31	2	15 - 25
MW-1D	1993	413242/865402	413242086540202	790.2	792.53	2	75 - 80
MW-2S	1993	413245/865407	413245086540701	788.5	790.91	2	15 - 25
MW-2D	1993	413245/865407	413245086540702	788.8	790.94	2	75 - 80
MW-2MD	04/21/97	413245/865406	413245086540601	791.4	794.26	2	125 - 130
MW-2XD	04/19/97	413245/865406	413245086540602	790.9	792.79	2	177 - 182
MW-3S	1993	413248/865406	413248086540601	795.2	797.54	2	15 - 25
MW-3D	1993	413248/865406	413248086540602	795.4	797.76	2	75 - 80

Table A1. Selected characteristics of monitoring wells and well points used to monitor ground-water flow and quality near Westville, Indiana—Continued

Well name	Date installed	Latitude/ longitude	USGS site ID number	Land-surface altitude (feet above sea level)	Measuring-point altitude (feet above sea level)	Inside diameter of well casing and screen (inches)	Screened interval (feet below land surface)
MW-4S	01/--/96	413235/865428	413235086542801	775.7	778.21	2	5 - 15
MW-4D	01/--/96	413235/865428	413235086542802	775.8	778.30	2	75- 80
MW-4XD	12/21/95	413235/865428	413235086542803	775.7	778.24	2	145 - 150
MW-5S	12/--/95	413238/865406	413238086540601	786.4	789.16	2	10 - 20
MW-5D	12/--/95	413238/865406	413238086540602	786.4	789.16	2	75 - 80
MW-5XD	12/15/95	413238/865406	413238086540603	786.0	788.42[a]	2	145 - 150
MW-6S	01/--/96	413242/865407	413242086540701	789.9	792.11	2	--
MW-6D	01/09/96	413242/865407	413242086540702	789.8	792.19	2	75 - 80
MW-7S	03/14/97	413253/865346	413253086534601	809.2	812.20	2	26 - 36
MW-7D	03/22/97	413253/865346	413253086534602	809.3	811.70	2	75 - 80
MW-7XD	03/26/97	413253/865346	413253086534603	809.2	810.91	2	205.5 - 210.5
MW-8S	04/21/97	413230/865434	413230086543401	775.4	778.50	2	3 - 13
MW-8D	03/12/97	413230/865434	413230086543402	775.5	778.67	2	59.5 - 64.5
MW-9S	04/21/97	413221/865434	413221086543401	774.2	777.80	2	3 - 13
MW-9XD	04/22/97	413221/865434	413221086543402	774.0	775.40	2	143 - 148
MW-10S	04/24/97	413222/865440	413222086544001	773.2	776.50	2	1.5 - 11.5
MW-10XD	05/07/97	413222/865440	413222086544002	773.2	774.67	2	148.5 - 153.5
MW-11S	05/08/97	413235/865456	413235086545601	785.6	788.16	2	10.5 - 20.5

Table A1. Selected characteristics of monitoring wells and well points used to monitor ground-water flow and quality near Westville, Indiana—Continued

Well name	Date installed	Latitude/ longitude	USGS site ID number	Land-surface altitude (feet above sea level)	Measuring-point altitude (feet above sea level)	Inside diameter of well casing and screen (inches)	Screened interval (feet below land surface)
MW-11D	05/09/97	413235/865456	413235086545602	785.6	787.77	2	70.5 - 75.5
MW-11XD	05/08/97	413235/865456	413235086545603	785.5	787.00	2	168.5 - 173.5
MW-12	09/09/97	413235/865502	413235086550201	786.0	787.65	2	10 - 20
MW-13S	09/26/97	413239/865441	413239086544101	793.1	794.40	2	19 - 29
MW-13D	09/23/97	413239/865441	413239086544102	793.5	796.50	2	75 - 80
MW-13XD	09/24/97	413239/865441	413239086544103	793.4	794.50	2	176 - 181
MW-14S	09/26/97	413239/865431	413239086543101	775.3	777.91	2	2.5 - 12.5
MW-14D	09/26/97	413239/865431	413239086543102	775.2	778.29	2	75 - 80
MW-14XD	09/25/97	413239/865431	413239086543103	775.1	777.28	2	156 - 161
MW-15S	11/10/97	413227/865436	413227086543601	773.2	775.68	2	3.5 - 13.5
MW-15MD	11/14/97	413227/865436	413227086543602	773.3	775.62	2	95 - 100
MW-15XD	11/11/97	413227/865436	413227086543603	773.2	775.47	2	151 - 156
MW-16S	11/10/97	413220/865451	413220086545101	772.8	775.38	2	3.5 - 13.5
MW-16D	11/19/97	413220/865451	413220086545102	772.5	774.97	2	57.5 - 62.5
MW-16XD	11/12/97	413220/865451	413220086545103	772.6	774.79	2	150 - 155
MW-17MD	11/18/97	413225/865446	413225086544601	777.8	780.00	2	115 - 120
MW-17XD	11/13/97	413225/865446	413225086544602	777.9	780.13	2	173 - 178
MW-18S	11/16/97	413231/865419	413231086541901	780.6	782.67	2	6 - 16

Table A1. Selected characteristics of monitoring wells and well points used to monitor ground-water flow and quality near Westville, Indiana—Continued

Well name	Date installed	Latitude/ longitude	USGS site ID number	Land-surface altitude (feet above sea level)	Measuring-point altitude (feet above sea level)	Inside diameter of well casing and screen (inches)	Screened interval (feet below land surface)
MW-18XD	11/17/97	413231/865419	413231086541902	780.8	782.88	2	145 - 150
NDF-MW1	01/24/92	413224/865447	413224086544701	777.4	779.54	2	7 - 12
NDF-MW2	01/24/92	413225/865446	413225086544603	777.7	779.81	2	7 - 12
OSW	--	--	--	791.1	794.22	6	? - 130
PZ-1S	03/27/97	413253/865314	413253086531401	814.1	815.12	2	29 - 39
PZ-1MD	04/02/97	413253/865314	413253086531402	814.1	817.07	2	145 - 150
PZ-1XD	04/03/97	413253/865314	413253086531403	814.2	816.80	2	180 - 185
PZ-2S	04/05/97	413252/865316	413252086531601	813.9	816.66	2	30 - 40
PZ-2MD	04/07/97	413252/865316	413252086531602	813.8	816.25	2	145 - 150
PZ-2XD	04/04/97	413252/865316	413252086531603	814.3	816.79	2	180 - 185
PZ-3S	04/09/97	413250/865316	413250086531601	813.6	816.05	2	30 - 40
PZ-3MD	04/09/97	413250/865316	413250086531602	813.5	816.06	2	145 - 150
PZ-3XD	04/08/97	413250/865316	413250086531603	813.6	816.05	2	180 - 185
TW-95A	12/19/95	413251/865317	413251086531701	813.3	815.84	5/4[c]	175 - 185
WP-1	04/08/97	413252/865426	--	771.9	775.05	2	2.1 - 3.1
WP-P	08/26/97	413239/865432[d]	--	770.6	772.44	2	2.6- 5.6
WP-2	03/25/97	413232/865433[d]	--	769.5	772.97	2	1.7 - 2.7
WP-2 new	08/26/97	413232/865433[d]	--	769.4	771.55	2	--

Table A1. Selected characteristics of monitoring wells and well points used to monitor ground-water flow and quality near Westville, Indiana—Continued

Well name	Date installed	Latitude/ longitude	USGS site ID number	Land-surface altitude (feet above sea level)	Measuring-point altitude (feet above sea level)	Inside diameter of well casing and screen (inches)	Screened interval (feet below land surface)
WP-3	04/14/97	413228/865434	--	768.7	771.44	2	2.5 - 3.5
WP-3 new	08/26/97	413228/865434	--	768.7	770.26	2	--
WP-4	06/06/97	413220/865434	--	767.0	770.64	2	1.7 - 2.7
WP-5	03/25/97	--	--	766.3	769.84	2	1.8 - 2.8
WP-6	03/25/97	413159/865448[d]	--	764.5	767.71	2	2.1 - 3.1
WP-7	03/25/97	413159/865500[d]	--	763.6	766.79	2	2.0 - 3.0
WP-8	06/06/97	413235/865509[d]	--	778.6	782.67	2	1.2 - 2.2

[a] Well repaired, change made to measuring-point altitude.
[b] Screen length determined by use of borehole camera.
[c] Latitude/longitude determined from 7.5-minute topographic map.
[d] Well has 5-inch-diameter casing and 4-inch-diameter screen.

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000

[nm, not measured; --, no data; O/S, outside of casing (surface-water level); I/S, inside of casing (ground-water level)]

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 06/02/97	Altitude of water surface 06/02/97 (feet above sea level)	Depth to water surface 07/22/97	Altitude of water surface 07/22/97 (feet above sea level)	Depth to water surface 08/27/97	Altitude of water surface 08/27/97 (feet above sea level)	Depth to water surface 10/21/97	Altitude of water surface 10/21/97 (feet above sea level)	Depth to water surface 12/16/97	Altitude of water surface 12/16/97 (feet above sea level)
B-1	808.51	30.41	778.10	30.35	778.16	30.14	778.37	30.92	777.59	31.37	777.14
B-2	796.18	18.74	777.44	18.69	777.49	18.59	777.59	nm	--	nm	--
B-4	797.50	20.48	777.02	20.45	777.05	20.40	777.10	21.14	776.36	21.55	775.95
EP-1	800.13	22.92	777.21	22.88	777.25	22.84	777.29	23.54	776.59	23.98	776.15
EP-2	798.12	20.41	777.71	20.36	777.76	20.26	777.86	20.96	777.16	21.40	776.72
EP-3	802.35	nm	--	nm	--	23.85	778.50	24.51	777.84	24.99	777.36
EP-4	807.30	30.03	777.27	30.00	777.30	29.82	777.48	30.65	776.65	31.09	776.21
LP-1	816.99	36.25	780.74	36.26	780.73	36.15	780.84	35.60	781.39	37.09	779.90
LP-2	786.98	15.42	771.56	15.33	771.65	15.63	771.35	16.40	770.58	16.66	770.32
LP-3	784.12	10.34	773.78	10.18	773.94	10.76	773.36	11.46	772.66	11.62	772.50
MW-1S	792.31	15.47	776.84	15.39	776.92	15.39	776.92	16.23	776.08	16.61	775.70
MW-1D	792.53	15.65	776.88	15.58	776.95	15.57	776.96	16.40	776.13	16.77	775.76
MW-2S	790.91	14.42	776.49	14.32	776.59	14.41	776.50	15.21	775.70	15.54	775.37
MW-2D	790.94	14.39	776.55	14.30	776.64	14.38	776.56	15.20	775.54	15.55	775.39
MW-2MD	794.26	17.67	776.59	17.55	776.71	17.64	776.62	18.44	775.82	18.79	775.47
MW-2XD	792.79	16.54	776.25	16.43	776.36	16.51	776.28	17.33	775.46	17.78	775.01
MW-3S	797.54	20.85	776.69	20.78	776.76	20.80	776.74	21.57	775.97	21.93	775.61
MW-3D	797.76	20.98	776.78	20.89	776.87	20.92	776.84	21.68	776.08	22.05	775.71

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 06/02/97	Altitude of water surface 06/02/97 (feet above sea level)	Depth to water surface 07/22/97	Altitude of water surface 07/22/97 (feet above sea level)	Depth to water surface 08/27/97	Altitude of water surface 08/27/97 (feet above sea level)	Depth to water surface 10/21/97	Altitude of water surface 10/21/97 (feet above sea level)	Depth to water surface 12/16/97	Altitude of water surface 12/16/97 (feet above sea level)
MW-4S	778.21	5.09	773.12	4.83	773.38	5.59	772.62	6.18	772.03	6.28	771.93
MW-4D	778.30	5.26	773.04	5.02	773.28	5.74	772.56	6.32	771.98	6.43	771.87
MW-4XD	778.24	5.52	772.72	5.30	772.94	5.98	772.26	6.55	771.69	6.73	771.51
MW-5S	789.16	12.72	776.44	12.66	776.50	12.84	776.32	13.99	775.17	14.24	774.92
MW-5D	789.16	13.13	776.03	13.02	776.14	13.18	775.98	14.02	775.14	14.34	774.82
MW-5XD	788.42	12.47	775.95	12.33	776.09	12.47	775.95	13.32	775.10	13.63	774.79
MW-6S	792.11	16.73[a]	775.38	16.67[b]	775.44	17.20[c]	774.91	17.85[d]	774.26	17.55[e]	774.56
MW-6D	792.19	15.87	776.32	15.78	776.41	15.90	776.29	16.74	775.45	17.07	775.12
MW-7S	812.20	32.78	779.42	32.71	779.49	32.59	779.61	33.17	779.03	33.68	778.52
MW-7D	811.70	32.29	779.41	32.22	779.48	32.09	779.61	32.67	779.03	33.18	778.52
MW-7XD	810.91	31.51	779.40	31.42	779.49	31.31	779.60	31.89	779.02	32.39	778.52
MW-8S	778.50	6.98	771.52	6.71	771.79	7.50	771.00	7.99	770.51	8.05	770.45
MW-8D	778.67	7.16	771.51	6.90	771.77	7.67	771.00	8.17	770.50	8.23	770.44
MW-9S	777.80	8.01	769.79	7.90	769.90	8.47	769.33	8.78	769.02	8.80	769.00
MW-9XD	775.40	5.12	770.28	5.01	770.39	5.70	769.70	6.11	769.29	6.13	769.27
MW-10S	776.50	6.15	770.35	6.10	770.40	6.95	769.55	7.49	769.01	7.52	768.98
MW-10XD	774.67	4.33	770.34	4.32	770.35	5.13	769.54	5.66	769.01	5.72	768.95
MW-11S	788.16	17.23	770.93	17.47	770.69	17.48	770.68	18.30	769.86	18.55	769.61
MW-11D	787.77	16.84	770.93	17.04	770.69	17.08	770.69	17.89	769.88	18.14	769.63
MW-11XD	787.00	16.11	770.89	16.26	770.74	16.31	770.69	17.12	769.88	17.37	769.63

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 06/02/97	Altitude of water surface 06/02/97 (feet above sea level)	Depth to water surface 07/22/97	Altitude of water surface 07/22/97 (feet above sea level)	Depth to water surface 08/27/97	Altitude of water surface 08/27/97 (feet above sea level)	Depth to water surface 10/21/97	Altitude of water surface 10/21/97 (feet above sea level)	Depth to water surface 12/16/97	Altitude of water surface 12/16/97 (feet above sea level)
MW-12	787.65	nm	--	nm	--	nm	--	18.11	769.54	18.38	769.27
MW-13S	794.49	nm	--	nm	--	nm	--	23.12	771.37	23.32	771.17
MW-13D	796.50	nm	--	nm	--	nm	--	25.23	771.27	25.43	771.07
MW-13XD	794.50	nm	--	nm	--	nm	--	23.29	771.21	23.61	770.89
MW-14S	777.91	nm	--	nm	--	nm	--	5.92	771.99	6.03	771.88
MW-14D	778.29	nm	--	nm	--	nm	--	6.26	772.03	6.39	771.90
MW-14XD	777.28	nm	--	nm	--	nm	--	5.97	771.31	6.12	771.16
MW-15S	775.68	nm	--	nm	--	nm	--	nm	--	5.85	769.83
MW-15MD	775.62	nm	--	nm	--	nm	--	nm	--	5.89	769.73
MW-15XD	775.47	nm	--	nm	--	nm	--	nm	--	5.95	769.52
MW-16S	775.38	nm	--	nm	--	nm	--	nm	--	7.32	768.06
MW-16D	774.97	nm	--	nm	--	nm	--	nm	--	6.89	768.08
MW-16XD	774.79	nm	--	nm	--	nm	--	nm	--	6.73	768.06
MW-17MD	780.00	nm	--	nm	--	nm	--	nm	--	10.92	769.08
MW-17XD	780.13	nm	--	nm	--	nm	--	nm	--	11.05	769.08
MW-18S	782.67	nm	--	nm	--	nm	--	nm	--	10.10	772.57
MW-18XD	782.88	nm	--	nm	--	nm	--	nm	--	10.29	772.59
NDF-MW-1	779.54	nm	--	nm	--	nm	--	nm	--	nm	--
NDF-MW-2	779.81	nm	--	nm	--	nm	--	nm	--	10.57	768.97
OSW	794.22	nm	--	nm	--	nm	--	nm	--	nm	--

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 06/02/97	Altitude of water surface 06/02/97 (feet above sea level)	Depth to water surface 07/22/97	Altitude of water surface 07/22/97 (feet above sea level)	Depth to water surface 08/27/97	Altitude of water surface 08/27/97 (feet above sea level)	Depth to water surface 10/21/97	Altitude of water surface 10/21/97 (feet above sea level)	Depth to water surface 12/16/97	Altitude of water surface 12/16/97 (feet above sea level)
PZ-1S	815.12	32.45	782.67	32.61[f]	782.51[f]	32.45	782.67	32.72	782.40	33.19	781.93
PZ-1MD	817.07	34.39	782.68	34.55[f]	782.52[f]	34.40	782.67	34.67	782.40	35.15	781.92
PZ-1XD	816.80	32.45	784.35	34.29[f]	782.51[f]	34.15	782.65	34.42	782.38	34.90	781.90
PZ-2S	816.66	nm	--	34.31[f]	782.35[f]	34.16	782.50	34.43	782.23	34.91	781.75
PZ-2MD	816.25	nm	--	33.91[f]	782.34[f]	33.75	782.50	34.05	782.20	34.52	781.73
PZ-2XD	816.53	nm	--	34.20[f]	782.33[f]	34.03	782.50	34.32	782.21	34.80	781.73
PZ-3S	816.05	nm	--	33.83[f]	782.22[f]	33.67	782.38	33.94	782.11	34.44	781.61
PZ-3MD	816.06	nm	--	33.84[f]	782.22[f]	33.67	782.39	33.61	782.45	34.45	781.61
PZ-3XD	816.05	nm	--	33.80[f]	782.25[f]	33.63	782.42	33.91	782.14	34.41	781.64
TW-95A	815.67	33.34	782.33	33.48[f]	782.19[f]	33.33	782.34	33.61	782.06	34.12	781.55
WP-1 O/S	775.05	2.69	772.36	2.58[f]	772.47[f]	2.73[g]	772.32[g]	2.69	772.36	2.72	772.33
WP-1 I/S	775.05	1.95	773.10	1.76[f]	773.29[f]	2.03[g]	773.02[g]	2.00	773.05	1.97	773.08
WP-P O/S	772.44	nm	--	nm	--	.87[g]	771.57[g]	.96	771.48	.82	771.62
WP-P I/S	772.44	nm	--	nm	--	.07[g]	772.37[g]	.45	771.99	.55	771.89
WP-2 O/S	772.97	1.02	771.95	2.38	770.59	2.44[g]	770.53[g]	2.48	770.49	2.42	770.55
WP-2 I/S	772.97	.14	772.83	1.53	771.44	1.87[g]	771.10[g]	2.11	770.86	2.12	770.85
WP-2N O/S	771.55	nm	--	nm	--	nm	--	nm	--	.99	770.56
WP-2N I/S	771.55	nm	--	nm	--	nm	--	nm	--	.63	770.92
WP-3 O/S	771.44	nm	--	nm	--	2.34	769.10	nm	--	2.33	769.11
WP-3 I/S	771.44	nm	--	nm	--	1.48	769.96	nm	--	1.64	769.80

