GROUND-WATER LEVELS AND DIRECTIONS OF FLOW IN THE VICINITY OF A WELL FIELD, ELKHART, INDIANA, DECEMBER 1989

By Richard F. Duwelius and Lee R. Watson

U.S. GEOLOGICAL SURVEY
Open-File Report 92-55

Prepared in cooperation with the
U.S. ENVIRONMENTAL PROTECTION AGENCY

Indianapolis, Indiana
1992

U.S. DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	*By*	*To obtain*
acre	4,047	square meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per mile (ft/mi)	0.1894	meter per kilometer
inch (in.)	2.54	centimeter
mile (mi)	1.609	kilometer
million gallons (Mgal)	3,785	cubic meter
million gallons per day (Mgal/d)	0.04381	cubic meter per second
square mile (mi^2)	2.59	square kilometer

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

$$^{\circ}C = (^{\circ}F - 32)/1.8$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum 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.

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ABSTRACT

Water levels were measured in 51 observation wells in the vicinity of the Elkhart Water Works Main Street well field during 5 days of normal pumping at the well field and little or no recharge to the ground water from precipitation. Water levels were measured once each day during December 18-22, 1989. Water-level altitudes were plotted and contoured on maps to determine the distribution of ground-water levels and directions of flow in the unconfined sand and gravel aquifer tapped by the well field.

Measured ground-water levels ranged from about 7.5 to 30 feet below land surface. Ground-water levels were highest north and northwest of the Main Street well field and lowest at the Main Street well field and near the St. Joseph River. Regional ground-water flow is toward the south or southeast. Ground-water levels near the river are higher than the river stage, indicating that ground water discharges to the river.

As a result of pumping, three cones of depression have formed in the water table in the mapped area. A small cone of depression northwest of the Main Street well field is caused by industrial pumping. Two cones of depression have formed at the Main Street well field--one in the eastern part of the well field and one in the western part of the well field.

Horizontal hydraulic gradients are variable in the study area but are largest in the eastern part of the Main Street well field and near the St. Joseph River. In general, water levels measured in seven sets of paired wells do not indicate a vertical hydraulic gradient; however, a downward gradient was measured in one set of paired wells near a pumped area at the Main Street well field.

INTRODUCTION

The city of Elkhart, Indiana, obtains its public water supply from well fields screened in sand-and-gravel outwash deposits. The oldest of the well fields, the Main Street well field, historically has supplied the largest volumes of ground water.

A water-quality sample of the Elkhart public water supply, collected by the U.S. Environmental Protection Agency (USEPA) in 1981, contained volatile organic compounds (VOC's) (Camp Dresser & McKee Inc. and others, 1989, section 1, p. 6). Consequently, the USEPA collected water-quality samples from selected production wells at the Main Street well field and from two other city well fields. The water-quality analyses indicated measurable concentrations of VOC's in water from at least three of the five wells sampled at the Main Street well field. As a result of these analyses, a well located in the southeastern part of the well field was removed from service (Camp Dresser & McKee Inc. and others, 1989, section 1, p. 7).

Subsequent investigations by the USEPA, the Elkhart Water Works, and the Indiana State Board of Health revealed that potential sources of ground-water contamination were located east of the Main Street well field (Camp Dresser & McKee Inc. and others, 1989, section 1, p. 9). In 1982, two interceptor wells were installed at the eastern boundary of the well field to provide a barrier to ground-water flow from the east. Ground-water pumpage from the interceptor wells was discharged to Christiana Creek.

Analyses of water-quality samples, collected during 1981-85 from production wells in the eastern part of the well field, indicated that concentrations of VOC's were decreasing. However, during 1983-85, water-quality analyses of the public water supply indicated that concentrations of VOC's were increasing. In 1984, increased concentrations of VOC's were detected in water from production wells located near the southwestern corner of the well field. By 1985, measurable concentrations of VOC's had been found in water from all the production wells (Camp Dresser & McKee Inc. and others, 1989, section 1, p. 9).

An air-stripping facility, designed to remove the VOC's, was placed in operation in late 1987. After that, water pumped from the two interceptor wells was routed to the air stripper. Since that time, studies have been done by various Federal, State and local agencies, and by private consultants to identify and quantify potential sources of ground-water contamination near the well field. At least 2 potential sources east of the well field and at least 10 potential sources to the west of the well field have been identified (Camp Dresser & McKee Inc. and others, 1989, section 2, p. 1-17).

In 1989, the USEPA needed information about the distribution of ground-water levels and directions of ground-water flow in the vicinity of the Main Street well field to help define the movement of ground-water contaminants near the well field. The U.S. Geological Survey (USGS) measured water levels daily in 51 observation wells near the well field during 5 days of normal pumping and little or no recharge of ground water by precipitation.