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 06/02/97	Altitude of water surface 06/02/97 (feet above sea level)	Depth to water surface 07/22/97	Altitude of water surface 07/22/97 (feet above sea level)	Depth to water surface 08/27/97	Altitude of water surface 08/27/97 (feet above sea level)	Depth to water surface 10/21/97	Altitude of water surface 10/21/97 (feet above sea level)	Depth to water surface 12/16/97	Altitude of water surface 12/16/97 (feet above sea level)
WP-3N O/S	770.26	nm	--	nm	--	nm	--	nm	--	1.15	769.11
WP-3N I/S	770.26	nm	--	nm	--	nm	--	nm	--	.48	769.78
WP-4 O/S	770.64	3.04[h]	767.60[h]	2.89[f]	767.75[f]	2.38[g]	768.26[g]	3.19	767.45	3.18	767.46
WP-4 I/S	770.64	2.20[h]	768.44[h]	1.91[f]	768.73[f]	1.50[g]	769.14[g]	2.35	768.29	2.35	768.29
WP-5 O/S	769.84	nm	--	nm	--	nm	--	nm	--	nm	--
WP-5 I/S	769.84	nm	--	nm	--	nm	--	nm	--	nm	--
WP-6 O/S	767.71	nm	--	2.14[f]	765.57[f]	nm	--	nm	--	2.68	765.03
WP-6 I/S	767.71	nm	--	1.51[f]	766.20[f]	nm	--	nm	--	2.25	765.46
WP-7 O/S	766.79	nm	--	nm	--	nm	--	nm	--	nm	--
WP-7 I/S	766.79	nm	--	nm	--	nm	--	nm	--	nm	--
WP-8 O/S	782.67	2.11[h]	780.56[h]	2.23	780.44	nm	--	3.60[i]	779.07[i]	dry	--
WP-8 I/S	782.67	nm	--	2.29	780.38	nm	--	3.66[i]	779.01[i]	4.04	778.63

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 01/28/98	Altitude of water surface 01/28/98 (feet above sea level)	Depth to water surface 03/19/98	Altitude of water surface 03/19/98 (feet above sea level)	Depth to water surface 05/21/98	Altitude of water surface 05/21/98 (feet above sea level)	Depth to water surface 07/08/98	Altitude of water surface 07/08/98 (feet above sea level)	Depth to water surface 05/06/99	Altitude of water surface 05/06/99 (feet above sea level)
B-1	808.51	31.12	777.39	30.98	777.53	29.74	778.77	29.65	778.86	31.34	777.17
B-2	796.18	nm	--	nm	--	nm	--	nm	--	nm	--
B-4	797.50	21.07	776.43	20.75	776.75	19.82	777.68	19.77	777.73	21.00	776.50
EP-1	800.13	23.50	776.63	23.30	776.83	22.22	777.91	22.19	777.94	23.82	776.31
EP-2	798.12	21.03	777.09	20.86	777.26	19.70	778.42	19.65	778.47	21.45	776.67
EP-3	802.35	24.74	777.61	24.64	777.71	23.35	779.00	23.25	779.10	25.30	777.05
EP-4	807.30	30.74	776.56	30.49	776.81	29.40	777.90	29.30	778.00	31.03	776.27
LP-1	816.99	37.26	779.73	37.36	779.63	35.88	781.11	35.44	781.55	38.24	778.75
LP-2	786.98	15.85	771.13	14.98	772.00	14.79	772.19	15.04	771.94	15.70	771.28
LP-3	784.12	11.16	772.96	9.45	774.67	10.42	773.70	10.00	774.12	11.06	773.06
MW-1S	792.31	16.15	776.16	15.64	776.67	14.96	777.35	14.79	777.52	17.69[j]	774.62
MW-1D	792.53	16.30	776.23	15.80	776.73	15.12	777.41	14.98	777.55	16.58	775.95
MW-2S	790.91	15.00	775.91	14.39	776.52	13.87	777.04	13.73	777.18	15.18	775.73
MW-2D	790.94	15.01	775.93	14.41	776.53	13.87	777.07	13.73	777.21	15.21	775.73
MW-2MD	794.26	20.27	775.99	17.66	776.60	17.13	777.13	16.97	777.29	18.48	775.78
MW-2XD	792.79	17.25	775.54	16.63	776.16	16.10	776.69	15.94	776.85	17.48	775.31
MW-3S	797.54	21.39	776.15	20.99	776.55	20.23	777.31	20.15	777.39	21.62	776.92
MW-3D	797.76	21.52	776.24	21.10	776.66	20.35	777.41	20.27	777.49	21.74	776.02

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 01/28/98	Altitude of water surface 01/28/98 (feet above sea level)	Depth to water surface 03/19/98	Altitude of water surface 03/19/98 (feet above sea level)	Depth to water surface 05/21/98	Altitude of water surface 05/21/98 (feet above sea level)	Depth to water surface 07/08/98	Altitude of water surface 07/08/98 (feet above sea level)	Depth to water surface 05/06/99	Altitude of water surface 05/06/99 (feet above sea level)
MW-4S	778.21	5.83	772.38	4.38	773.83	5.29	772.92	4.95	773.26	5.82	772.39
MW-4D	778.30	5.98	772.32	4.54	773.76	5.42	772.88	5.07	773.23	5.93	772.37
MW-4XD	778.24	6.20	772.04	4.74	773.50	5.57	772.67	5.22	773.02	6.03	772.21
MW-5S	789.16	13.49	775.67	12.73	776.43	12.34	776.82	12.18	776.98	12.94	776.22
MW-5D	789.16	13.84	775.32	13.01	776.15	12.75	776.41	12.57	776.59	13.91	775.25
MW-5XD	788.42	13.10	775.32	12.26	776.16	11.98	776.44	11.71	776.71	13.12	775.30
MW-6S	792.11	nm	--	16.02[k]	776.09	15.79[l]	776.32	15.59[m]	776.52	18.93[n]	773.18
MW-6D	792.19	16.54	775.65	15.77	776.42	15.44	776.75	15.24	776.95	16.72	775.47
MW-7S	812.20	33.59	778.61	33.63	778.57	32.20	780.00	31.95	780.25	34.37	777.83
MW-7D	811.70	33.09	778.61	33.13	778.57	31.71	779.99	31.45	780.25	33.87	777.83
MW-7XD	810.91	32.32	778.59	32.34	778.57	30.91	780.00	30.67	780.24	33.08	777.83
MW-8S	778.50	7.68	770.82	6.37	772.13	7.29	771.21	6.99	771.51	7.64	770.86
MW-8D	778.67	7.87	770.80	6.54	772.13	7.45	771.22	7.17	771.50	7.81	770.86
MW-9S	777.80	8.59	769.21	7.60	770.20	8.35	769.45	8.09	769.71	8.52	769.28
MW-9XD	775.40	5.87	769.53	4.60	770.80	5.54	769.86	5.21	770.19	5.78	769.62
MW-10S	776.50	7.10	769.40	5.41	771.09	6.65	769.85	6.32	770.18	6.95	769.55
MW-10XD	774.67	5.28	769.39	3.60	771.07	4.82	769.85	4.49	770.18	5.10	769.57
MW-11S	788.16	17.68	770.48	17.01	771.15	16.54	771.62	17.00	771.16	17.52	770.64
MW-11D	787.77	17.27	770.50	16.56	771.21	16.14	771.63	16.55	771.22	17.11	770.66

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 01/28/98	Altitude of water surface 01/28/98 (feet above sea level)	Depth to water surface 03/19/98	Altitude of water surface 03/19/98 (feet above sea level)	Depth to water surface 05/21/98	Altitude of water surface 05/21/98 (feet above sea level)	Depth to water surface 07/08/98	Altitude of water surface 07/08/98 (feet above sea level)	Depth to water surface 05/06/99	Altitude of water surface 05/06/99 (feet above sea level)
MW-11XD	787.00	16.51	770.49	15.77	771.23	15.39	771.61	15.78	771.22	16.37	770.63
MW-12	787.65	17.47	770.18	16.78	770.87	16.09	771.56	16.77	770.88	17.28	770.37
MW-13S	794.49	22.65	771.84	21.72	772.77	21.78	772.71	21.82	772.67	22.48	772.01
MW-13D	796.50	24.76	771.74	23.83	772.67	23.89	772.61	23.93	772.57	24.60	771.90
MW-13XD	794.50	22.94	771.56	21.91	772.59	22.08	772.42	22.09	772.41	22.78	771.72
MW-14S	777.91	5.63	772.28	4.31	773.60	5.12	772.79	4.80	773.11	5.51	772.40
MW-14D	778.29	5.94	772.35	4.64	773.65	5.43	772.86	5.12	773.17	5.85	772.44
MW-14XD	777.28	5.46	771.82	4.00	773.28	4.72	772.56	4.40	772.88	5.10	772.18
MW-15S	775.68	5.47	770.21	4.04	771.64	5.02	770.66	4.75	770.93	5.32	770.36
MW-15MD	775.62	5.52	770.10	4.11	771.51	5.07	770.55	4.82	770.80	5.38	770.24
MW-15XD	775.47	5.56	769.91	4.16	771.31	5.10	770.37	4.85	770.62	5.43	770.04
MW-16S	775.38	6.72	768.66	4.75	770.63	6.07	769.31	5.87	769.51	6.47	768.91
MW-16D	774.97	6.28	768.69	4.32	770.65	5.64	769.33	5.43	769.54	6.03	768.94
MW-16XD	774.79	6.11	768.68	4.16	770.63	5.47	769.32	5.27	769.52	5.85	768.94
MW-17MD	780.00	10.33	769.67	8.77	771.23	9.67	770.33	9.56	770.44	10.12	769.88
MW-17XD	780.13	10.43	769.70	8.88	771.25	9.76	770.37	9.66	770.47	10.20	769.93
MW-18S	782.67	9.62	773.05	7.92	774.75	8.83	773.84	8.40	774.27	9.51	773.16
MW-18XD	782.88	9.78	773.10	8.14	774.74	9.07	773.81	8.57	774.31	9.68	773.20
NDF-MW-1	779.54	10.14	769.84	8.38	771.16	9.50	770.04	9.33	770.21	10.17[o]	769.37[o]

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 01/28/98	Altitude of water surface 01/28/98 (feet above sea level)	Depth to water surface 03/19/98	Altitude of water surface 03/19/98 (feet above sea level)	Depth to water surface 05/21/98	Altitude of water surface 05/21/98 (feet above sea level)	Depth to water surface 07/08/98	Altitude of water surface 07/08/98 (feet above sea level)	Depth to water surface 05/06/99	Altitude of water surface 05/06/99 (feet above sea level)
NDF-MW-2	779.81	9.97	770.49	8.46	771.35	9.45	770.36	9.33	770.48	10.15^{o}	769.66^{o}
OSW	794.22	nm	--	nm	--	16.44	777.78	16.34	777.88	17.98	776.24
PZ-1S	815.12	33.67	781.45	33.88	781.24	32.34	782.78	31.61	783.51	34.93	780.19
PZ-1MD	817.07	35.62	781.45	35.83	781.24	34.29	782.78	33.57	783.50	36.89	780.18
PZ-1XD	816.80	35.36	781.44	35.57	781.23	34.03	782.77	33.31	783.49	36.63	780.17
PZ-2S	816.66	35.38	781.28	35.57	781.09	34.02	782.64	33.32	783.34	36.63	780.03
PZ-2MD	816.25	34.96	781.29	35.17	781.08	33.61	782.64	32.92	783.33	36.23	780.02
PZ-2XD	816.53	35.27	781.26	35.45	781.08	33.89	782.64	33.20	783.33	36.50	780.03
PZ-3S	816.05	34.89	781.16	35.09	780.96	33.50	782.55	32.81	783.24	36.13	779.92
PZ-3MD	816.06	34.90	781.16	35.10	780.96	33.52	782.54	32.82	783.23	36.15	779.91
PZ-3XD	816.05	34.86	781.19	35.05	781.00	33.47	782.58	32.79	783.26	36.11	779.94
TW-95A	815.67	34.54	781.13	34.74	780.93	33.17	782.50	32.49	783.18	35.78	779.89
WP-1 O/S	775.05	2.77	772.28	2.10	772.95	2.73	772.32	2.59	772.46	2.67	772.38
WP-1 I/S	775.05	1.67	773.38	1.01	774.04	1.68	773.37	1.41	773.64	1.53	773.52
WP-P O/S	772.44	.86	771.58	.27	772.17	.79^{p}	771.65^{p}	.59	771.85	.92	771.52
WP-P I/S	772.44	.18	772.26	flowing	--	flowing^{p}	--	flowing	--	.14	772.30
WP-2 O/S	772.97	2.59	770.38	2.23	770.74	2.80^{p}	770.17^{p}	2.62	770.35	3.11	769.86
WP-2 I/S	772.97	1.95	771.02	1.17	771.80	1.98^{p}	770.99^{p}	1.73	771.24	2.20	770.77
WP-2N O/S	771.55	1.10	770.45	.74	770.81	1.38^{p}	770.17^{p}	1.09	770.46	1.63	769.92

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 01/28/98	Altitude of water surface 01/28/98 (feet above sea level)	Depth to water surface 03/19/98	Altitude of water surface 03/19/98 (feet above sea level)	Depth to water surface 05/21/98	Altitude of water surface 05/21/98 (feet above sea level)	Depth to water surface 07/08/98	Altitude of water surface 07/08/98 (feet above sea level)	Depth to water surface 05/06/99	Altitude of water surface 05/06/99 (feet above sea level)
WP-2N I/S	771.55	.39	771.16	flowing	--	.24[p]	771.31[p]	flowing	--	.50	771.05
WP-3 O/S	771.44	2.35	769.09	2.03	769.41	2.32[p]	769.12[p]	2.28	769.16	2.40	769.04
WP-3 I/S	771.44	1.54	769.90	.91	770.53	1.41[p]	770.03[p]	1.28	770.16	1.49	769.95
WP-3N O/S	770.26	1.17	769.09	.85	769.41	1.16[p]	769.10[p]	1.13	769.13	1.22	769.04
WP-3N I/S	770.26	.37	769.89	flowing	--	.27[p]	769.99[p]	.14	770.12	.34	769.92
WP-4 O/S	770.64	3.14	767.50	2.68	767.96	3.05[p]	767.59[p]	3.04	767.60	3.07	767.57
WP-4 I/S	770.64	2.28	768.36	1.60	769.04	2.10[p]	768.54[p]	1.99	768.65	2.18	768.46
WP-5 O/S	769.84	nm	--	nm	--	nm	--	nm	--	nm	--
WP-5 I/S	769.84	nm	--	nm	--	nm	--	nm	--	nm	--
WP-6 O/S	767.71	2.76	764.95	2.20	765.51	2.53[p]	765.18[p]	2.23	765.48	2.95	764.76
WP-6 I/S	767.71	2.19	765.52	1.16	766.55	1.92[p]	765.79[p]	1.55	766.16	2.11	765.60
WP-7 O/S	766.79	nm	--	nm	--	nm	--	2.07	764.72	nm	--
WP-7 I/S	766.79	nm	--	nm	--	nm	--	1.40	765.39	nm	--
WP-8 O/S	782.67	2.93[q]	779.74[q]	1.92[r]	780.75[r]	1.99[p]	780.68[p]	2.41	780.26	2.00	780.67
WP-8 I/S	782.67	3.00[q]	779.67[q]	1.94	780.73	1.98[p]	780.69[p]	2.44	780.23	1.98	780.69

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 08/18/99	Altitude of water surface 08/18/99 (feet above sea level)	Depth to water surface 12/08/99	Altitude of water surface 12/08/99 (feet above sea level)	Depth to water surface 05/10/00	Altitude of water surface 05/10/00 (feet above sea level)	Depth to water surface 08/23/00	Altitude of water surface 08/23/00 (feet above sea level)
B-1	808.51	32.38	776.13	33.31	775.20	34.16	774.35	33.81	774.70
B-2	796.18	nm	--	nm	--	nm	--	nm	--
B-4	797.50	22.40	775.10	24.36	773.14	23.91	773.59	23.58	773.92
EP-1	800.13	24.86	775.27	25.87	774.26	26.50	773.63	26.10	774.03
EP-2	798.12	22.33	775.79	24.34	773.78	24.10	774.02	23.68	774.44
EP-3	802.35	nm	--	nm	--	nm	--	nm	--
EP-4	807.30	32.00	775.30	32.88	774.42	33.53	773.77	33.24	774.06
LP-1	816.99	38.44	778.55	39.69	777.83	40.76	776.23	40.34	776.65
LP-2	786.98	17.24	769.74	17.85	769.13	17.78	769.20	17.65	769.33
LP-3	784.12	12.31	771.79	12.68	771.44	12.89	771.23	13.00	771.12
MW-1S	792.31	18.64[s]	773.67	19.89[t]	772.42	20.34[u]	771.97	18.77[v]	773.54
MW-1D	792.53	17.66	774.87	18.54[w]	773.99	19.07	773.46	18.84	773.69
MW-2S	790.91	16.36	774.55	17.21	773.70	17.66	773.25	17.45	773.46
MW-2D	790.94	16.37	774.57	17.22	773.72	17.68	773.26	17.46	773.48
MW-2MD	794.26	19.62	774.64	19.46	774.80	20.95	773.31	20.73	773.53
MW-2XD	792.79	18.59	774.20	19.43	773.36	19.90	772.89	19.69	773.10
MW-3S	797.54	22.78	774.76	23.68	773.86	24.18	773.36	23.92	773.62
MW-3D	797.76	22.90	774.86	23.79	773.97	24.29	773.47	24.03	773.73

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 08/18/99	Altitude of water surface 08/18/99 (feet above sea level)	Depth to water surface 12/08/99	Altitude of water surface 12/08/99 (feet above sea level)	Depth to water surface 05/10/00	Altitude of water surface 05/10/00 (feet above sea level)	Depth to water surface 08/23/00	Altitude of water surface 08/23/00 (feet above sea level)
MW-4S	778.21	6.95	771.26	7.25	770.96	7.38	770.83	7.48	770.73
MW-4D	778.30	7.06	771.24	7.36	770.94	7.50	770.80	7.60	770.70
MW-4XD	778.24	7.15	771.09	7.35	770.89	7.57	770.67	7.65	770.59
MW-5S	789.16	15.11	774.05	15.86	773.30	16.28	772.88	16.13[x]	773.03[x]
MW-5D	789.16	15.15	774.01	15.88	773.28	16.32	772.84	16.20[x]	772.96[x]
MW-5XD	788.42	14.33	774.09	15.09	773.33	15.53	772.89	15.39[x]	773.03[x]
MW-6S	792.11	19.29[y]	772.82	19.67[z]	772.44	nm	--	20.13[aa]	771.98[x]
MW-6D	792.19	17.92	774.27	18.72	773.47	nm	--	18.98[x]	773.21[x]
MW-7S	812.20	34.82	777.38	36.75	775.45	36.89	775.31	36.46	775.74
MW-7D	811.70	34.34	777.36	36.27	775.43	36.41	775.29	35.98	775.72
MW-7XD	810.91	33.55	777.36	35.47	775.44	35.61	775.30	35.18	775.73
MW-8S	778.50	8.65	769.85	8.76	769.74	8.80	769.70	8.94	769.56
MW-8D	778.67	8.83	769.84	8.95	769.72	8.99	769.68	9.12	769.55
MW-9S	777.80	9.20	768.60	9.13	768.67	9.21	768.59	9.32	768.48
MW-9XD	775.40	6.61	768.79	6.55	768.85	6.65	768.75	5.76	769.64
MW-10S	776.50	8.15	768.35	8.05	768.45	8.08	768.42	8.27	768.23
MW-10XD	774.67	8.32	768.35	6.25	768.42	6.27	768.40	5.46	769.21
MW-11S	788.16	19.11	769.05	19.74	768.42	19.58	768.58	19.46	768.70
MW-11D	787.77	18.69	769.08	19.33	768.44	19.18	768.59	19.06	768.71
MW-11XD	787.00	17.94	769.06	18.55	768.45	18.42	768.58	18.29	768.71

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 08/18/99	Altitude of water surface 08/18/99 (feet above sea level)	Depth to water surface 12/08/99	Altitude of water surface 12/08/99 (feet above sea level)	Depth to water surface 05/10/00	Altitude of water surface 05/10/00 (feet above sea level)	Depth to water surface 08/23/00	Altitude of water surface 08/23/00 (feet above sea level)
MW-12	787.65	18.97	768.68	19.69	767.96	19.49	768.16	19.36	768.29
MW-13S	794.49	23.87	770.62	24.35	770.14	24.39	770.10	24.32	770.17
MW-13D	796.50	26.01	770.49	26.50	770.00	26.51	769.99	26.45	770.05
MW-13XD	794.50	21.14	770.36	24.62	769.88	24.64	769.86	24.58	769.92
MW-14S	777.91	6.68	771.23	dry	--	dry	--	dry	--
MW-14D	778.29	7.04	771.25	7.38	770.91	7.44	770.85	7.54	770.75
MW-14XD	777.28	6.74	770.54	7.05	770.23	7.10	770.18	7.15	770.13
MW-15S	775.68	6.40	769.28	6.48	769.20	6.45	769.23	5.61^{x}	770.07^{x}
MW-15MD	775.62	6.46	769.16	6.50	769.12	6.49	769.13	5.86^{x}	769.76^{x}
MW-15XD	775.47	6.64	768.83	6.72	768.757	6.70	768.77	6.65^{x}	768.82^{x}
MW-16S	775.38	8.01	767.37	8.01	767.37	7.90	767.48	8.06	767.32
MW-16D	774.97	7.58	767.39	7.58	767.39	7.47	767.50	7.62	767.35
MW-16XD	774.79	7.41	767.38	7.41	767.38	7.31	767.48	7.46	767.33
MW-17MD	780.00	11.59	768.41	11.76	768.24	11.64	768.36	11.76	768.24
MW-17XD	780.13	11.68	768.45	11.84	768.29	11.73	768.40	11.87	768.26
MW-18S	782.67	10.80	771.87	11.17	771.50	11.43	771.24	11.57	771.10
MW-18XD	782.88	10.95	771.93	11.32	771.56	11.63	771.25	11.69	771.19
NDF-MW-1	779.54	11.41	768.13	11.51	768.03	nm	--	11.53	768.01
NDF-MW-2	779.81	11.37	768.44	11.51	768.30	nm	--	11.51	768.30

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 08/18/99	Altitude of water surface 08/18/99 (feet above sea level)	Depth to water surface 12/08/99	Altitude of water surface 12/08/99 (feet above sea level)	Depth to water surface 05/10/00	Altitude of water surface 05/10/00 (feet above sea level)	Depth to water surface 08/23/00	Altitude of water surface 08/23/00 (feet above sea level)
OSW	794.22	18.99	775.23	19.88	774.34	20.49	773.73	20.22	774.00
PZ-1S	815.12	34.91	780.21	35.79	779.33	37.22	777.90	37.04	778.08
PZ-1MD	817.07	36.86	780.21	37.73	779.34	39.18	777.89	38.99	778.08
PZ-1XD	816.80	36.61	780.19	37.47	779.33	38.92	777.88	38.74	778.06
PZ-2S	816.66	36.60	780.06	37.50	779.16	38.90	777.76	38.70	777.96
PZ-2MD	816.25	36.18	780.07	37.08	779.17	38.51	777.74	38.32	777.93
PZ-2XD	816.53	36.48	780.05	37.35	779.18	38.80	777.73	38.59	777.94
PZ-3S	816.05	36.08	779.97	37.01	779.04	38.40	777.65	38.19	777.86
PZ-3MD	816.06	36.13	779.93	37.01	779.05	38.43	777.63	38.22	777.84
PZ-3XD	816.05	36.08	779.97	36.97	779.08	38.38	777.67	38.17	777.88
TW-95A	815.67	35.76	779.91	36.63	779.04	38.07	777.60	37.86	777.81
WP-1 O/S	775.05	2.73	772.32	2.86	772.19	dry	--	dry	--
WP-1 I/S	775.05	2.29	772.76	2.90	771.15	3.15	771.90	3.03	772.02
WP-P O/S	772.44	.98	771.46	dry	--	1.19	771.25	dry	--
WP-P I/S	772.44	1.12	772.30	1.51	770.93	1.58	770.86	1.72	770.72
WP-2 O/S	772.97	2.77	770.20	2.97	770.00	3.05	769.92	2.62	770.35
WP-2 I/S	772.97	2.62	770.35	2.82	770.15	2.89	770.08	2.82	770.15
WP-2N O/S	771.55	1.31	770.24	1.55	770.00	1.62	769.93	1.12	770.43
WP-2N I/S	771.55	1.12	771.05	1.36	770.19	1.49	770.06	1.42	770.13

Table A2. Water levels measured in monitoring wells and well points near Westville, Indiana, June 1997 through August 2000—Continued

Well name	Measuring-point altitude (feet above sea level)	Depth to water surface 08/18/99	Altitude of water surface 08/18/99 (feet above sea level)	Depth to water surface 12/08/99	Altitude of water surface 12/08/99 (feet above sea level)	Depth to water surface 05/10/00	Altitude of water surface 05/10/00 (feet above sea level)	Depth to water surface 08/23/00	Altitude of water surface 08/23/00 (feet above sea level)
WP-3 O/S	771.44	2.43	769.01	nm	--	nm	--	2.52	768.92
WP-3 I/S	771.44	1.93	769.51	nm	--	nm	--	2.14	769.30
WP-3N O/S	770.26	1.24	769.02	nm	--	nm	--	1.38	768.88
WP-3N I/S	770.26	.76	769.50	nm	--	nm	--	1.00	769.26
WP-4 O/S	770.64	3.10	767.54	3.12	767.52	3.11	767.53	2.47	768.17
WP-4 I/S	770.64	2.52	768.12	2.48	768.16	2.53	768.11	2.43	768.21
WP-5 O/S	769.84	nm	--	nm	--	nm	--	nm	--
WP-5 I/S	769.84	nm	--	nm	--	nm	--	nm	--
WP-6 O/S	767.71	2.66	765.05	2.63[bb]	765.08[bb]	2.86	764.85	3.03	764.68
WP-6 I/S	767.71	2.52	765.19	2.37[bb]	765.34[bb]	2.53	765.18	2.55	765.16
WP-7 O/S	766.79	nm	--	nm	--	nm	--	nm	--
WP-7 I/S	766.79	nm	--	nm	--	nm	--	nm	--
WP-8 O/S	782.67	dry	--	dry	--	3.61	779.06	3.42	779.25
WP-8 I/S	782.67	4.48	778.19	dry	--	3.60	779.07	3.42	779.25

[a] Observed floating oil in well.
[b] Depth to oil was 15.57 feet.
[c] Depth to oil was 15.62 feet.
[d] Measurement made September 22, 1997; depth to oil was 16.52 feet.
[e] Depth to oil was16.89 feet.
[f] Measurement made July 23, 1997.
[g] Measurement made August 28, 1997.
[h] Measurement made June 5, 1997.
[i] Measurement made September 22, 1997.
[j] Depth to oil was 16.19 feet.
[k] Depth to oil was 15.60 feet.
[l] Depth to oil was 15.28 feet.
[m] Depth to oil was15.10 feet.
[n] Depth to oil was 16.47 feet.
[o] Measurement made May 10, 1999.
[p] Measurement made May 22, 1998.
[q] Water frozen in well point and pond.
[r] Water frozen in pond.
[s] Depth to oil was 17.30 feet.
[t] Depth to oil was 18.13 feet.
[u] Depth to oil was 18.67 feet.
[v] Depth to oil was 18.50 feet.
[w] Depth to oil was 18.52 feet.
[x] Measurement made August 24, 2000.
[y] Depth to oil was 17.58 feet.
[z] Depth to oil was 18.51 feet.
[aa] Measurement made August 24, 2000; depth to oil was 18.70 feet.
[bb] Measurement made December 9, 1999.

Appendix B.
Quality Assurance

Quality-Assurance Sample Collection

Duplicate samples were collected sequentially during sample collection from selected wells at a rate of 1 duplicate sample for every 10 regular samples. Duplicate samples can indicate the variability of the sampled medium or the variability of the methods of sample collection and laboratory analysis. Samples also were collected for use as matrix spikes at a rate of 1 matrix spike for every 20 regular samples. Matrix-spike samples are used by the laboratory to determine recovery rates by adding known concentrations of a substance to the sample and analyzing for that substance. Matrix-spike samples also can be used to evaluate whether the sample water contains substances that may cause interference with the analysis.

Two types of blank samples were collected—trip blanks and equipment-rinse blanks. Trip blanks consisted of laboratory-certified organic-free water poured into sample bottles for analysis of volatile organic compounds (VOC's) and 1,4-dioxane. A trip blank was kept in a cooler that accompanied each sampling crew during sample collection and subsequently was sent to the laboratory for analysis. Trip blanks can indicate if contamination of the regular samples occurred during shipping.

Equipment-rinse blanks, sometimes referred to as method blanks, were collected after decontamination of the sampling equipment by pumping distilled or deionized water through the sampling pump and discharge tubing. The blank sample was collected from the discharge tubing in the same manner as the regular samples. Equipment-rinse blanks were collected for each sampling device used, with a maximum frequency of 1 equipment blank for every 20 samples collected. Analysis of these blank samples can indicate whether the decontamination procedures were effective or if contaminants were introduced by the sampling equipment.

Results of Quality Assurance

Results of analysis of duplicate samples (tables B1 through B4) were compared by use of the relative percent difference (RPD). The RPD was calculated with the following formula for 33 analytes detected in the regular and duplicate samples

$$\mathrm{RPD} = \frac{(C1 - C2) \times 100 \text{ percent}}{(C1 + C2)/2} \qquad (3)$$

where,

$C1$ is the larger of the two concentrations, and
$C2$ is the smaller of the two concentrations (U.S. Environmental Protection Agency (1989, p. 13).

Analytes detected in one but not both of the sample pairs and analytes not detected are not included in the RPD analysis because of uncertainty in the actual concentration of analytes reported as less than the quantitation limit.

The RPD analysis generally indicated small differences between concentrations of most analytes in the sample pairs (table B5). Of 110 individual comparisons, only 13 RPD's are greater than 25 percent. Although the range of RPD's is varied among analytes, the median RPD's for 23 of the 33 analytes are 10 or less. The median RPD's for two analytes—copper and thallium—exceeded 25. These analytes are not critical to the discussion of water quality in this report.

Of the 11 sample pairs analyzed for 1,4-dioxane (table B4), 4 were reported as less than the quantitation limit in the regular and duplicate samples. The RPD analysis for 1,4-dioxane (table B5) is based on the remaining seven sample pairs. The RPD's for 1,4-dioxane range from 0 to 36.6 and have a median of 16.7. The largest RPD is for samples collected from well MW-4XD during April 1997. Estimated concentrations of 1,4-dioxane in the regular and duplicate samples exceeded 3,000 µg/L. An RPD of 22.2 was calculated for regular and duplicate samples collected from well MW-2D during May 1999. These samples were diluted for analysis, and the reported concentrations exceeded 8,000 µg/L. The RPD analysis of 1,4-dioxane may indicate an error in the dilution process or a loss of analytical precision at large concentrations.

Results of the equipment-rinse samples (table B6) indicate that the sampling equipment and procedures did not alter the water chemistry substantially. With the exception of potassium in one sample and sodium in two samples, concentrations of major elements reported for equipment-rinse samples were less than the smallest concentration reported for these constituents in the environmental samples. Potassium and sodium are common constituents in water and may have been present in the deionized or distilled water used for equipment decontamination and to make up the equipment-rinse sample.

Except for aluminum, concentrations of minor elements in equipment-rinse samples generally were low (table B6); however, concentrations reported for barium, copper, thallium, and zinc, as well as aluminum, are within the range of concentrations reported for the environmental samples. Detection of these constituents may indicate that minor elements were present in the water used for equipment decontamination or that decontamination was inadequate to remove these elements. In either event, the detection of these minor elements in water samples is not critical to the interpretation of water quality in relation to the former refinery.

Several of the VOC's detected during April–June 1997 were not detected in subsequent samples from the same wells. For example, small concentrations of acetone were detected in water from wells B-1, MW-4XD, MW-11D, and MW-10S, as well as small concentrations of toluene in water from well EP-4 and all three wells at MW-5. Those results were not duplicated in samples collected from these wells during later sampling rounds. In fact, no VOC's were detected in samples from these wells during the remainder of the investigation. The initial detections of VOC's in samples from wells B-1, EP-4, MW-4XD and all wells at MW-5, MW-10S, and MW-11D probably are not indicative of ground-water quality and may have resulted from contamination in the field or the laboratory.

Five volatile organic compounds were detected at least once in the 10 equipment-rinse samples analyzed during the study (table B6). Acetone was detected in four equipment-rinse samples at concentrations ranging from 15 to 49 μg/L; bromodichloromethane and dibromochlromethane were detected in two samples at concentrations ranging from 3 to 6 μg/L; 2-butanone and toluene were detected in one sample each at concentrations of 10 and 0.5 μg/L, respectively. Detections of 2-butanone and dibromochloromethane were not reported for any of the environmental samples. Acetone was detected in three environmental samples, and bromodichloromethane was detected in one environmental sample. These compounds, however, were reported in samples collected during April and May 1997, and the detections in the equipment-rinse samples occurred during August–September and December 1997. Toluene was detected in 12 environmental samples collected from eight wells at concentrations ranging from 1 to 7 μg/L. Of these, only one sample was collected during December 1997, when toluene was reported in the equipment-rinse sample.

Analysis of the trip-blank samples detected no volatile organic compounds (table B7). These results indicate no contamination of the samples in the field during handling and shipping.

Table B1. Concentrations of common constituents in duplicate ground-water samples collected near Westville, Indiana, April–June 1997

[mg/L, milligram per liter; $CaCO_3$, calcium carbonate; --, not sampled; J, concentration is estimated; >, greater than]

Well	Date of sample collection	Bi-carbonate alkalinity (mg/L)	Ammonia as nitrogen (mg/L)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	Total Kjeldahl nitrogen (mg/L)	Total organic carbon (percent)
MW-4XD	04/29/97	1,080	2.7	2,620	512	> 260	228	3.24 J	42.1 J	> 375	4.44	15
Duplicate		1,060	--	>2,640	527	252	226	3.12 J	41.2 J	> 1,500	--	--
MW-8D	04/29/97	375	--	652	--	380	--	--	--	0	--	--
Duplicate		385	--	664	--	395	--	--	--	8	--	--
MW-9S	04/29/97	232	--	236	99.8	58	30.0	1.69 J	13.9 J	76	--	--
Duplicate		237	--	296	95.5	64	29.4	1.60 J	12.4 J	84	--	--
MW-2S	05/01/97	340	--	420	111 J	56	27.5 J	5.46 J	33.5 J	140	--	46
Duplicate		365	--	420	112 J	--	27.6 J	5.32 J	32.8 J	--	--	46
MW-2XD	05/01/97	852	--	2,360	522	> 132	212	19.5 J	36.5 J	> 375	--	--
Duplicate		--	2.7	1,160	526	> 266	215	20.0 J	37.3 J	>375	4.65	16
MW-10XD	06/03/97	--	--	--	139	--	58.3	2.63	52.2 J	--	--	--
Duplicate		--	--	--	155	--	64.2	2.70 J	53.7 J	--	--	--
MW-11D	06/03/97	--	--	--	86.8	--	34.4	.679	4.07 J	--	--	--
Duplicate		--	--	--	86.9	--	34.3	.673	4.06	--	--	--

Table B2. Concentrations of minor elements in duplicate ground-water samples collected near Westville, Indiana, April–June 1997

[µg/L, microgram per liter; J, concentration is estimated; <, less than]

Well	Date of sample collection)	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)
MW-4XD	04/29/97	< 9	4.0 J	5.4	21.1	< 1	< 1	1.5	< 1	2	65,100
Duplicate		18.4 J	4.0 J	7.7 J	20.1 J	< 1	< 1	< 1	1.3 J	1.5 J	66,300
MW-9S	04/29/97	229	2.3 J	< 2	55.4	< 1	< 1	3.1	1.7	1.9	3,540
Duplicate		183	3.1 J	< 2	54.2	< 1	< 1	2.7	1.3	1.4	3,170
MW -2S	05/01/97	138 J	3.7 J	9.9 J	70.9 J	< 1	5.6	1.3 J	113	< 1	15,100
Duplicate		140 J	4.0 J	7.9 J	71.4 J	< 1	5.8	1.1 J	116	< 1	15,000
MW-2XD	05/01/97	1,120 J	2.5 J	3.0 J	21.7 J	< 1	< 1	2.4 J	< 1	3.6 J	37,700
Duplicate		1,380 J	3.7 J	3.4 J	23.6 J	< 1	< 1	2.2 J	< 1	3 J	38,300
MW-10D	06/03/97	28.7 J	6.8 J	< 6	498	< 1	< 1	< 1	< 1	9.9	2,530
Duplicate		< 4	8.1 J	< 6	516	< 1	< 1	< 1	< 1	6.6 J	2,790
MW-11D	06/03/97	18.1 J	6.3 J	< 6	28.1	< 1	< 1	< 1	< 1	2.8 J	1,480
Duplicate		18.3	< 3	< 6	28.1	< 1	< 1	< 1	< 1	3	1,470

Table B2. Concentrations of minor elements in duplicate ground-water samples collected near Westville, Indiana, April–June 1997—Continued

Well	Date of sample collection	Lead (µg/L)	Manganese (µg/L)	Mercury (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
MW-4XD	04/29/97	< 1	160	<0.2	82.7	< 3 J	< 1	6.3 J	< 1	6.1
Duplicate		< 1	159	< .2 J	80.3	< 3	< 1	11.2 J	< 1	7.2 J
MW-9S	04/29/97	2	173	< .2	3.5	< 3 J	< 1	< 2	< 1	12.5
Duplicate		< 1	154	< .2	2.8	< 3 J	< 1	< 2	< 1	9.2
MW-2S	05/01/97	< 1	3,500	< .2 J	182	< 3	< 1	.5 J	1.9	503 J
Duplicate		< 1	3,580	< .2	185	< 3	< 1	6.4 J	1.8	515 J
MW-2XD	05/01/97	< 1	434	< .2 J	5.2	< 3	< 1	5.8 J	3.1	41.5 J
Duplicate		< 1	443	< .2 J	5.5	< 3	< 1	5.2 J	2.9	10.0 J
MW-10D	06/03/97	< 2	56.5	< .2	3.6	< 4	< 1	< 5	< 1	< 3
Duplicate		< 2	58.5	< .2	3	< 4	< 1	< 5	< 1	< 3
MW-11D	06/03/97	< 2	90.4	< .2	1.5	< 4	< 1	< 5	< 1	< 3
Duplicate		< 2	90.3	< .2	1.5	< 4	< 1	< 5	< 1	< 3

Table B3. Concentrations of volatile organic compounds in duplicate ground-water samples collected near Westville, Indiana, April 1997 through May 1999

[Chemical Abstract Service (CAS) Registry Numbers are in parentheses in column header; µg/L, microgram per liter; <, less than; J, concentration is estimated, number given is below quantification limit]