Purpose and Scope

This report presents the results of a study by the USGS, in cooperation with the USEPA, to determine ground-water levels and directions of ground-water flow in the unconfined sand and gravel aquifer in the vicinity of the Elkhart Water Works Main Street well field. Daily water-level measurements were made in 51 wells during December 18-22, 1989. Water-level altitudes from 44 wells were plotted and contoured on maps. Maps for each of the 5 days when measurements were made are included. Ground-water flow directions are indicated by arrows on the maps.

Site Description

The city of Elkhart occupies an area of about 17 mi^2 in northwestern Elkhart County, about 5 mi south of the Indiana-Michigan border in north-central Indiana (fig. 1). In 1980, the population of Elkhart was 43,100 and the population of the city proper and the suburbs was 68,000 (Elkhart Chamber of Commerce, 1990). Industrial activities in and near Elkhart include the manufacture of pharmaceuticals, recreational vehicles, mobile homes, and musical instruments. Agriculture, including dairy, poultry, and fruit farming, is the predominant land use in Elkhart County (Imbrigiotta and Martin, 1981, p. 4).

The Main Street well field is located in northwestern Elkhart, southwest of the intersection of North Main Street and Simonton Street (fig. 2). The well field, which consists of an area of about 48 acres, is bordered on the north, south, and west by residential areas and on the northeast, east, and southwest by industrial and commercial facilities. The well field includes 15 production wells; 2 interceptor/production wells; 6 recharge ponds; a water-treatment facility, including a packed-tower air stripper; and two 2-Mgal storage tanks (Donald Snyder, Elkhart Water Works, oral commun., 1991).

The area of study (fig. 3) contains the Main Street well field and the surrounding area in northwestern Elkhart, and includes about 1.24 mi^2. The area is bordered on the north by Bristol Street, on the south by Maple Row and the St. Joseph River, on the east by Cassopolis Street, and on the west by Oak Street.