Well	Date of sample collection	Chloro-methane (74-87-3) (µg/L)	Bromo-methane (74-83-9) (µg/L)	Vinyl chloride (75-01-4) (µg/L)	Chloroethane (75-00-3) (µg/L)	Methylene chloride (75-09-2) (µg/L)	Acetone (67-64-1) (µg/L)	Carbon disulfide (75-15-0) (µg/L)	1,1-Dichloro-ethene (75-35-4) (µg/L)	1,1-Dichloro-ethane (75-34-3) (µg/L)	1,2-Dichloro-ethene (total) (540-59-0) (µg/L)	Chloroform (67-66-3) (µg/L)
B-2	04/29/97	< 33 J	< 33	61	11 J	< 33	< 33	< 33	< 33	150	1,500	< 33
Duplicate		< 100 J	< 100	58 J	< 100	< 100	< 100	< 100	< 100	160	1,500	< 100
MW-4XD	04/29/97	< 10	< 10	< 10	< 10	< 10	6 J	< 10	<10	<10	<10	<10
Duplicate		< 10 J	< 10	< 10	< 10	< 10	< 10	<10	<10	< 10	<10	< 10
MW-9S	04/29/97	< 10 J	<10 J	<10 J	< 10 J	< 10 J	<10 J	<10 J	<10 J	<10 J	<10 J	<10 J
Duplicate		< 10 J	<10 J	<10 J	< 10 J	< 10 J	<10 J	<10 J	<10 J	<10 J	<10 J	<10 J
MW-2S	05/01/97	< 10 J	<10 J	<10 J	90 J	6 J	<10 J	<10 J	<10 J	<10 J	<10 J	<10 J
Duplicate		< 10 J	<10 J	<10 J	90 J	5 J	<10 J	<10 J	<10 J	<10 J	<10 J	<10 J
MW-2XD	05/01/97	< 10 J	<10 J	<10 J	< 10 J	< 10 J	<10 J	<10 J	<10 J	<10 J	<10 J	<10 J
Duplicate		< 10 J	<10 J	<10 J	< 10 J	< 10 J	<10 J	<10 J	<10 J	<10 J	<10 J	<10 J
EP-4	09/03/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1	< 1
Duplicate		< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1	< 1
PZ-3XD	09/03/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1	< 1
Duplicate		< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1	< 1

Table B3. Concentrations of volatile organic compounds in duplicate ground-water samples collected near Westville, Indiana, April 1997 through May 1999—Continued

Well	Date of sample collection	Chloro-methane (74-87-3) (μg/L)	Bromo-methane (74-83-9) (μg/L)	Vinyl chloride (75-01-4) (μg/L)	Chloroethane (75-00-3) (μg/L)	Methylene chloride (75-09-2) (μg/L)	Acetone (67-64-1) (μg/L)	Carbon disulfide (75-15-0) (μg/L)	1,1-Dichloro-ethene (75-35-4) (μg/L)	1,1-Dichloro-ethane (75-34-3) (μg/L)	1,2-Dichloro-ethene (total) (540-59-0) (μg/L)	Chloroform (67-66-3) (μg/L)
MW-10XD	09/08/93	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1	< 1
Duplicate		< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1	< 1
MW-15XD	12/09/97	< 1	< 1	< 1	< 1	< 1	< 3	< 2 J	< 1	< 1	< 1	< 1
Duplicate		< 1	< 1	< 1	< 1	< 1	< 3	< 2 J	< 1	< 1	< 1	< 1
MW-14D	12/10/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1	< 1
Duplicate		< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1	< 1
MW-17MD	12/16/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1	< 1
Duplicate		< 1	< 1	< 1	< 1	< 1	< 3	< 4 J	< 1	< 1	< 1	< 1
MW-2D	05/04/99	< 10	< 10	< 10	< 10	3 J	< 10	< 10	< 10	< 10	< 10	< 10
Duplicate		< 10	< 10	< 10	< 10	3 J	< 10	< 10	< 10	< 10	< 10	< 10
MW-7XD	05/03/99	< 10	< 10	< 10	< 10	3 J	< 10	< 10	< 10	< 10	< 10	< 10
Duplicate		< 10	< 10	< 10	< 10	3 J	< 10	< 10	< 10	< 10	< 10	< 10

Table B3. Concentrations of volatile organic compounds in duplicate ground-water samples collected near Westville, Indiana, April 1997 through May 1999—Continued

Well	Date of sample collection	1,2-Dichloro-ethane (107-06-2) (μg/L)	2-Butanone (78-93-3) (μg/L)	1,1,1-Trichloro-ethane (71-55-6) (μg/L)	Carbon tetrachloride (56-23-5) (μg/L)	Bromo-dichloro-methane (75-27-4) (μg/L)	1,2-Dichloro-propane (78-87-5) (μg/L)	cis-1,3-Dichloro-propene (10061-01-5) (μg/L)	Trichloro-ethene (79-01-6) (μg/L)	Dibromo-chloro-methane (124-48-1) (μg/L)	1,1,2-Trichloro-ethane (79-00-5) (μg/L)	Benzene (71-43-2) (μg/L)
B-2	04/29/97	< 33	< 33	< 33	< 33J	< 33	< 33	< 33	28 J	< 33	< 33	4 J
Duplicate		< 100	< 100	< 100	< 100	< 100	< 100	< 100	29 J	< 100	< 100	< 100
MW-4XD	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Duplicate		< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-9S	04/29/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
Duplicate		< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
MW-2S	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	16 J
Duplicate		< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	16 J
MW-2XD	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
Duplicate		< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
EP-4	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Duplicate	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PZ-3XD	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Duplicate	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Table B3. Concentrations of volatile organic compounds in duplicate ground-water samples collected near Westville, Indiana, April 1997 through May 1999—Continued

Well	Date of sample collection	1,2-Dichloro-ethane (107-06-2) (μg/L)	2-Butanone (78-93-3) (μg/L)	1,1,1-Trichloro-ethane (71-55-6) (μg/L)	Carbon tetrachloride (56-23-5) (μg/L)	Bromo-dichloro-methane (75-27-4) (μg/L)	1,2-Dichloro-propane (78-87-5) (μg/L)	cis-1,3-Dichloro-propene (10061-01-5) (μg/L)	Trichloro-ethene (79-01-6) (μg/L)	Dibromo-chloro-methane (124-48-1) (μg/L)	1,1,2-Trichloro-ethane (79-00-5) (μg/L)	Benzene (71-43-2) (μg/L)
MW-10XD	09/08/93	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Duplicate	09/08/93	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-15XD	12/09/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Duplicate	12/09/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-14D	12/10/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Duplicate	12/10/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-17MD	12/16/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Duplicate	12/16/97	< 1	< 3	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J
MW-7XD	05/03/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Duplicate	05/03/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-2D	05/04/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Duplicate	05/04/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10

Table B3. Concentrations of volatile organic compounds in duplicate ground-water samples collected near Westville, Indiana, April 1997 through May 1999—Continued

Well	Date of sample collection	trans-1,3-Dichloro-propene (10061-02-6) (μg/L)	Bromoform (75-25-2) (μg/L)	4-Methyl-2-pentanone (108-10-1) (μg/L)	2-Hexanone (591-78-6) (μg/L)	Tetrachloro-ethene (127-18-4) (μg/L)	1,1,2,2-Tetrachloro-ethane (79-34-5) (μg/L)	Toluene (108-88-3) (μg/L)	Chloro-benzene (108-90-7) (μg/L)	Ethyl benzene (100-41-4) (μg/L)	Styrene (100-42-5) (μg/L)	Xylene (total) (1330-20-7) (μg/L)
B-2	04/29/97	< 33	< 33	< 33	< 33J	26 J	< 33	< 33	< 33	< 33	< 33	< 33
Duplicate		< 100	< 100	< 100	< 100	24 J	< 100	< 100	< 100	< 100	< 100	< 100
MW-4XD	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Duplicate		< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-9S	04/29/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
Duplicate		< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
MW-2S	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	1 J	< 10 J	< 10 J	< 10 J	< 10 J
Duplicate		< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	1 J	< 10 J	< 10 J	< 10 J	< 10 J
MW-2XD	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
Duplicate		< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	1 J	< 10 J	< 10 J	< 10 J	< 10 J
EP-4	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Duplicate	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Table B3. Concentrations of volatile organic compounds in duplicate ground-water samples collected near Westville, Indiana, April 1997 through May 1999—Continued

Well	Date of sample collection	trans-1,3-Dichloro-propene (10061-02-6) (μg/L)	Bromoform (75-25-2) (μg/L)	4-Methyl-2-pentanone (108-10-1) (μg/L)	2-Hexanone (591-78-6) (μg/L)	Tetrachloro-ethene (127-18-4) (μg/L)	1,1,2,2-Tetrachloro-ethane (79-34-5) (μg/L)	Toluene (108-88-3) (μg/L)	Chloro-benzene (108-90-7) (μg/L)	Ethyl benzene (100-41-4) (μg/L)	Styrene (100-42-5) (μg/L)	Xylene (total) (1330-20-7) (μg/L)
PZ-3XD	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Duplicate	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-10XD	09/08/93	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-10XD D	09/08/93	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-15XD	12/09/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-15XD D	12/09/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-14D	12/10/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-14D D	12/10/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-17MD	12/16/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Duplicate	12/16/97	< 1 J	< 1 J	< 2 J	< 2 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J
MW-7XD	05/03/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Duplicate	05/03/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-2D	05/04/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Duplicate	05/04/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10

Table B4. Concentrations of 1,4-dioxane in duplicate groundwater samples collected near Westville, Indiana, April 1997 through May 1999

[Chemical Abstract Service (CAS) Registry Numbers are in parentheses in column header; µg/L, microgram per liter; <, less than; D, concentration determined after dilution; J, concentration is estimated, number given is below quantification limit; E, concentration is estimated, sample required dilution to increase accuracy]

Well	Date of sample collection	1,4-Dioxane (123-91-1) (µg/L)
MW-4XD	04/29/97	3,800 E
Duplicate		5,500 E
EP-4	09/03/97	< 5
Duplicate		< 5
PZ-3XD	09/03/97	< 5
Duplicate		< 5
MW-10XD	09/08/97	6
Duplicate		6
MW-15XD	12/09/97	318 D
Duplicate		305 D
MW-14D	12/10/97	13
Duplicate		11
MW-17MD	12/16/97	< 5
Duplicate		< 5
MW-2D	05/04/99	8,800 D
Duplicate		11,000 D
MW-7XD	05/03/99	< 5
Duplicate		< 5
MW-10XD	05/07/99	5 J
Duplicate		5 J
MW-14D	05/07/99	9
Duplicate		7

Table B5. Statistical summary of relative percent differences for analytes detected in duplicate ground-water samples collected near Westville, Indiana, April 1997 through May 1999

[RPD, relative percent difference; mg/L, milligram per liter; $CaCO_3$, calcium carbonate; J, concentration is estimated for at least one sample of the pair; --, insufficient data; E, concentration is estimated for at least one sample of the pair, sample required dilution to increase accuracy]

Analyte	Number of sample pairs	Minimum RPD	Maximum RPD	Median RPD	Number of sample pairs exceeding 25 RPD
Common constituents					
Bicarbonate alkalinity	4	1.9	7.1	2.0	0
Hardness (mg/L as $CaCo_3$)	4	0	68.2	12.2	1
Calcium	6	.12	10.9	1.9 J	0
Chloride	2	3.9	9.8	6.85	0
Magnesium	6	.29	9.6	1.14	0
Potassium	6	.89	5.5 J	2.6 J	0
Sodium	6	.25 J	11.4 J	2.2 J	0
Sulfate	1	--	--	10.0	0
Total organic carbon	1	--	--	0	0
Minor elements					
Aluminum	4	1.1 J	22.3	11.1 J	0
Antimony	5	0 J	38.7 J	17.4 J	2
Arsenic	3	12.5 J	35.1 J	22.5 J	1
Barium	6	0	8.4 J	2.9	0
Cadmium	1	--	--	3.5	0
Chromium	3	8.7 J	16.7 J	13.8	0
Cobalt	2	2.6	26.7	14.65	1
Copper	5	6.9 J	40.0 J	28.6 J	3
Iron	6	.66	11.0	1.7	0
Manganese	6	.63	11.6	2.85	0
Nickel	6	0	22.2	4.25	0
Thallium	3	10.9 J	171 J	56.0 J	2
Vanadium	2	5.4	6.7	6.05	0
Zinc	4	2.4 J	122 J	23.45 J	2

Table B5. Statistical summary of relative percent differences for analytes detected in duplicate ground-water samples collected near Westville, Indiana, April 1997 through May 1999—Continued

Analyte	Number of sample pairs	Minimum RPD	Maximum RPD	Median RPD	Number of sample pairs exceeding 25 RPD
Organic compounds					
Vinyl chloride	1	--	--	5.0 J	0
Chloroethane	1	--	--	0 J	0
Methylene chloride	3	0 J	18.2 J	0 J	0
1,1-Dichloroethane	1	--	--	6.4	0
1,2-Dichloroethene	1	--	--	0	0
Trichloroethene	1	--	--	3.5 J	0
Benzene	1	--	--	0 J	0
Tetrachloroethene	1	--	--	8.0 J	0
Toluene	1	--	--	0 J	0
1,4-dioxane	7	0	36.6 E	16.7	1

Table B6. Concentrations of water-quality constituents in equipment-rinse samples collected near Westville, Indiana, April through December 1997

[mg/L, milligram per liter; µg/L, microgram per liter; <, less than; --, not sampled; J, concentration is estimated]

Sample	Date of sample collection	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)
EQUIP 1 F	06/03/97	0.162	0.012	0.011	0.069
EQUIP 2	05/01/97	32.2	10.3	1.16 J	6.51 J
EQUIP 3K	05/01/97	.202	.079	.076 J	4.79 J

Sample	Date of sample collection	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)
EQUIP 1F	06/03/97	12.4 J	< 3	< 6	< 1	< 1	< 1	< 1	< 1	< 1	< 15
EQUIP 2	05/01/97	66.6 J	< 2	< 2	17.5	< 1	< 1	< 1	1	11	10.3
EQUIP 3K	05/01/97	25.2	< 2	< 2	< 1	< 1	< 1	1.7	< 1	< 1	< 9

Sample	Date of sample collection	Lead (µg/L)	Manganese (µg/L)	Mercury (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
EQUIP 1F	06/03/97	< 2	< 1	< 0.2	< 1	< 4	< 1	< 5	< 1	< 3
EQUIP 2	05/01/97	< 1	< 1	< .2 J	< 1	< 3	< 1	2.8 J	< 1	7.6 J
EQUIP 3K	05/01/97	< 1	< 1	< .2	< 1	< 3	< 1	2.7 J	< 1	5.9 J

Table B6. Concentrations of water-quality constituents in equipment-rinse samples collected near Westville, Indiana, April through December 1997—Continued

Sample	Date of sample collection	Chloro-methane (74-87-3) (µg/L)	Bromo-methane (74-83-9) (µg/L)	Vinyl chloride (75-01-4) (µg/L)	Chloro-ethane (75-00-3) (µg/L)	Methylene chloride (75-09-2) (µg/L)	Acetone (67-64-1) (µg/L)	Carbon disulfide (75-15-0) (µg/L)	1,1-Dichloro-ethene (75-35-4) (µg/L)	1,1-Dichloro-ethane (75-34-3) (µg/L)	1,2-Dichloro-ethene (total) (540-59-0) (µg/L)	Chloroform (67-66-3) (µg/L)
SW-method1	05/03/97	< 10	< 10	< 10	< 10	< 10	< 10 J	< 10	< 10	< 10	< 10	< 10
SW-method2	05/30/97	< 10 J	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
BAILER 1	08/97	< 1	< 1	< 1	< 1	< 2	18	< 1	< 1	< 1	< 1	< 1
PUMP 1	09/03/97	< 1	< 1	< 1	< 1	< 2	15	< 1	< 1	< 1	< 1	< 1
PUMP 2	09/04/97	< 1	< 1	< 1	< 1	< 2	15	< 1	< 1	< 1	< 1	< 1
PUMP 1	12/08/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1	< 1
PUMP 2	12/11/97	< 1	< 1	< 1	< 1	< 1	49	< 3 J	< 1	< 1	< 1	< 1
PUMP 3	12/11/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1	< 1
BAILER 1	12/12/97	< 1	< 1	< 1	< 1	< 1	< 3	< 2 J	< 1	< 1	< 1	< 1
PUMP 4	12/15/97	< 1	< 1	< 1	< 1	< 1	< 3	< 4 J	< 1	< 1	< 1	< 1

Table B6. Concentrations of water-quality constituents in equipment-rinse samples collected near Westville, Indiana, April through December 1997—Continued

Sample	Date of sample collection	1,2-Dichloro-ethane (107-06-2) (μg/L)	2-Butanone (78-93-3) (μg/L)	1,1,1-Trichloro-ethane (71-55-6) (μg/L)	Carbon tetrachloride (56-23-5) (μg/L)	Bromo-dichloro-methane (75-27-4) (μg/L)	1,2-Dichloro-propane (78-87-5) (μg/L)	cis-1,3-Dichloro-propene (10061-01-5) (μg/L)	Trichloro-ethene (79-01-6) (μg/L)	Dibromo-chloro-methane (124-48-1) (μg/L)	1,1,2-Trichloro-ethane (79-00-5) (μg/L)	Benzene (71-43-2) (μg/L)
SW-method1	05/03/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
SW-method2	05/30/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
BAILER 1	08/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PUMP 1	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PUMP 2	09/04/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PUMP 1	12/08/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PUMP 2	12/11/97	< 1	10	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PUMP 3	12/11/97	< 1	< 3	< 1	< 1	6	< 1	< 1	< 1	3	< 1	< 1
BAILER 1	12/12/97	< 1	< 3	< 1	< 1	4	< 1	< 1	< 1	3	< 1	< 1
PUMP 4	12/15/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Table B6. Concentrations of water-quality constituents in equipment-rinse samples collected near Westville, Indiana, April through December 1997—Continued

Sample	Date of sample collection	trans-1,3-Dichloro-propene (10061-02-6) (μg/L)	Bromoform (75-25-2) (μg/L)	4-Methyl-2-pentanone (108-10-1) (μg/L)	2-Hexanone (591-78-6) (μg/L)	Tetrachloro-ethene (127-18-4) (μg/L)	1,1,2,2-Tetrachloro-ethane (79-34-5) (μg/L)	Toluene (108-88-3) (μg/L)	Chloro-benzene (108-90-7) (μg/L)	Ethyl benzene (100-41-4) (μg/L)	Styrene (100-42-5) (μg/L)	Xylene (total) (1330-20-7) (μg/L)
SW-method 1	05/03/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
SW-method2	05/30/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
BAILER 1	08/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PUMP 1	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PUMP 2	09/04/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PUMP 1	12/08/97	< 1	< 1	< 2	< 2	< 1	< 1	.5 J	< 1	< 1	< 1	< 1
PUMP 2	12/11/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PUMP 3	12/11/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
BAILER 1	12/12/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PUMP 4	12/15/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Table B7. Concentrations of volatile organic compounds in trip-blank samples collected near Westville, Indiana, April through December 1997

[Chemical Abstract Service (CAS) Registry Numbers are in parentheses in column header; µg/L, microgram per liter; <, less than; J, concentration is estimated, number given is below quantification limit]

Sample	Date of sample collection	Chloro-methane (74-87-3) (µg/L)	Bromo-methane (74-83-9) (µg/L)	Vinyl chloride (75-01-4) (µg/L)	Chloro-ethane (75-00-3) (µg/L)	Methylene chloride (75-09-2) (µg/L)	Acetone (67-64-1) (µg/L)	Carbon disulfide (75-15-0) (µg/L)	1,1-Dichloro-ethene (75-35-4) (µg/L)	1,1-Dichloro-ethane (75-34-3) (µg/L)	1,2-Dichloro-ethene (total) (540-59-0) (µg/L)	Chloroform (67-66-3) (µg/L)
TRP BLK 1	05/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	10	< 10	3 J
TRP BLK 2	05/01/97	< 10 J	< 10	< 10 J	< 10	< 10	< 10 J	< 10	< 10	10	< 10	2 J
TRP BLK 3	05/29/97	<10	<10	<10	<10	<10	< 10 J	<10	<10	<10	<10	3 J
TRP BLK 1	09/02/97	<1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1	< 1
TRP BLK 2	09/03/97	<1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1	< 1
TRP BLK 3	09/04/97	<1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1	< 1
TRP BLK 4	09/08/97	<1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1	< 1
TRP BLK 1	12/09/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1	< 1
TRP BLK 2	12/10/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1	< 1
TRP BLK 3	12/15/97	< 1	< 1	< 1	< 1	< 1	< 3	< 2 J	< 1	< 1	< 1	< 1

Table B7. Concentrations of volatile organic compounds in trip-blank samples collected near Westville, Indiana, April through December 1997—Continued

Sample	Date of sample collection	1,2-Dichloro-ethane (107-06-2) (μg/L)	2-Butanone (78-93-3) (μg/L)	1,1,1-Trichloro-ethane (71-55-6) (μg/L)	Carbon tetrachloride (56-23-5) (μg/L)	Bromo-dichloro-methane (75-27-4) (μg/L)	1,2-Dichloro-propane (78-87-5) (μg/L)	cis-1,3-Dichloro-propene (10061-01-5) (μg/L)	Trichloro-ethene (79-01-6) (μg/L)	Dibromo-chloro-methane (124-48-1) (μg/L)	1,1,2-Trichloro-ethane (79-00-5) (μg/L)	Benzene (71-43-2) (μg/L)
TRP BLK 1	05/29/97	<10	<10	<10	<10	<10	< 10	<10	<10	<10	<10	<10
TRP BLK 2	05/01/97	< 10 J	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
TRP BLK 3	05/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
TRP BLK 1	09/02/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
TRP BLK 2	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
TRP BLK 3	09/04/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
TRP BLK 4	09/08/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
TRP BLK 1	12/09/97	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
TRP BLK 2	12/10/97	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
TRP BLK 3	12/15/97	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Table B7. Concentrations of volatile organic compounds in trip-blank samples collected near Westville, Indiana, April through December 1997—Continued

Sample	Date of sample collection	trans-1,3-Dichloro-propene (10061-02-6) (μg/L)	Bromoform (75-25-2) (μg/L)	4-Methyl-2-pentanone (108-10-1) (μg/L)	2-Hexanone (591-78-6) (μg/L)	Tetrachloro-ethene (127-18-4) (μg/L)	1,1,2,2-Tetrachloro-ethane (79-34-5) (μg/L)	Toluene (108-88-3) (μg/L)	Chloro-benzene (108-90-7) (μg/L)	Ethyl benzene (100-41-4) (μg/L)	Styrene (100-42-5) (μg/L)	Xylene (total) (1330-20-7) (μg/L)
TRP BLK 1	05/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
TRP BLK 2	05/01/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
TRP BLK 3	05/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
TRP BLK 1	09/02/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
TRP BLK 2	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
TRP BLK 3	09/04/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
TRP BLK 4	09/08/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
TRP BLK 1	12/09/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
TRP BLK 2	12/10/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
TRP BLK 3	12/15/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Appendix C.
Water Quality

Table C1. On-site measurements of ground-water samples collected near Westville, Indiana, April 1997 through May 1999

[°C, degree Celsius; mv, millivolt; mg/L, milligram per liter; µS/cm, microsiemen per centimeter at 25°C; ntu, nephelometric turbidity unit; --, not measured; <, less than]

Well	Date of sample collection	Temperature (°C)	pH (units)	Oxidation-reduction potential (mv)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Turbidity (ntu)
B-1	04/29/97	12.2	7.10	-35	4.0	1,030	1.2
	09/05/97	11.9	7.11	-55	.10	973	.7
B-2	04/29/97	12.3	6.75	-28	6.1	1,110	3.1
	09/09/97	12.6	6.60	-46	.13	1,320	1.7
B-4	05/01/97	10.2	6.36	-50	.20	1,430	6.8
	09/08/97	11.1	6.48	-76	.38	1,080	--
	12/11/97	10.5	6.38	-6	.14	923	2
	05/04/99	11.0	6.65	161	.16	890	1
EP-1	04/29/97	10.8	7.72	146	7.3	554	100
	09/03/97	10.8	7.51	319	7.4	501	45
EP-2	04/28/97	10.9	6.96	290	6.2	799	15
	09/02/97	10.7	6.66	155	.35	677	65
	12/08/97	10.5	6.68	337	.13	705	--
EP-3	09/02/97	10.8	7.26	30	4.1	795	--
	12/08/97	10.5	7.35	330	3.04	819	--
EP-4	04/30/97	13.0	7.03	--	5.6	855	146
	09/03/97	11.9	6.88	278	6.3	761	23
	12/10/97	11.7	6.69	377	4.6	792	1.1
LP-1	09/02/97	11.1	6.95	188	8.5	678	0
LP-2	04/30/97	10.8	7.02	--	2.4	684	90
	09/03/97	11.0	6.78	341	2.8	633	2.2
	12/10/97	10.9	6.78	374	2.8	681	.2
LP-3	04/30/97	10.3	7.35	> 200	.50	647	175
	09/03/97	11.8	7.10	103	.52	630	14
	12/10/97	11.4	6.95	332	1.5	657	2.3

Table C1. On-site measurements of ground-water samples collected near Westville, Indiana, April 1997 through May 1999—Continued

Well	Date of sample collection	Temperature (°C)	pH (units)	Oxidation-reduction potential (mv)	Dissolved oxygen (mg/L)	Specific conductance (μS/cm)	Turbidity (ntu)
MW-1S	05/01/97	11.0	7.01	--	0.16	756	6.5
	09/09/97	13.2	6.80	-65	.08	960	2
	12/10/97	12.6	6.69	104	1.5	928	.3
	05/05/99	12.4	6.91	207	.05	829	1
MW-1D	04/30/97	12.2	7.45	-129	.75	1,160	.4
	09/09/97	12.2	7.28	-118	.07	848	.6
	12/10/97	10.9	7.08	16	.76	708	--
	05/04/99	12.1	6.92	--	.08	1,100	--
MW-2S	05/01/97	11.0	6.24	33	.16	1,010	5
	09/09/97	11.8	6.20	-32	.08	1,160	1.8
	12/15/97	11.8	6.33	-43	.18	952	0
	05/03/99	11.3	6.22	240	.11	630	2.7
MW-2D	05/01/97	12.7	6.78	-100	.08	1,450	1.2
	09/09/97	13.0	6.81	-120	.05	1,310	1.9
	12/15/97	12.4	6.69	-196	.17	1,280	.6
	05/03/99	12.9	6.93	111	.05	1,010	3.2
MW-2MD	05/01/97	12.4	7.28	-145	.30	509	.4
	09/08/97	12.8	7.50	-189	.05	528	--
	12/12/97	12.0	7.07	-157	.08	510	--
	05/05/99	13.8	7.10	109	.19	481	--
MW-2XD	05/01/97	12.2	6.15	--	.08	3,640	.2
	09/08/97	12.7	6.22	-61	.05	3,450	--
	12/12/97	12.0	6.01	-115	.12	3,630	--
	05/05/99	12.4	6.16	193	.67	3,780	1
MW-3S	05/01/97	10.9	7.02	13	2.1	1,480	2.9
	09/08/97	12.1	6.56	-56	.45	1,260	--
	05/04/99	11.4	6.44	203	3.2	1,630	1

Table C1. On-site measurements of ground-water samples collected near Westville, Indiana, April 1997 through May 1999—Continued

Well	Date of sample collection	Temp-erature (°C)	pH (units)	Oxidation-reduction potential (mv)	Dissolved oxygen (mg/L)	Specific conductance (μS/cm)	Turbidity (ntu)
MW-3D	05/01/97	14.8	7.22	-66	3.5	1,320	8.3
	09/08/97	14.0	7.02	-68	4.7	1,100	--
	05/04/99	16.6	6.88	193	5.8	1,500	3
MW-4S	04/29/97	9.1	7.38	334	--	800	5.4
	09/05/97	15.8	6.77	242	.08	842	--
	12/15/97	12.4	6.82	202	1.1	863	2.4
MW-4D	04/29/97	12.9	7.07	-109	--	1,770	.4
	09/04/97	12.0	6.60	-103	.05	2,210	.15
	12/12/97	11.2	6.68	-317	.06	2,330	.1
MW-4XD	04/29/97	13.1	6.28	-57	--	2,900	1.2
	09/05/97	12.9	6.15	-45	.1	3,510	--
	12/12/97	11.3	5.96	-226	.09	3,720	.9
MW-5S	04/30/97	10.3	6.89	227	3.0	439	10
	09/04/97	12.8	6.14	298	.82	351	1.6
	12/09/97	11.7	6.39	259	.45	533	1
MW-5D	04/30/97	11.9	7.68	35	1.5	820	.2
	09/04/97	12.0	7.12	72	.05	693	.2
	12/09/97	11.2	7.24	18	.04	680	1
MW-5XD	04/30/97	11.5	7.5	72	1.7	458	.1
	09/04/97	11.7	7.18	73	.04	448	.3
	12/09/97	11.2	7.33	329	.04	476	1
MW-6S	05/01/97	9.1	6.75	-120	1.4	630	163
	09/09/97	13.4	6.66	-140	.12	652	--
	05/05/99	10.4	6.50	135	.07	812	4
MW-6D	05/01/97	12.0	7.36	-83	1.0	1,290	1.0
	09/09/97	12.3	7.15	-117	.08	1,350	15
	12/11/97	11.4	6.86	-83	1.8	1,250	.2
	05/05/99	12.4	6.82	185	.16	1,810	--

Table C1. On-site measurements of ground-water samples collected near Westville, Indiana, April 1997 through May 1999—Continued

Well	Date of sample collection	Temperature (°C)	pH (units)	Oxidation-reduction potential (mv)	Dissolved oxygen (mg/L)	Specific conductance (μS/cm)	Turbidity (ntu)
MW-7S	04/28/97	12.7	7.57	98	9.2	565	3.9
	09/02/97	11.7	6.97	372	8.0	504	3.1
	12/09/97	10.4	7.19	419	7.0	557	.3
	05/03/99	11.7	6.88	728	6.5	652	.7
MW-7D	04/28/97	11.8	7.80	-85	2.6	602	.9
	09/02/97	11.9	7.08	-98	.05	520	.35
	12/08/97	10.4	7.42	-109	.07	593	--
	05/03/99	11.1	7.06	162	.57	605	.2
MW-7XD	05/01/97	10.7	7.90	-89	1.8	515	15
	09/02/97	12.0	7.13	-155	.04	437	.42
	12/08/97	10.0	7.42	-167	.07	481	0
	05/03/99	8.5	7.24	107	.14	541	.2
MW-8S	04/29/97	9.8	7.48	-206	--	970	8
	09/09/97	17.5	7.27	-148	.08	806	12
	12/10/97	12.3	7.24	5	.11	738	1.1
MW-8D	04/29/97	12.2	7.03	--	.18	1,640	3.5
	09/09/97	12.2	6.88	-141	.08	1,600	.8
	12/10/97	11.1	6.65	7	.12	1,510	0
MW-9S	04/29/97	11.1	7.36	--	.19	778	< 1
	09/03/97	13.0	7.28	-43	.36	491	113
	12/09/97	11.6	7.38	-92	.26	475	--
MW-9XD	04/29/97	11.8	7.55	--	.04	330	16
	09/03/97	11.6	7.55	-156	.07	523	1.8
	12/09/97	11.3	7.54	-153	.05	504	2
MW-10S	06/03/97	10.8	7.02	-1	1.2	1,620	--
	09/08/97	15.4	6.95	-145	.05	1,520	7.1
	12/09/97	11.0	6.91	-70	.10	1,240	13
	05/10/99	11.6	6.84	200	1.8	2,040	4

Table C1. On-site measurements of ground-water samples collected near Westville, Indiana, April 1997 through May 1999—Continued

Well	Date of sample collection	Temp-erature (°C)	pH (units)	Oxidation-reduction potential (mv)	Dissolved oxygen (mg/L)	Specific conductance (μS/cm)	Turbidity (ntu)
MW-10XD	06/03/97	11.9	7.43	-128	0.05	1,530	2.6
	09/08/97	12.6	7.25	-217	.04	1,410	.4
	12/09/97	11.1	7.18	-139	.04	1,580	--
	05/10/99	12.7	7.14	106	.07	1,950	--
MW-11S	06/03/97	10.0	7.03	157	7.6	1,010	10
	09/04/97	11.5	6.81	111	.78	908	34
	12/09/97	10.9	6.77	250	5.0	921	2.1
MW-11D	06/03/97	11.1	7.22	-74	.09	729	1.8
	09/04/97	11.1	7.03	-96	.07	720	0
	12/09/97	10.2	7.00	-147	.09	696	0
MW-11XD	06/03/97	11.2	7.68	-157	.06	496	4.2
	09/04/97	11.4	7.47	-169	.14	504	.4
	12/09/97	10.4	7.44	-222	.07	484	0
MW-12	09/10/97	10.7	5.52	181	.62	503	--
	12/11/97	9.4	5.68	568	.70	393	--
MW-13S	12/10/97	10.6	6.95	109	.34	560	7
MW-13D	12/10/97	10.4	7.14	-102	.04	575	0
MW-13XD	12/10/97	10.9	6.91	-122	.04	1,650	3
MW-14S	12/11/97	10.6	4.77	52	.14	528	12
	05/07/99	10.5	7.20	291	.03	570	1
MW-14D	12/10/97	10.9	6.88	-117	.05	1,820	10
	05/07/99	11.9	6.67	160	.04	2,160	1
MW-14XD	12/10/97	10.9	5.83	-70	.08	4,750	1
	05/07/99	11.7	5.83	202	.16	5,770	0
MW-15S	12/09/97	12.0	6.86	34	4.2	997	14
	05/07/99	11.3	6.93	182	.34	1,740	10
MW-15MD	12/09/97	10.8	6.76	-122	.06	1,810	0
	05/07/99	14.1	6.96	144	.07	2,150	4

Table C1. On-site measurements of ground-water samples collected near Westville, Indiana, April 1997 through May 1999—Continued

Well	Date of sample collection	Temp-erature (°C)	pH (units)	Oxidation-reduction potential (mv)	Dissolved oxygen (mg/L)	Specific conductance (μS/cm)	Turbidity (ntu)
MW-15XD	12/09/97	10.9	6.68	-154	1.82	2,740	0.1
	05/07/99	11.6	6.60	167	.10	3,870	2.1
MW-16S	12/11/97	10.5	6.67	32	5.7	1,190	15
	05/06/99	9.5	6.78	216	.15	2,570	0
MW-16D	12/11/97	10.9	6.78	-20	.12	763	1.5
	05/06/99	11.6	7.01	163	.28	941	1
MW-16XD	12/11/97	10.9	7.15	-223	.07	625	0
	5/06/99	11.1	7.33	107	.11	820	0
MW-17MD	12/16/97	11.1	7.05	-231	.08	901	0
	05/06/99	11.4	7.08	143	1.1	1,020	--
MW-17XD	12/16/97	10.9	7.22	-230	.10	992	0
	05/06/99	11.7	7.30	106	.05	1,020	1
MW-18S	12/11/97	11.0	6.89	300	.13	567	3.8
	05/11/99	9.8	7.16	686	2.7	686	5
MW-18XD	12/11/97	10.9	7.10	-21	.44	371	0
	05/11/99	11.6	7.36	108	.12	463	0
PZ-1S	09/03/97	11.4	6.93	343	9.3	555	1.1
PZ-1MD	09/03/97	11.9	7.12	-132	.05	384	.4
PZ-1XD	09/03/97	11.8	7.07	-113	.04	410	.3
PZ-3S	09/03/97	11.5	7.11	348	9.1	493	1.1
PZ-3MD	09/04/97	11.7	7.09	-133	.04	500	4.0
PZ-3XD	09/03/97	11.9	7.10	-118	.04	400	.4
MUN-1	09/03/97	11.8	8.23	103	.05	588	--
	12/16/97	--	--	--	--	--	--
	05/06/99	--	--	--	--	--	--
WP-P	12/11/97	9.4	4.42	90	2.1	524	--
WP-2	12/11/97	10.8	4.48	51	1.5	849	--
WP-3	12/11/97	10.4	4.43	74	10.4	784	--

Table C2. Concentrations of common constituents in ground-water samples collected near Westville, Indiana, April–June 1997

[mg/L, milligram per liter; $CaCO_3$, Calcium carbonate; -- not sampled; J, concentration is estimated; <, less than; >, greater than]

Well	Date of sample collection	Bi-carbonate alkalinity (mg/L)	Ammonia as nitrogen (mg/L)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	Total Kjeldahl nitrogen (mg/L)	Total organic carbon (percent)
B-1	04/29/97	388	--	388	98.9	72	29.0	1.8 J	64.6 J	12	--	--
B-2	04/29/97	282	--	506	137	--	36.6	1.29 J	24.8 J	--	--	--
B-4	05/01/97	522	--	655	181	52	43.1	6.15 J	22.5 J	305	--	43
EP-1	04/29/97	136	--	258	71.2 J	32	25.6 J	.621 J	2.24 J	4	--	--
EP-2	04/28/97	278	--	280	114	30	30.0	1.34 J	7.55 J	60	--	--
EP-4	04/30/97	--	< .05	248	107 J	26	37.7 J	19.2 J	11.6 J	40	< .1	< 3
LP-2	04/30/97	168	--	320	70.3	56	29.8	1.56 J	17.2 J	30	--	--
LP-3	04/30/97	246	--	312	80.6 J	15	33.8 J	3.68 J	10.6 J	84	--	--
MW-1S	05/01/97	316	< .05	386	91.4	34	34.0	6.74 J	15.4 J	38	< .1	5
MW-1D	04/30/97	265	< .05	328	75.0 J	184	25.5 J	1.71 J	94.3 J	104	< .1	3.1
MW-2S	05/01/97	340	--	420	111 J	56	27.5 J	5.46 J	33.5 J	140	--	46
MW-2D	05/01/97	650	.48	290	145	144	26.7	2.62 J	97.2 J	5	2.02	55
MW-2MD	05/01/97	250	< .05	294	73.8 J	23	21.4 J	.996 J	8.37 J	38	< .1	4.3
MW-2XD	05/01/97	852	2.7	2,360	522	> 132	212	19.5 J	36.5 J	> 375	4.65	--
MW-3S	05/01/97	580	2.73	> 820	204	66	66.6	3.31 J	18.7 J	265	3.69	15
MW-3D	05/01/97	446	1.76	578	154 J	100	66.9	4.40 J	26.2 J	252	2.26	14
MW-4S	04/29/97	301	--	470	96.6	62	40.4	2.10 J	21.8 J	72	--	--
MW-4D	04/29/97	466	--	876	214	790	82.7	2.30 J	86.4 J	8	--	--
MW-4XD	04/29/97	1,080	2.7	2,620	512	> 260	228	3.24 J	42.1 J	> 375	4.44	15

Table C2. Concentrations of common constituents in ground-water samples collected near Westville, Indiana, April–June 1997—Continued

Well	Date of sample collection	Bi-carbonate alkalinity (mg/L)	Ammonia as nitrogen (mg/L)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	Total Kjeldahl nitrogen (mg/L)	Total organic carbon (percent)
MW-5S	04/30/97	123	--	212	51.6	44	17.9	3.17 J	9.83 J	60	--	--
MW-5D	04/30/97	280	--	472	107	66	379	1.13 J	24.5 J	128	--	--
MW-5XD	04/30/97	--	--	286	71.3	< 20	23.3	.748 J	2.28 J	92	--	--
MW-6S	05/01/97	--	--	--	44.3	--	11.6	2.42 J	30.2 J	--	--	--
MW-6D	05/01/97	325	--	278	64.2	436	22.5	3.02 J	147 J	4	--	--
MW-7S	04/28/97	203	--	314	71.8	< 20	26.4	.865 J	3.09	32	--	--
MW-7D	04/28/97	183	--	358	81.3	16	30.9	.910 J	3.46 J	132	--	--
MW-7XD	05/01/97	245	< .05	298	66.8	< 10	24.8	.970 J	6.52 J	4	.86	< 3
MW-8S	04/29/97	--	--	272	116 J	88	30.0 J	4.49 J	29.6 J	0	--	--
MW-8D	04/29/97	375	--	652	169	380	578	2.44 J	64.9 J	0	--	--
MW-9S	04/29/97	232	--	236	99.8	58	30.0	1.69 J	13.9 J	76	--	--
MW-9XD	04/29/97	261	--	280	69.3	< 20	27.4	1.34 J	16.6 J	0	--	--
MW-10S	06/03/97	--	--	--	86.2	--	25.9	3.84	165 J	--	--	--
MW-10XD	06/03/97	--	--	--	139	--	58.3	2.63	52.2 J	--	--	--
MW-11S	06/03/97	--	--	--	129	--	54.4	3.51	38.0 J	--	--	--
MW-11D	06/03/97	--	--	--	86.8	--	34.4	.679	4.07 J	--	--	--
MW-11XD	06/03/97	--	--	--	59.0	--	23.8	.866	10.1 J	--	--	--

Table C3. Concentrations of minor elements in ground-water samples collected near Westville, Indiana, April–June 1997

[µg/L, microgram per liter; <, less than; J, concentration is estimated]

Well	Date of sample collection	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)
B-1	04/29/97	< 9	3 J	4.2	45.2	< 1	< 1	< 1	1.4	< 1	3,510
B-2	04/29/97	< 9	3.4 J	6	49.3	< 1	< 1	< 1	9.9	4.4	4,640
B-4	05/01/97	13.7	5.0 J	20	115	< 1	< 1	1.3	3.3	< 1	29,600
EP-1	04/29/97	463 J	< 2	< 2	11.8 J	< 1	< 1	2.6 J	2.2 J	4.4 J	776
EP-2	04/28/97	185	2.6 J	< 2	45.5	< 1	< 1	1.2	14.2	3.9	477
EP-4	04/30/97	705 J	3.1 J	2.3 J	51.6 J	< 1	< 1	63.4	6.9	8.1 J	2,840
LP-2	04/30/97	343	3.5 J	2.1	18.8	< 1	< 1	2.7	2.2	2.5	1,290
LP-3	04/30/97	586 J	2.9 J	3.8 J	66.0 J	< 1	< 1	2.7 J	1.6 J	1.1 J	1,280
MW-1S	05/01/97	< 9	< 2	4.1	35.3	< 1	< 1	1.4	2.8	< 1	3,120
MW-1D	04/30/97	16.3 J	2.2 J	2.6 J	49.3 J	< 1	< 1	< 1	< 1	3.2 J	1,660
MW -2S	05/01/97	138 J	3.7 J	9.9 J	70.9 J	< 1	5.6	1.3 J	113	< 1	15,100
MW-2D	05/01/97	102	9.1 J	< 2	68.9	< 1	< 1	2.4	< 1	2.7	18,300
MW-2MD	05/01/97	23.6 J	2.1 J	6.1 J	30.8 J	< 1	< 1	< 1	< 1	< 1	6,480
MW-2XD	05/01/97	1,120 J	2.5 J	3.0 J	21.7 J	< 1	< 1	2.4 J	< 1	3.6 J	37,700
MW-3S	05/01/97	33.5 J	2.4 J	10.3 J	66.4 J	< 1	< 1	< 1	9.9	7.5 J	15,700
MW-3D	05/01/97	35.2 J	2.5 J	3.1 J	51 J	< 1	< 1	2.4 J	1.9 J	24.7 J	5,730
MW-4S	04/29/97	< 9	2.7 J	4.5	82.8	< 1	< 1	< 1	1.6	2	185
MW-4D	04/29/97	< 9	3.3 J	7.9	186	< 1	< 1	< 1	1.5	< 1	10,400
MW-4XD	04/29/97	< 9	4.0 J	5.4	21.1	< 1	< 1	1.5	< 1	2	65,100

Table C3. Concentrations of minor elements in ground-water samples collected near Westville, Indiana, April–June 1997—Continued

Well	Date of sample collection	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)
MW-5S	04/30/97	328	2.3 J	< 2	54.4	< 1	< 1	2.1	3.7	10.9	1,120
MW-5D	04/30/97	< 9	< 2	5.2	42.7	< 1	< 1	< 1	2.8	2.8	430
MW-5XD	04/30/97	< 9	< 2	< 2	29.0	< 1	< 1	< 1	2.2	1.2	66.8
MW-6S	05/01/97	9.3	2.1 J	29.4	81.5	< 1	< 1	< 1	3.1	2.8	69,300
MW-6D	05/01/97	< 9	< 2	4.3	97.6	< 1	< 1	1.3	3.3	< 1	29,600
MW-7S	04/28/97	9 J	< 2	< 2	14.5	1.4 J	< 1	1.4	1.7 J	1.9	31.5 J
MW-7D	04/28/97	< 9	< 2	< 2	13.0	< 1	< 1	< 1	< 1	< 1	918
MW-7XD	05/01/97	100	2.3 J	7.5	176	< 1	< 1	1.2	< 1	1.3	1,730
MW-8S	04/29/97	612 J	< 2	3.5 J	70.6 J	< 1	< 1	5.3 J	1.2 J	2.4 J	4,650
MW-8D	04/29/97	11.6 J	4.4 J	3.6 J	176	< 1	< 1	< 1	1.4 J	< 1	5,740
MW-9S	04/29/97	229	2.3 J	< 2	55.4	< 1	< 1	3.1	1.7	1.9	3,540
MW-9XD	04/29/97	33.4	< 2	< 2	175	< 1	< 1	2.2	< 1	< 1	1,500
MW-10S	06/03/97	182 J	4.7 J	< 6	94.7	< 1	< 1	< 1	1.5	6.8 J	2,940
MW-10D	06/03/97	28.7 J	6.8 J	< 6	498	< 1	< 1	< 1	< 1	9.9	2,530
MW-11S	06/03/97	1,230	5.1 J	8.6	70.0	< 1	< 1	2.4	9.7	38.5	4,380
MW-11D	06/03/97	18.1 J	6.3 J	< 6	28.1	< 1	< 1	< 1	< 1	2.8 J	1,480
MW-11XD	06/03/97	15.9 J	3.1 J	< 6	188	< 1	< 1	< 1	< 1	1.4 J	1,530

Table C3. Concentrations of minor elements in ground-water samples collected near Westville, Indiana, April–June 1997—Continued

Well	Date of sample collection	Lead (µg/L)	Manganese (µg/L)	Mercury (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
B-1	04/29/97	< 1	479	<0.2	1.4	< 3 J	< 1	< 2	< 1	5.8
B-2	04/29/97	< 1	3,360	< .2	19	< 3 J	< 1	< 2	< 1	4.5
B-4	05/01/97	< 1	824	< .2	11.2	< 3 J	< 1	4.8 J	< 1	16
EP-1	04/29/97	< 1	26.3	.2 J	3.6	< 3	< 1	< 2	1.4	10.5 J
EP-2	04/28/97	< 1	1,960	< .2	16	< 3 J	< 1	< 2	< 1	43.8
EP-4	04/30/97	3.1	61	< .2 J	27.1	< 3	< 1	6.0 J	2.6	24.6 J
LP-2	04/30/97	< 1	26	< .2	4.9	< 3 J	< 1	< 2	< 1	15.6
LP-3	04/30/97	< 1	104	< .2 J	1.8	< 3	< 1	< 2	1.3	17.5 J
MW-1S	05/01/97	< 1	134	< .2	2.6	< 3 J	< 1	2.1 J	< 1	6.2
MW-1D	04/30/97	< 1	137	< .2 J	< 1	< 3	< 1	4.1 J	< 1	2.6 J
MW-2S	05/01/97	< 1	3,500	< .2 J	182	< 3	< 1	.5 J	1.9	503 J
MW-2D	05/01/97	< 1	153	< .2	18.2	< 3 J	< 1	< 2 J	< 1	21.6
MW-2MD	05/01/97	< 1	76.2	< .2 J	1.8	< 3	< 1	3.0 J	< 1	3.4 J
MW-2XD	05/01/97	< 1	434	< .2 J	5.2	< 3	< 1	5.8 J	3.1	41.5 J
MW-3S	05/01/97	< 1	819	< .2 J	9.8	< 3	< 1	5.1 J	< 1	5.8 J
MW-3D	05/01/97	< 1	467	< .2 J	5.5	< 3	< 1	2.5 J	< 1	7.8 J
MW-4S	04/29/97	< 1	296	< .2	2.1	< 3 J	< 1	< 2	< 1	4.5
MW-4D	04/29/97	< 1	179	< .2	16	< 3 J	< 1	< 2 J	< 1	< 1
MW-4XD	04/29/97	< 1	160	< .2	82.7	< 3 J	< 1	6.3 J	< 1	6.1

Table C3. Concentrations of minor elements in ground-water samples collected near Westville, Indiana, April–June 1997—Continued

Well	Date of sample collection	Lead (µg/L)	Manganese (µg/L)	Mercury (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
MW-5S	04/30/97	< 1	162	< .2	24.9	< 3 J	< 1	< 2	< 1	47.1
MW-5D	04/30/97	< 1	256	< .2	3.6	< 3 J	< 1	< 2	< 1	2.7
MW-5XD	04/30/97	< 1	410	< .2	1.8	< 3 J	< 1	< 2	< 1	8.1
MW-6S	05/01/97	< 1	606	< .2	2.5	< 3 J	< 1	9.4 J	< 1	5.9
MW-6D	05/01/97	< 1	84.6	< .2	1.7	< 3 J	< 1	2.6 J	< 1	16
MW-7S	04/28/97	< 1	7.8	< .2	1.1	< 3	< 1	3.3 J	< 1	7.3 J
MW-7D	04/28/97	< 1	99.2	< .2	1.3	< 3 J	< 1	< 2	< 1	2.8
MW-7XD	05/01/97	< 1	82.2	< .2	5.7	< 3 J	< 1	< 2	< 1	6.4
MW-8S	04/29/97	< 1	204	< .2 J	4	< 3	< 1	4.0 J	1.3	11.4 J
MW-8D	04/29/97	< 1	158	< .2 J	9.2	< 3	< 1	4.0 J	< 1	3.3 J
MW-9S	04/29/97	2	173	< .2	3.5	< 3 J	< 1	< 2	< 1	12.5
MW-9XD	04/29/97	< 1	38	< .2	< 1	< 3 J	< 1	< 2	< 1	9.2
MW-10S	06/03/97	< 2	197	< .2	< 1	5.4	< 1	9.7 J	< 1	4.7
MW-10D	06/03/97	< 2	56.5	< .2	3.6	< 4	< 1	< 5	< 1	< 3
MW-11S	06/03/97	8.7	142	< .2	20.3	< 4	1.1 J	< 5	3.1	53.2
MW-11D	06/03/97	< 2	90.4	< .2	1.5	< 4	< 1	< 5	< 1	< 3
MW-11XD	06/03/97	< 2	19.7	< .2	< 1	< 4	1.4 J	< 5	< 1	< 3

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999

[Chemical Abstract Service (CAS) Registry Numbers are in parentheses in column header; µg/L, microgram per liter; <, less than; E, concentration is estimated, sample required dilution to increase accuracy; J, concentration is estimated, number given is below quantification limit; D, sample was diluted; H, concentration is estimated, result is biased high; R, data not usable]

Well	Date of sample collection	Chloro-methane (74-87-3) (µg/L)	Bromo-methane (74-83-9) (µg/L)	Vinyl chloride (75-01-4) (µg/L)	Chloroethane (75-00-3) (µg/L)	Methylene chloride (75-09-2) (µg/L)	Acetone (67-64-1) (µg/L)	Carbon disulfide (75-15-0) (µg/L)	1,1-Dichloro-ethene (75-35-4) (µg/L)	1,1-Dichloro-ethane (75-34-3) (µg/L)	1,2-Dichloro-ethene (total) (540-59-0) (µg/L)	Chloroform (67-66-3) (µg/L)
B-1	04/29/97	< 10	< 10	< 10	< 10	< 10	4 J	< 10	< 10	< 10	< 10	< 10
	09/05/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
B-2	04/29/97	< 33 J	< 33	61	11 J	< 33	< 33	< 33	< 33	150	1,500	< 33
	09/09/97	< 1	< 1	47 E	4	< 2	< 5	< 1	.6 J	150 E	1,420[b]	< 1
B-4	05/01/97	< 25 J	< 25 J	< 25 J	390 J	6 J	< 25 J	< 25 J	< 25 J	160 J	< 25 J	240 J
	09/08/97	< 1	< 1	< 1	520 E	4	< 5	< 1	< 1	140 E	.9[c] J	< 1
	12/11/97	< 1	< 1	.8 J	620 D	4	< 3	< 2 J	< 1	140 D	< 1[a]	< 1
	05/04/99	< 10	< 10	< 10	240	7 J	< 10	< 10	< 10	19	< 10	< 10
EP-1	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10 J	< 10	< 10	< 10	< 10	< 10
	09/03/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
EP-2	04/28/97	< 10	< 10	< 10	< 10	< 10	< 10 J	< 10	< 10	< 10	< 10	< 10
	09/02/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/08/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
EP-3	09/02/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/08/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
EP-4	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/03/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/10/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	Chloro-methane (74-87-3) (µg/L)	Bromo-methane (74-83-9) (µg/L)	Vinyl chloride (75-01-4) (µg/L)	Chloroethane (75-00-3) (µg/L)	Methylene chloride (75-09-2) (µg/L)	Acetone (67-64-1) (µg/L)	Carbon disulfide (75-15-0) (µg/L)	1,1-Dichloro-ethene (75-35-4) (µg/L)	1,1-Dichloro-ethane (75-34-3) (µg/L)	1,2-Dichloro-ethene (total) (540-59-0) (µg/L)	Chloroform (67-66-3) (µg/L)
LP-1	09/02/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1^{a}	< 1
LP-2	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/03/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1^{a}	< 1
LP-3	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/03/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1^{a}	< 1
	12/10/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1^{a}	< 1
MW-1S	05/01/97	< 10 J	< 10 J	< 10 J	2 J	< 10 J	< 10 J	< 10 J	< 10 J	86 J	91 J	< 10 J
	09/09/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	78 E	101^{d} E	< 1
	12/10/97	< 1	< 1	.6 J	2	< 1	< 3	< 3 J	6	49 D	68^{e} D	< 1
	05/05/99	<10	<10	<10	<10	<10	< 10	<10	<10	57	70	<10
MW-1D	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/09/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1^{a}	< 1
	12/10/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1^{a}	< 1
	05/04/99	< 10	<10	<10	<10	3 J	< 10	<10	<10	<10	<10	<10
MW -2S	05/01/97	< 10 J	< 10 J	< 10 J	<10 J	90 J	6 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/09/97	< 1	< 1	< 1	74 E	4	< 5	< 1	< 1	< 1	< 1^{a}	< 1
	12/15/97	< 1	< 1	< 1	120 D	5	< 3	< 2 J	< 1	< 1	< 1^{a}	< 1
	05/04/99	<10	<10	<10	52 H	4 J	< 10	<10	<10	<10	<10	<10

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	Chloro-methane (74-87-3) (µg/L)	Bromo-methane (74-83-9) (µg/L)	Vinyl chloride (75-01-4) (µg/L)	Chloroethane (75-00-3) (µg/L)	Methylene chloride (75-09-2) (µg/L)	Acetone (67-64-1) (µg/L)	Carbon disulfide (75-15-0) (µg/L)	1,1-Dichloro-ethene (75-35-4) (µg/L)	1,1-Dichloro-ethane (75-34-3) (µg/L)	1,2-Dichloro-ethene (total) (540-59-0) (µg/L)	Chloroform (67-66-3) (µg/L)
MW-2D	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/09/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/15/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
	05/04/99	< 10	< 10	< 10	< 10	3 J	< 10	< 10	< 10	< 10	< 10	< 10
MW-2MD	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/08/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/12/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
	05/05/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-2XD	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/08/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/12/97	< 1 R	< 1 R	< 1 R	< 1 R	< 1 R	< 3 R	< 3 R	< 1 R	< 1 R	< 1[a] R	< 1 R
	05/05/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-3S	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	15 J	22 J	< 10 J
	09/08/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	14[f]	< 1
	05/04/99	< 10	< 10	3 J	< 10	3 J	< 10	< 10	< 10	< 10	< 10	< 10
MW-3D	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/08/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	05/04/99	< 10	< 10	< 10	< 10	3 J	< 10	< 10	< 10	< 10	< 10	< 10

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	Chloro-methane (74-87-3) (µg/L)	Bromo-methane (74-83-9) (µg/L)	Vinyl chloride (75-01-4) (µg/L)	Chloroethane (75-00-3) (µg/L)	Methylene chloride (75-09-2) (µg/L)	Acetone (67-64-1) (µg/L)	Carbon disulfide (75-15-0) (µg/L)	1,1-Dichloro-ethene (75-35-4) (µg/L)	1,1-Dichloro-ethane (75-34-3) (µg/L)	1,2-Dichloro-ethene (total) (540-59-0) (µg/L)	Chloroform (67-66-3) (µg/L)
MW-4S	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/05/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/15/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-4D	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/04/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/12/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-4XD	04/29/97	< 10	< 10	< 10	< 10	< 10	6 J	< 10	< 10	< 10	< 10	< 10
	09/05/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/12/97	< 1 R	< 1 R	< 1 R	< 1 R	< 1 R	< 3 R	< 3 R	< 1 R	< 1 R	< 1[a] R	< 1 R
MW-5S	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	1 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/04/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/09/97	< 1	< 1	< 1	< 1	< 1	< 3	< 2 J	< 1	< 1	< 1[a]	< 1
MW-5D	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/04/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/09/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-5XD	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/04/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/09/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	Chloro-methane (74-87-3) (μg/L)	Bromo-methane (74-83-9) (μg/L)	Vinyl chloride (75-01-4) (μg/L)	Chloroethane (75-00-3) (μg/L)	Methylene chloride (75-09-2) (μg/L)	Acetone (67-64-1) (μg/L)	Carbon disulfide (75-15-0) (μg/L)	1,1-Dichloro-ethene (75-35-4) (μg/L)	1,1-Dichloro-ethane (75-34-3) (μg/L)	1,2-Dichloro-ethene (total) (540-59-0) (μg/L)	Chloroform (67-66-3) (μg/L)
MW-6S	05/01/97	< 10	< 10	< 10	< 10	< 10	8 J	< 10	< 10	< 10	< 10	< 10
	09/09/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	05/05/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-6D	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/09/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/11/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
	05/05/99	< 10	< 10	< 10	< 10	3 J	< 10	< 10	< 10	< 10	< 10	< 10
MW-7S	04/28/97	< 10 J	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/02/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/09/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
	05/03/99	< 10	< 10	< 10	< 10	3 J	< 10	< 10	< 10	< 10	< 10	< 10
MW-7D	04/28/97	< 10 J	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/02/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/08/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
	05/03/99	< 10	< 10	< 10	< 10	3 J	< 10	< 10	< 10	< 10	< 10	< 10
MW-7XD	05/01/97	< 10	< 10	< 10	< 10	< 10	< 10 J	< 10	< 10	< 10	< 10	< 10
	09/02/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/08/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
	05/03/99	< 10	< 10	< 10	< 10	3 J	< 10	< 10	< 10	< 10	< 10	< 10

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	Chloro-methane (74-87-3) (μg/L)	Bromo-methane (74-83-9) (μg/L)	Vinyl chloride (75-01-4) (μg/L)	Chloroethane (75-00-3) (μg/L)	Methylene chloride (75-09-2) (μg/L)	Acetone (67-64-1) (μg/L)	Carbon disulfide (75-15-0) (μg/L)	1,1-Dichloro-ethene (75-35-4) (μg/L)	1,1-Dichloro-ethane (75-34-3) (μg/L)	1,2-Dichloro-ethene (total) (540-59-0) (μg/L)	Chloroform (67-66-3) (μg/L)
MW-8S	04/29/97	<10	<10	<10	<10	<10	< 10 J	<10	<10	<10	<10	<10
	09/09/97	<1	<1	<1	< 1	<2	< 5	<1	<1	<1	< 1[a]	<1
MW-8D	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/09/97	<1	<1	<1	< 1	<2	< 5	<1	<1	<1	< 1[a]	<1
MW-9S	04/29/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/03/97	<1	<1	<1	< 1	<2	< 5	<1	<1	<1	< 1[a]	<1
MW-9XD	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/03/97	<1	<1	<1	< 1	<2	< 5	<1	<1	<1	< 1[a]	<1
MW-10S	06/03/97	<10	<10	<10	<10	<10	< 10 J	<10	<10	<10	<10	<10
	09/08/97	<1	<1	<1	< 1	<2	< 5	<1	<1	<1	< 1[a]	<1
MW-10XD	06/03/97	<10	<10	<10	<10	<10	< 10 J	<10	<10	<10	<10	<10
	09/08/97	<1	<1	<1	< 1	<2	< 5	<1	<1	<1	< 1[a]	<1
MW-11S	06/03/97	<10	<10	<10	<10	<10	< 10 J	<10	<10	<10	<10	<10
	09/04/97	<1	<1	<1	< 1	<2	< 5	<1	<1	<1	< 1[a]	<1
MW-11D	06/03/97	<10	<10	<10	<10	<10	< 10 J	<10	<10	<10	<10	<10
	09/04/97	<1	<1	<1	< 1	<2	< 5	<1	<1	<1	< 1[a]	<1
MW-11XD	06/03/97	<10	<10	<10	<10	<10	< 10 J	<10	<10	<10	<10	<10
	09/04/97	<1	<1	<1	< 1	<2	< 5	<1	<1	<1	< 1[a]	<1

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	Chloro-methane (74-87-3) (μg/L)	Bromo-methane (74-83-9) (μg/L)	Vinyl chloride (75-01-4) (μg/L)	Chloroethane (75-00-3) (μg/L)	Methylene chloride (75-09-2) (μg/L)	Acetone (67-64-1) (μg/L)	Carbon disulfide (75-15-0) (μg/L)	1,1-Dichloro-ethene (75-35-4) (μg/L)	1,1-Dichloro-ethane (75-34-3) (μg/L)	1,2-Dichloro-ethene (total) (540-59-0) (μg/L)	Chloroform (67-66-3) (μg/L)
MW-12	09/10/97	< 1	< 1	< 1	< 1	< 2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12//11/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-13S	12/10/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-13D	12/10/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-13XD	12/10/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-14S	12/11/97	< 1	< 1	< 1	< 1	1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-14D	12/10/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-14XD	12/10/97	< 1 R	< 1 R	< 1 R	< 1 R	< 1 R	< 3 R	< 3 R	< 1 R	< 1 R	< 1[a] R	< 1 R
MW-15S	12/09/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-15MD	12/09/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-15XD	12/09/97	< 1	< 1	< 1	< 1	< 1	< 3	< 2 J	< 1	< 1	< 1[a]	< 1
MW-16S	12/11/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-16D	12/11/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-16XD	12/11/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-17MD	12/16/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-17XD	12/16/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-18S	12/11/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
MW-18XD	12/11/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	Chloro-methane (74-87-3) (μg/L)	Bromo-methane (74-83-9) (μg/L)	Vinyl chloride (75-01-4) (μg/L)	Chloroethane (75-00-3) (μg/L)	Methylene chloride (75-09-2) (μg/L)	Acetone (67-64-1) (μg/L)	Carbon disulfide (75-15-0) (μg/L)	1,1-Dichloro-ethene (75-35-4) (μg/L)	1,1-Dichloro-ethane (75-34-3) (μg/L)	1,2-Dichloro-ethene (total) (540-59-0) (μg/L)	Chloroform (67-66-3) (μg/L)
MUN-1	09/03/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1[a]	< 1
	12/16/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
	05/06/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
NDF-MW1	12/16/97	< 1	< 1	< 1	< 1	< 1	< 3	< 5 J	< 1	< 1	< 1[a]	< 1
NDF-MW2	12/16/97	< 1	< 1	< 1	< 1	< 1	< 3	< 3 J	< 1	< 1	< 1[a]	< 1
PZ-1S	09/03/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1[a]	< 1
PZ-1MD	09/03/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	<1[a]	< 1
PZ-1XD	09/03/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1[a]	< 1
PZ-3S	09/03/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1[a]	< 1
PZ-3MD	09/04/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1[a]	< 1
PZ-3XD	09/03/97	< 1	< 1	< 1	< 1	<2	< 5	< 1	< 1	< 1	< 1[a]	< 1

[a] Laboratory reported as less than 1 microgram per liter cis-1,2-dichloroethene (CAS number, 156-59-2) and less than 1 microgram per liter trans-1,2-dichloroethene (CAS number, 156-60-5).

[b] Laboratory reported as 1,400 micrograms per liter cis-1,2-dichloroethene (CAS number, 156-59-2) and 20 micrograms per liter trans-1,2-dichloroethene (CAS number, 156-60-5).

[c] Laboratory reported as less than 1 microgram per liter cis-1,2-dichloroethene (CAS number, 156-59-2) and 0.9 microgram per liter trans-1,2-dichloroethene (CAS number, 156-60-5).

[d] Laboratory reported as 96 micrograms per liter cis-1,2-dichloroethene (CAS number, 156-59-2) and 5 micrograms per liter trans-1,2-dichloroethene (CAS number, 156-60-5).

[e] Laboratory reported as 63 micrograms per liter cis-1,2-dichloroethene (CAS number, 156-59-2) and 5 micrograms per liter trans-1,2-dichloroethene (CAS number, 156-60-5).

[f] Laboratory reported as 13 micrograms per liter cis-1,2-dichloroethene (CAS number, 156-59-2) and 1 microgram per liter trans-1,2-dichloroethene (CAS number, 156-60-5).

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	1,2-Dichloro-ethane (107-06-2) (µg/L)	2-Butanone (78-93-3) (µg/L)	1,1,1-Trichloro-ethane (71-55-6) (µg/L)	Carbon tetrachloride (56-23-5) (µg/L)	Bromo-dichloro-methane (75-27-4) (µg/L)	1,2-Dichloro-propane (78-87-5) (µg/L)	cis-1,3-Dichloro-propene (10061-01-5) (µg/L)	Trichloro-ethene (79-01-6) (µg/L)	Dibromo-chloro-methane (124-48-1) (µg/L)	1,1,2-Trichloro-ethane (79-00-5) (µg/L)	Benzene (71-43-2) (µg/L)
B-1	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/05/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
B-2	04/29/97	< 33	< 33	< 33	< 33	< 33	< 33	< 33	28 J	< 33	< 33	4 J
	09/09/97	3	< 5	3	< 1	< 1	< 1	< 1	37	< 1	< 1	6
B-4	05/01/97	< 25 J	< 25 J	< 25 J	< 25 J	12 J	< 25 J	< 25 J	< 25 J	< 25 J	< 25 J	140 J
	09/08/97	8	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	100 E
	12/11/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	120 D
	05/04/99	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	130
EP-1	04/29/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
EP-2	04/28/97	1 J	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/02/97	< 1	< 5	.6 J	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/08/97	< 1	< 3	.8 J	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
EP-3	09/02/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/08/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
EP-4	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/10/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	1,2-Dichloro-ethane (107-06-2) (μg/L)	2-Butanone (78-93-3) (μg/L)	1,1,1-Trichloro-ethane (71-55-6) (μg/L)	Carbon tetrachloride (56-23-5) (μg/L)	Bromo-dichloro-methane (75-27-4) (μg/L)	1,2-Dichloro-propane (78-87-5) (μg/L)	cis-1,3-Dichloro-propene (10061-01-5) (μg/L)	Trichloro-ethene (79-01-6) (μg/L)	Dibromo-chloro-methane (124-48-1) (μg/L)	1,1,2-Trichloro-ethane (79-00-5) (μg/L)	Benzene (71-43-2) (μg/L)
LP-1	09/02/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
LP-2	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
LP-3	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/10/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-1S	05/01/97	< 10 J	< 10 J	96 J	< 10 J	< 10 J	< 10 J	< 10 J	12 J	< 10 J	< 10 J	8 J
	09/09/97	<1	<5	120 E	<1	<1	<1	<1	15	<1	<1	9
	12/10/97	< 1	< 3	80 D	< 1	< 1	< 1	< 1	17	< 1	< 1	8
	05/05/99	<10	<10	63	<10	<10	<10	<10	7 J	<10	<10	3 J
MW-1D	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/09/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/10/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	05/04/99	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
MW-2S	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	16 J
	09/09/97	2	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	13
	12/15/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	20
	05/04/99	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	14 H

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	1,2-Dichloro-ethane (107-06-2) (μg/L)	2-Butanone (78-93-3) (μg/L)	1,1,1-Trichloro-ethane (71-55-6) (μg/L)	Carbon tetrachloride (56-23-5) (μg/L)	Bromo-dichloro-methane (75-27-4) (μg/L)	1,2-Dichloro-propane (78-87-5) (μg/L)	cis-1,3-Dichloro-propene (10061-01-5) (μg/L)	Trichloro-ethene (79-01-6) (μg/L)	Dibromo-chloro-methane (124-48-1) (μg/L)	1,1,2-Trichloro-ethane (79-00-5) (μg/L)	Benzene (71-43-2) (μg/L)
MW-2D	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	1 J
	09/09/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/15/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	05/04/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-2MD	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/08/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/12/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	05/05/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-2XD	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/09/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/12/97	< 1 R	< 3 R	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J
	05/05/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-3S	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	5 J
	09/08/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	3
	05/04/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	4 J
MW-3D	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/08/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	05/04/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	1,2-Dichloro-ethane (107-06-2) (μg/L)	2-Butanone (78-93-3) (μg/L)	1,1,1-Trichloro-ethane (71-55-6) (μg/L)	Carbon tetrachloride (56-23-5) (μg/L)	Bromo-dichloro-methane (75-27-4) (μg/L)	1,2-Dichloro-propane (78-87-5) (μg/L)	cis-1,3-Dichloro-propene (10061-01-5) (μg/L)	Trichloro-ethene (79-01-6) (μg/L)	Dibromo-chloro-methane (124-48-1) (μg/L)	1,1,2-Trichloro-ethane (79-00-5) (μg/L)	Benzene (71-43-2) (μg/L)
MW-4S	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/05/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/15/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-4D	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/04/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/12/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-4XD	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/05/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/12/97	< 1 R	< 3 R	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J
MW-5S	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/04/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/09/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-5D	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/04/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/09/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-5XD	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/04/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/09/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	1,2-Dichloro-ethane (107-06-2) (µg/L)	2-Butanone (78-93-3) (µg/L)	1,1,1-Trichloro-ethane (71-55-6) (µg/L)	Carbon tetrachloride (56-23-5) (µg/L)	Bromo-dichloro-methane (75-27-4) (µg/L)	1,2-Dichloro-propane (78-87-5) (µg/L)	cis-1,3-Dichloro-propene (10061-01-5) (µg/L)	Trichloro-ethene (79-01-6) (µg/L)	Dibromo-chloro-methane (124-48-1) (µg/L)	1,1,2-Trichloro-ethane (79-00-5) (µg/L)	Benzene (71-43-2) (µg/L)
MW-6S	05/01/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/09/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	05/05/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-6D	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/09/97	.9 J	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/11/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	05/05/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-7S	04/28/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/02/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/09/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	05/03/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-7D	04/28/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/02/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/08/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	05/03/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-7XD	05/01/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/02/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/08/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	05/03/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	1,2-Dichloro-ethane (107-06-2) (µg/L)	2-Butanone (78-93-3) (µg/L)	1,1,1-Trichloro-ethane (71-55-6) (µg/L)	Carbon tetrachloride (56-23-5) (µg/L)	Bromo-dichloro-methane (75-27-4) (µg/L)	1,2-Dichloro-propane (78-87-5) (µg/L)	cis-1,3-Dichloro-propene (10061-01-5) (µg/L)	Trichloro-ethene (79-01-6) (µg/L)	Dibromo-chloro-methane (124-48-1) (µg/L)	1,1,2-Trichloro-ethane (79-00-5) (µg/L)	Benzene (71-43-2) (µg/L)
MW-8S	04/29/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/09/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-8D	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/09/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-9S	04/29/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-9XD	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-10S	06/03/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/08/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-10XD	06/03/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/08/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-11S	06/03/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/04/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-11D	06/03/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/04/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-11XD	06/03/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/04/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	1,2-Dichloro-ethane (107-06-2) (μg/L)	2-Butanone (78-93-3) (μg/L)	1,1,1-Trichloro-ethane (71-55-6) (μg/L)	Carbon tetrachloride (56-23-5) (μg/L)	Bromo-dichloro-methane (75-27-4) (μg/L)	1,2-Dichloro-propane (78-87-5) (μg/L)	cis-1,3-Dichloro-propene (10061-01-5) (μg/L)	Trichloro-ethene (79-01-6) (μg/L)	Dibromo-chloro-methane (124-48-1) (μg/L)	1,1,2-Trichloro-ethane (79-00-5) (μg/L)	Benzene (71-43-2) (μg/L)
MW-12	09/19/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/11/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-13S	12/10/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-13D	12/10/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-13XD	12/10/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-14S	12/11/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-14D	12/10/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-14XD	12/10/97	< 1 R	< 3 R	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J
MW-15S	12/09/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-15MD	12/09/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-15XD	12/09/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-16S	12/11/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-16D	12/11/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-16XD	12/11/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-17MD	12/16/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-17XD	12/16/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-18S	12/11/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-18XD	12/11/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	1,2-Dichloro-ethane (107-06-2) (μg/L)	2-Butanone (78-93-3) (μg/L)	1,1,1-Trichloro-ethane (71-55-6) (μg/L)	Carbon tetrachloride (56-23-5) (μg/L)	Bromo-dichloro-methane (75-27-4) (μg/L)	1,2-Dichloro-propane (78-87-5) (μg/L)	cis-1,3-Dichloro-propene (10061-01-5) (μg/L)	Trichloro-ethene (79-01-6) (μg/L)	Dibromo-chloro-methane (124-48-1) (μg/L)	1,1,2-Trichloro-ethane (79-00-5) (μg/L)	Benzene (71-43-2) (μg/L)
MUN-1	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/16/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	05/06/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
NDF-MW1	12/16/97	< 1	< 3	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J
NDF-MW2	12/16/97	< 1	< 3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PZ-1S	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PZ-1MD	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PZ-1XD	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PZ-3S	09/04/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PZ-3MD	09/04/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PZ-3XD	09/03/97	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	trans-1,3-Dichloro-propene (10061-02-6) (µg/L)	Bromoform (75-25-2) (µg/L)	4-Methyl-2-pentanone (108-10-1) (µg/L)	2-Hexanone (591-78-6) (µg/L)	Tetrachloro-ethene (127-18-4) (µg/L)	1,1,2,2-Tetrachloro-ethane (79-34-5) (µg/L)	Toluene (108-88-3) (µg/L)	Chloro-benzene (108-90-7) (µg/L)	Ethyl benzene (100-41-4) (µg/L)	Styrene (100-42-5) (µg/L)	Xylene (total) (1330-20-7) (µg/L)
B-1	04/29/97	< 1	< 1	< 1	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	09/05/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
B-2	04/29/97	< 33	< 33	< 33	< 33	26 J	< 33	< 33	< 33	< 33	< 33	< 33
	09/09/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
B-4	05/01/97	< 25 J	< 25 J	< 25 J	< 25 J	< 25 J	< 25 J	7 J	< 25 J	4 J	< 25 J	< 25 J
	09/08/97	< 1	< 1	< 5	< 5	< 1	< 1	1	< 1	2	< 1	1
	12/11/97	< 1	< 1	< 2	< 2	< 1	< 1	1	< 1	3	< 1	.8[g] J
	05/04/99	< 10	< 10	< 10	< 10	< 10	< 10	2 J	< 10	4 J	< 10	2 J
EP-1	04/29/97	< 10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
EP-2	04/28/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/02/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/08/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
EP-3	09/02/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	12/08/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
EP-4	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	1 J	< 10 J	1 J	< 10 J	< 10 J
	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/10/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	trans-1,3-Dichloro-propene (10061-02-6) (µg/L)	Bromoform (75-25-2) (µg/L)	4-Methyl-2-pentanone (108-10-1) (µg/L)	2-Hexanone (591-78-6) (µg/L)	Tetrachloro-ethene (127-18-4) (µg/L)	1,1,2,2-Tetrachloro-ethane (79-34-5) (µg/L)	Toluene (108-88-3) (µg/L)	Chloro-benzene (108-90-7) (µg/L)	Ethyl benzene (100-41-4) (µg/L)	Styrene (100-42-5) (µg/L)	Xylene (total) (1330-20-7) (µg/L)
LP-1	09/02/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
LP-2	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
LP-3	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/10/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-1S	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/09/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/10/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
	05/05/99	<10	<10	<10 J	<10	<10	<10	2 J	<10	1 J	<10	5 J
MW-1D	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/09/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/10/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
	05/04/99	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
MW-2S	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	1 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/09/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/15/97	< 1	< 1	< 2	< 2	< 1	< 1	1	< 1	< 1	< 1	< 1[h]
	05/04/99	<10	<10	<10	<10	<10	<10	1 J	<10	<10	<10	<10

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	trans-1,3-Dichloro-propene (10061-02-6) (µg/L)	Bromoform (75-25-2) (µg/L)	4-Methyl-2-pentanone (108-10-1) (µg/L)	2-Hexanone (591-78-6) (µg/L)	Tetrachloro-ethene (127-18-4) (µg/L)	1,1,2,2-Tetrachloro-ethane (79-34-5) (µg/L)	Toluene (108-88-3) (µg/L)	Chloro-benzene (108-90-7) (µg/L)	Ethyl benzene (100-41-4) (µg/L)	Styrene (100-42-5) (µg/L)	Xylene (total) (1330-20-7) (µg/L)
MW-2D	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/09/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/15/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
	05/04/99	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
MW-2MD	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/08/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/12/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
	05/05/99	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
MW-2XD	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/08/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/12/97	< 1 J	< 1 J	< 2 J	< 2 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1[h] J
	05/05/99	<10	<10	<10	<10	<10	<10	1 J	<10	<10	<10	1 J
MW-3S	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/08/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	05/04/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-3D	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/08/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	05/04/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	trans-1,3-Dichloro-propene (10061-02-6) (µg/L)	Bromoform (75-25-2) (µg/L)	4-Methyl-2-pentanone (108-10-1) (µg/L)	2-Hexanone (591-78-6) (µg/L)	Tetrachloro-ethene (127-18-4) (µg/L)	1,1,2,2-Tetrachloro-ethane (79-34-5) (µg/L)	Toluene (108-88-3) (µg/L)	Chloro-benzene (108-90-7) (µg/L)	Ethyl benzene (100-41-4) (µg/L)	Styrene (100-42-5) (µg/L)	Xylene (total) (1330-20-7) (µg/L)
MW-4S	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/05/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/15/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-4D	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/04/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/12/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-4XD	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/05/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/12/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10[i] J
MW-5S	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	2 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/04/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/09/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-5D	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	2 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/04/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/09/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-5XD	04/30/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	1 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/04/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/09/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	trans-1,3-Dichloro-propene (10061-02-6) (μg/L)	Bromoform (75-25-2) (μg/L)	4-Methyl-2-pentanone (108-10-1) (μg/L)	2-Hexanone (591-78-6) (μg/L)	Tetrachloro-ethene (127-18-4) (μg/L)	1,1,2,2-Tetrachloro-ethane (79-34-5) (μg/L)	Toluene (108-88-3) (μg/L)	Chloro-benzene (108-90-7) (μg/L)	Ethyl benzene (100-41-4) (μg/L)	Styrene (100-42-5) (μg/L)	Xylene (total) (1330-20-7) (μg/L)
MW-6S	05/01/97	< 10	< 10	3 J	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/09/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	05/05/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-6D	05/01/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/09/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/11/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
	05/05/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-7S	04/28/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/02/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/09/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
	05/03/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
MW-7D	04/28/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/02/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/08/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
	05/03/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	2 J	< 10
MW-7XD	05/01/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/02/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/08/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
	05/03/99	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	trans-1,3-Dichloro-propene (10061-02-6) (µg/L)	Bromoform (75-25-2) (µg/L)	4-Methyl-2-pentanone (108-10-1) (µg/L)	2-Hexanone (591-78-6) (µg/L)	Tetrachloro-ethene (127-18-4) (µg/L)	1,1,2,2-Tetrachloro-ethane (79-34-5) (µg/L)	Toluene (108-88-3) (µg/L)	Chloro-benzene (108-90-7) (µg/L)	Ethyl benzene (100-41-4) (µg/L)	Styrene (100-42-5) (µg/L)	Xylene (total) (1330-20-7) (µg/L)
MW-8S	04/29/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/09/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-8D	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/09/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-9S	04/29/97	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J	< 10 J
	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-9XD	04/29/97	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-10S	06/03/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/08/97	< 1	< 1	< 5	< 5	< 1	< 1	1	< 1	< 1	< 1	< 1
MW-10XD	06/03/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/08/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-11S	06/03/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/04/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
MW-11D	06/03/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/04/97	< 1	< 1	< 5	< 5	< 1	< 1	1	< 1	< 1	< 1	< 1
MW-11XD	06/03/97	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	09/04/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	trans-1,3-Dichloro-propene (10061-02-6) (μg/L)	Bromoform (75-25-2) (μg/L)	4-Methyl-2-pentanone (108-10-1) (μg/L)	2-Hexanone (591-78-6) (μg/L)	Tetrachloro-ethene (127-18-4) (μg/L)	1,1,2,2-Tetrachloro-ethane (79-34-5) (μg/L)	Toluene (108-88-3) (μg/L)	Chloro-benzene (108-90-7) (μg/L)	Ethyl benzene (100-41-4) (μg/L)	Styrene (100-42-5) (μg/L)	Xylene (total) (1330-20-7) (μg/L)
MW-12	09/10/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/11/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-13S	12/10/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-13D	12/10/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-13XD	12/10/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-14S	12/11/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-14D	12/10/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-14XD	12/10/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-15S	12/09/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-15MD	12/09/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-15XD	12/09/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-16S	12/11/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-16D	12/11/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-16XD	12/11/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-17MD	12/16/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-17XD	12/16/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-18S	12/11/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
MW-18XD	12/11/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]

Table C4. Concentrations of volatile organic compounds in ground-water samples collected near Westville, Indiana, April through May 1999—Continued

Well	Date of sample collection	trans-1,3-Dichloro-propene (10061-02-6) (μg/L)	Bromoform (75-25-2) (μg/L)	4-Methyl-2-pentanone (108-10-1) (μg/L)	2-Hexanone (591-78-6) (μg/L)	Tetrachloro-ethene (127-18-4) (μg/L)	1,1,2,2-Tetrachloro-ethane (79-34-5) (μg/L)	Toluene (108-88-3) (μg/L)	Chloro-benzene (108-90-7) (μg/L)	Ethyl benzene (100-41-4) (μg/L)	Styrene (100-42-5) (μg/L)	Xylene (total) (1330-20-7) (μg/L)
MUN-1	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	12/16/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
	05/06/99	<10	<10	<10 J	<10	<10	<10	<10	<10	<10	<10	<10
NDF-MW1	12/16/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
NDF-MW2	12/16/97	< 1	< 1	< 2	< 2	< 1	< 1	< 1	< 1	< 1	< 1	< 1[h]
PZ-1S	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PZ-1MD	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PZ-1XD	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PZ-3S	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PZ-3MD	09/04/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
PZ-3XD	09/03/97	< 1	< 1	< 5	< 5	< 1	< 1	< 1	< 1	< 1	< 1	< 1

[g] Laboratory reported as 0.8 microgram per liter m- and/or p-xylene (CAS number 1083836423) and less than 1 microgram per liter o-xylene (CAS number, 95-47-6).

[h] Laboratory reported as less than 1 microgram per liter m- and/or p-xylene (CAS number 1083836423) and less than 1 microgram per liter o-xylene (CAS number, 95-47-6).

[i] Laboratory reported as less than 10 micrograms per liter m- and/or p-xylene (CAS number 1083836423) and less than 10 micrograms per liter o-xylene (CAS number, 95-47-6).

Table C5. Concentrations of 1,4-dioxane in ground-water samples collected near Westville, Indiana, April 1997 through May 1999

[J, concentration is estimated below the quantification limit; D, concentration determined after dilution; E, estimated concentration from analysis of diluted sample; <, less than]

Well	1,4-dioxane, in micrograms per liter			
	April–May 1997	September 1997	December 1997	May 1999
B-1	not sampled	3 J	not sampled	not sampled
B-2	620 E	220 D	not sampled	not sampled
B-4	(unusable)	200 D	153 D	240 D
EP-1	< 5 J	< 5	< 5	not sampled
EP-2	<5 J	< 5	< 5	not sampled
EP-4	16	< 5	< 5	not sampled
LP-2	15 J	< 5	< 5	not sampled
LP-3	not sampled	3 J	3 J	not sampled
MW-1S	140 E	< 5	< 5	< 5
MW-1D	< 5 J	< 5	< 5	8
MW-2S	(unusable)	880 D	1,900 D	820 D
MW-2D	31,000 E	11,000 E	3,800 E	8,800 D
MW-2MD	1,600 E	640 D	380 D	82
MW-2XD	4,700 E	1,200 D	1,500 D	1,100 D
MW-3S	2,600 E	370 D	not sampled	740 D
MW-3D	6,400 E	1,600 D	not sampled	12
MW-4S	(unusable)	9	< 5	not sampled
MW-4D	970 E	200 J	249 D	not sampled
MW-4XD	3,800 E	760 D	870 D	not sampled
MW-5S	< 5 J	< 5	< 5	not sampled
MW-5D	(unusable)	< 5	< 5	not sampled
MW-5XD	< 5 J	< 5 J	< 5	not sampled
MW-6S	1,040 E	< 5	not sampled	< 5
MW-6D	82 E	29	20	25
MW-7S	< 5 J	< 5	< 5	< 5
MW-7D	< 5 J	< 5	< 5	< 5
MW-7XD	19 J	< 5	8	< 5
MW-8S	(unusable)	28	16	not sampled
MW-8D	7,700 E	3,800 D	4,270 D	not sampled

Table C5. Concentrations of 1,4-dioxane in ground-water samples collected near Westville, Indiana, April 1997 through May 1999—Continued

Well	1,4-dioxane, in micrograms per liter			
	April–May 1997	September 1997	December 1997	May 1999
MW-9S	(unusable)	< 5	< 5	not sampled
MW-9XD	(unusable)	< 5	< 5	not sampled
MW-10S	not sampled	10	7	5 J
MW-10XD	not sampled	6	10	5 J
MW-11S	not sampled	< 5	< 5	not sampled
MW-11D	not sampled	< 5	< 5	not sampled
MW-11XD	not sampled	< 5	< 5	not sampled
MW-12	not sampled	< 5	< 5	not sampled
MW-13S	not sampled	not sampled	< 5	not sampled
MW-13D	not sampled	not sampled	< 5	not sampled
MW-13XD	not sampled	not sampled	< 5	not sampled
MW-14S	not sampled	not sampled	109 D	42
MW-14D	not sampled	not sampled	13	9
MW-14XD	not sampled	not sampled	1,480 D	1,700 D
MW-15S	not sampled	not sampled	3 J	< 5
MW-15MD	not sampled	not sampled	2,400 D	3,500 D
MW-15XD	not sampled	not sampled	318 D	580 D
MW-16S	not sampled	not sampled	< 5	< 5
MW-16D	not sampled	not sampled	< 5	< 5
MW-16XD	not sampled	not sampled	< 5	< 5
MW-17MD	not sampled	not sampled	< 5	< 5
MW-17XD	not sampled	not sampled	< 5	< 5
MW-18S	not sampled	not sampled	< 5	< 5
MW-18XD	not sampled	not sampled	< 5	< 5
PZ-1S	not sampled	< 5	not sampled	not sampled
PZ-1MD	not sampled	< 5	not sampled	not sampled
PZ-1XD	not sampled	< 5	not sampled	not sampled
PZ-3S	not sampled	< 5	not sampled	not sampled
PZ-3MD	not sampled	< 5	not sampled	not sampled
PZ-3XD	not sampled	< 5	not sampled	not sampled

Table C6. On-site measurements of surface-water samples collected near Westville, Indiana, April 1997 through May 1999

[°C, degree Celsius; mv, millivolt; mg/L milligram per liter; µs/cm, microsiemen per centimeter at 25°C; ntu, nephelometric turbidity unit; --, not measured]

Surface-water site	Date of sample collection	Temp- erature (°C)	pH (units)	Oxidation- reduction potential (mv)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Turbidity (ntu)
SW-1	04/29/97	15.7	8.03	331	13.55	834	--
	08/27/97	14.8	7.35	-17	9.14	848	7.8
	05/04/99	14.3	7.42	--	7.83	759	--
SW-2	04/29/97	18.5	8.21	289	13.45	349	--
	08/27/97	15.8	7.42	-7	9.36	856	12.4
SW-3	05/01/97	16.8	8.31	278	12.54	825	--
	08/27/97	15.1	7.43	25	9.44	798	6.4
SW-4	04/29/97	16.7	8.22	265	9.26	936	--
	08/27/97	17.2	7.46	-8	8.52	900	0
SW-5	04/28/97	10.7	7.56	435	8.53	898	--
	08/27/97	21.4	7.40	187	7.66	966	0
SW-6	05/02/97	14.3	7.57	464	8.0	944	--
	05/04/99	19.5	7.66	--	9.42	839	--
SW-7	04/30/97	13.4	7.58	396	8.05	1,080	--
	08/27/97	18.8	7.30	-40	5.66	1,140	0
SW-8	04/30/97	17.5	7.72	329	8.68	1,160	--
	08/27/97	19.9	7.27	-18	4.84	1,270	8
SW-9	05/01/97	17.5	7.72	329	8.68	1,160	--
	08/27/97	11.0	6.78	341	2.8	633	2.2
SW-10	08/28/97	20.0	7.28	-35	4.41	1,150	0
	09/03/97	11.0	7.10	103	.5	630	14
SW-11	05/01/97	14.3	7.75	286	9.16	1,350	--
	08/27/97	19.9	7.36	-19	7.33	1,260	0
SW-12	05/01/97	10.0	7.83	401	6.77	758	--
	08/27/97	17.2	7.30	-27	7.25	777	0

Table C6. On-site measurements of surface-water samples collected near Westville, Indiana, April 1997 through May 1999—Continued

Surface-water site	Date of sample collection	Temp-erature (°C)	pH (units)	Oxidation-reduction potential (mv)	Dissolved oxygen (mg/L)	Specific conductance (μS/cm)	Turbidity (ntu)
SW-13	05/01/97	13.0	7.85	357	10.59	559	--
	08/27/97	15.2	7.29	-31	4.51	601	15
	12/11/97	7.27	4.58	101	4.31	1,020	--
	05/04/99	17.1	7.31	--	7.8	371	--
SW-WP-2	08/28/97	7.02	7.38	-51	7.02	1,130	8
	12/11/97	7.4	4.56	113	6.28	893	--
	05/04/99	17.2	7.64	--	9.3	1,230	--
SW-WP-3	12/11/97	8.31	4.45	167	5.93	519	--
	05/04/99	17.7	7.28	--	7.62	1,210	--
SW-WP-P	08/28/97	15.2	7.27	-43	5.16	668	8
	12/11/97	12.4	6.69	-196	.17	1,280	.6
	05/04/99	18.3	7.70	--	10.5	540	--

Table C7. Concentrations of common constituents in surface-water samples collected near Westville, Indiana, April–May 1997

[mg/L, milligram per liter; $CaCO_3$, Calcium carbonate; -- not sampled; >, greater than]

Surface-water site	Date of sample collection	Bi-carbonate alkalinity (mg/L)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)
SW-1	04/29/97	239	325	116	32	30.9	4.72	30.8	176
SW-2	04/29/97	241	355	105	48	34.1	3.12	18.7	160
SW-3	05/01/97	253	323	114	22	34.6	1.7	8.11	184
SW-4	04/29/97	243	410	104	76	35.3	4.99	32.6	144
SW-5	04/28/97	238	392	96.4	83	33.3	5.14	32.7	120
SW-6	04/30/97	233	378	94.5	132	34.4	7.41	40.6	112
SW-7	04/30/97	244	393	93.4	100	34.2	6.87	60.9	100
SW-8	04/30/97	251	424	94.4	216	35.3	6.66	69.8	100
SW-9	05/01/97	243	432	95.8	190	36.2	6.92	70.4	96
SW-11	04/30/97	217	404	90.9	> 140	34.1	1.11	98.1	108
SW-12	05/01/97	246	392	90.3	64	34.7	1.17	13.8	100
SW-13	05/01/97	290	288	63.3	27	20.0	3.31	4.22	0

Table C8. Concentrations of minor elements in surface-water samples collected near Westville, Indiana, April–May 1997

[mm, month; dd, day; yy, year; µg/L, microgram per liter; <, less than; J, concentration is estimated]

Surface-water site	Date of sample collection (mm/dd/yy)	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)
SW-1	04/29/97	590 J	< 2	< 2	73.8	1.7 J	< 1	5.1	2.2 J	2.6	4,680
SW-2	04/29/97	9 J	< 2	< 2	44.1	1.8 J	< 1	< 1	1.5 J	1.2	1,370
SW-3	05/01/97	9 J	2.4 J	< 2	63.6	1.8 J	< 1	< 1	1.4 J	8.4	1,490
SW-4	04/29/97	20 J	< 2	< 2	44.4	1.3 J	< 1	< 1	1.3 J	1.9	1,380
SW-5	04/28/97	63.6 J	4 J	< 2	41.2	1.2 J	< 1	< 1	2.2 J	2.8	1,400
SW-6	04/30/97	134 J	2.2 J	< 2	53	1.4 J	< 1	1.1	1.2 J	5.1	1,390
SW-7	04/30/97	120 J	< 2	< 2	51.7	< 1	< 1	< 1	1.6 J	4.5	1,450
SW-8	03/10/97	70.5 J	< 2	< 2	50.2	1.2 J	< 1	< 1	1.9 J	4.3	1,490
SW-9	05/01/97	184 J	< 2	< 2	52.8	1 J	< 1	< 1	2 J	5	1,720
SW-11	04/30/97	44.1 J	2.2 J	< 2	31.6	1.1 J	< 1	< 1	2.2 J	4.4	806
SW-12	05/01/97	9 J	2.2 J	< 2	33.4	1.2 J	< 1	< 1	1.8 J	< 1	723
SW-13	05/01/97	251 J	< 2	< 2	43.6	1.4 J	< 1	1.1	2.6 J	1.9 J	2.230

Table C8. Concentrations of minor elements in surface-water samples collected near Westville, Indiana, April–May 1997—Continued

Surface-water site	Date of sample collection (mm/dd/yy)	Lead (µg/L)	Manganese (µg/L)	Mercury (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
SW-1	04/29/97	< 1	208	<0.2	3	< 3	< 1	4 J	1.6	10.4 J
SW-2	04/29/97	< 1	114	< .2	1.1	< 3	< 1	3.8 J	< 1	10.3 J
SW-3	05/01/97	< 1	111	< .2	< 1	< 3	< 1	4 J	< 1	8 J
SW-4	04/29/97	< 1	141	< .2	1.3	< 3	< 1	3.5 J	< 1	12.6 J
SW-5	04/28/97	< 1	145	< .2	1.5	< 3	< 1	2.8 J	1	17.1 J
SW-6	04/30/97	< 1	114	< .2	2	< 3	< 1	3.4 J	< 1	31.4 J
SW-7	04/30/97	< 1	97.1	< .2	1.6	< 3	< 1	3.6 J	< 1	63.1 J
SW-8	04/30/97	< 1	78.4	< .2	2.1	< 3	< 1	< 2	< 1	72.6 J
SW-9	05/01/97	< 1	80.6	< .2	1.8	< 3	< 1	3.9 J	< 1	72.6 J
SW-11	04/30/97	< 1	62.4	< .2	1.9	< 3	< 1	2.3 J	< 1	121 J
SW-12	05/01/97	< 1	140	< .2	1.4	< 3	< 1	3.4 J	< 1	3.1 J
SW-13	05/01/97	< 1	1,220	< .2	2.6	< 3	< 1	2.6 J	1.2	7.6 J

Table C9. Concentrations of 1,4-dioxane in surface-water samples and well points collected near Westville, Indiana, April 1997 through May 1999

[J, concentration is estimated below the quantification limit; D, concentration determined after dilution; E, estimated concentration from analysis of diluted sample; <, less than]

Sample location	Concentration of 1,4-dioxane in micrograms per liter			
	April–May 1997	August 1997	December 1997	May 1999
SW-1	unusable	8	not sampled	3 J
SW-2	unusable	12	not sampled	not sampled
SW-3	< 5 J	< 5	not sampled	not sampled
SW-4	unusable	22	not sampled	not sampled
SW-5	118 D, J	33	not sampled	not sampled
SW-6	170 E	not sampled	not sampled	26
SW-7	600 E	83	not sampled	not sampled
SW-8	unusable	140 D	not sampled	not sampled
SW-9	670 E	130 E	not sampled	not sampled
SW-10	not sampled	98 D	not sampled	not sampled
SW-11	180 E	73	not sampled	not sampled
SW-12	unusable	72	not sampled	not sampled
SW-13	< 5 J	< 5	< 5	< 5
SW-WP-2	not sampled	77	55	43
SW-WP-3	not sampled	not sampled	90	84
SW-WP-P	not sampled	54	27	26
Well points				
WP-P	not sampled	180 D	160 D	not sampled
WP-2	not sampled	5	< 5	not sampled
WP-3	not sampled	< 5	< 5	not sampled