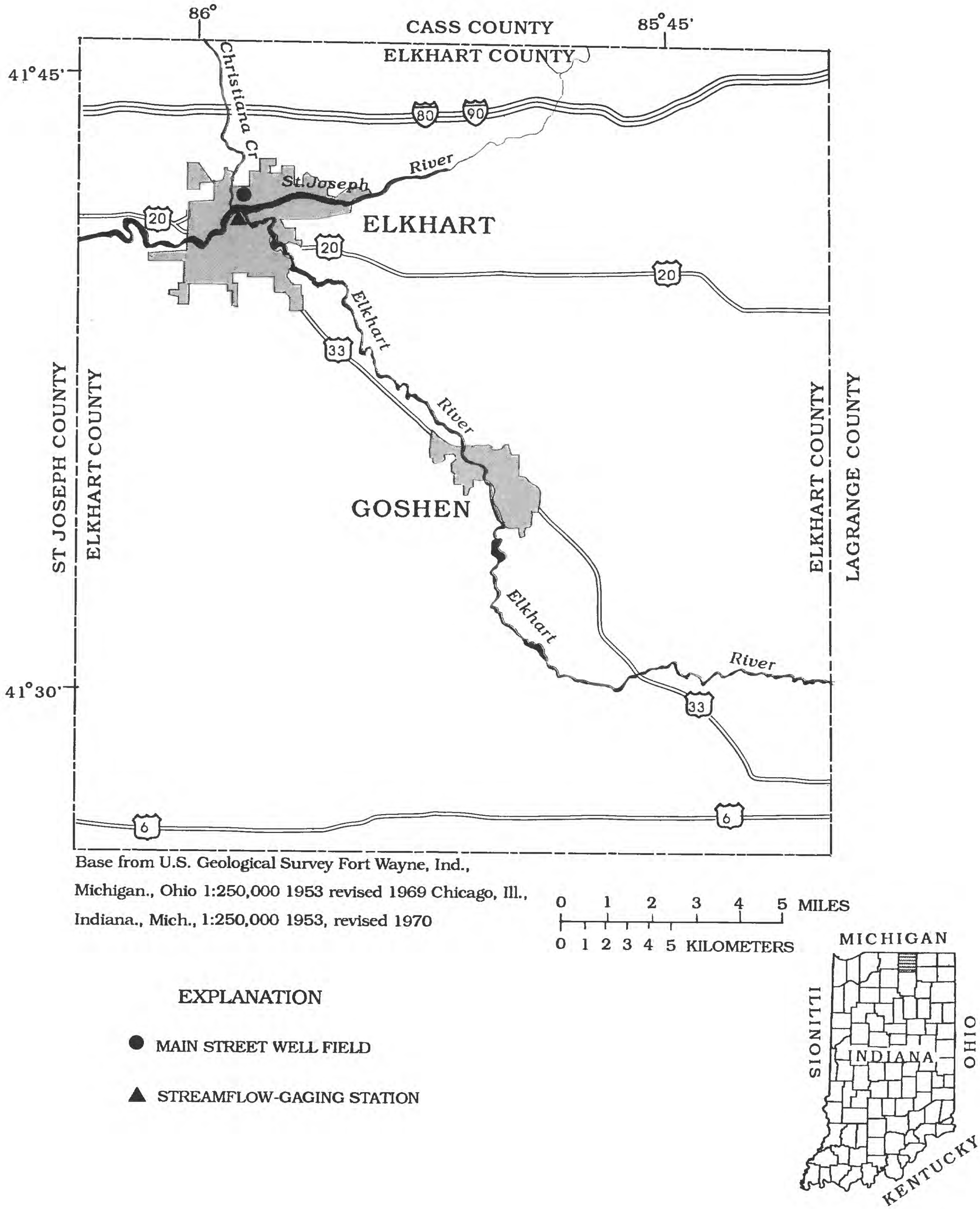
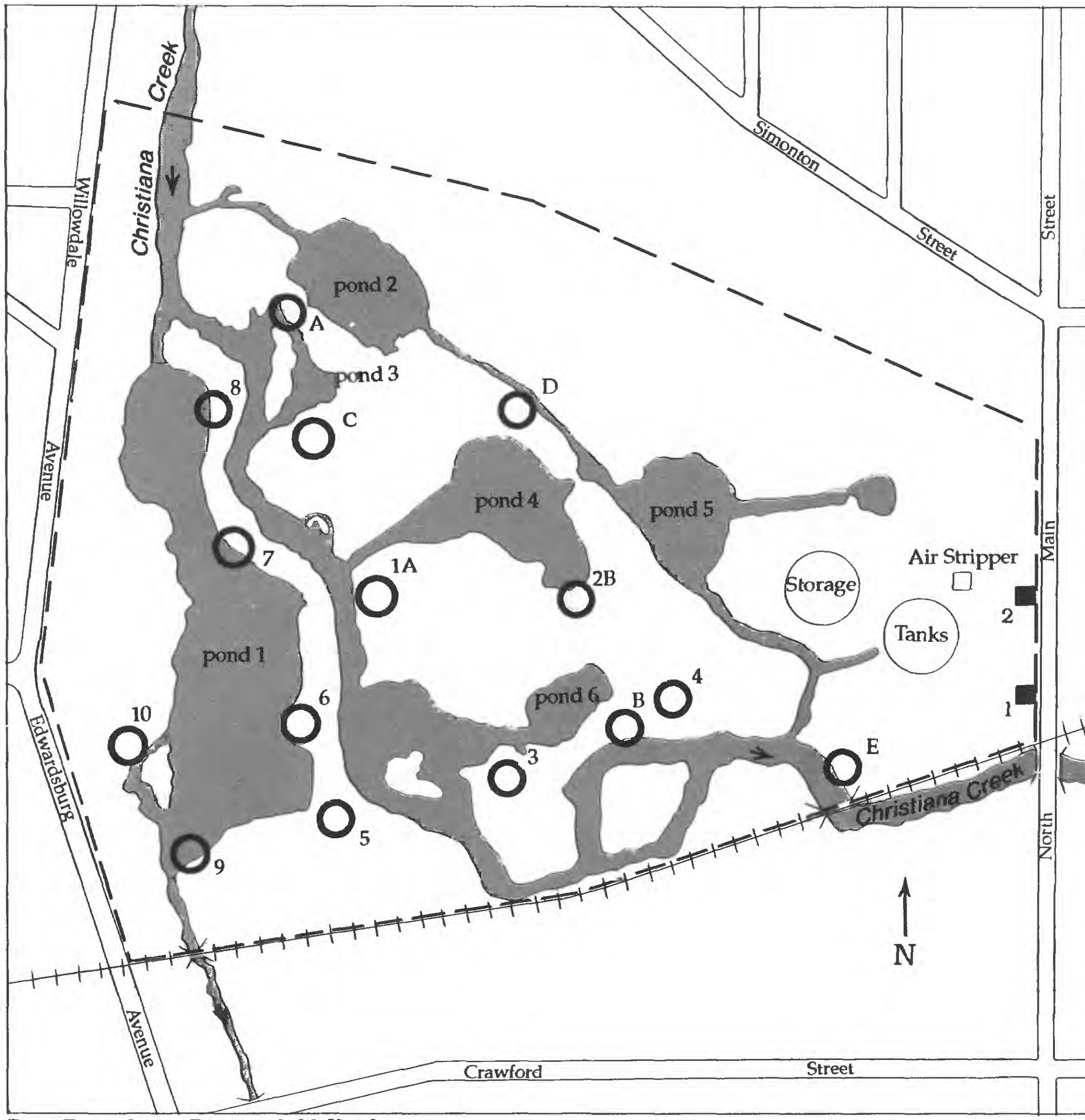


Figure 1. Location of Elkhart and the Main Street well field, Elkhart County, Indiana.



Base From Camp Dresser & McKee Inc. and others 1989

0 100 200 300 400 500 FEET

0 50 100 150 METERS

EXPLANATION

— — — WELL-FIELD BOUNDARY

DIRECTION OF FLOW

■ 1 INTERCEPTOR/PRODUCTION WELL AND DESIGNATION

O B PRODUCTION WELL AND DESIGNATION

Figure 2. Main Street well field, Elkhart, Indiana.

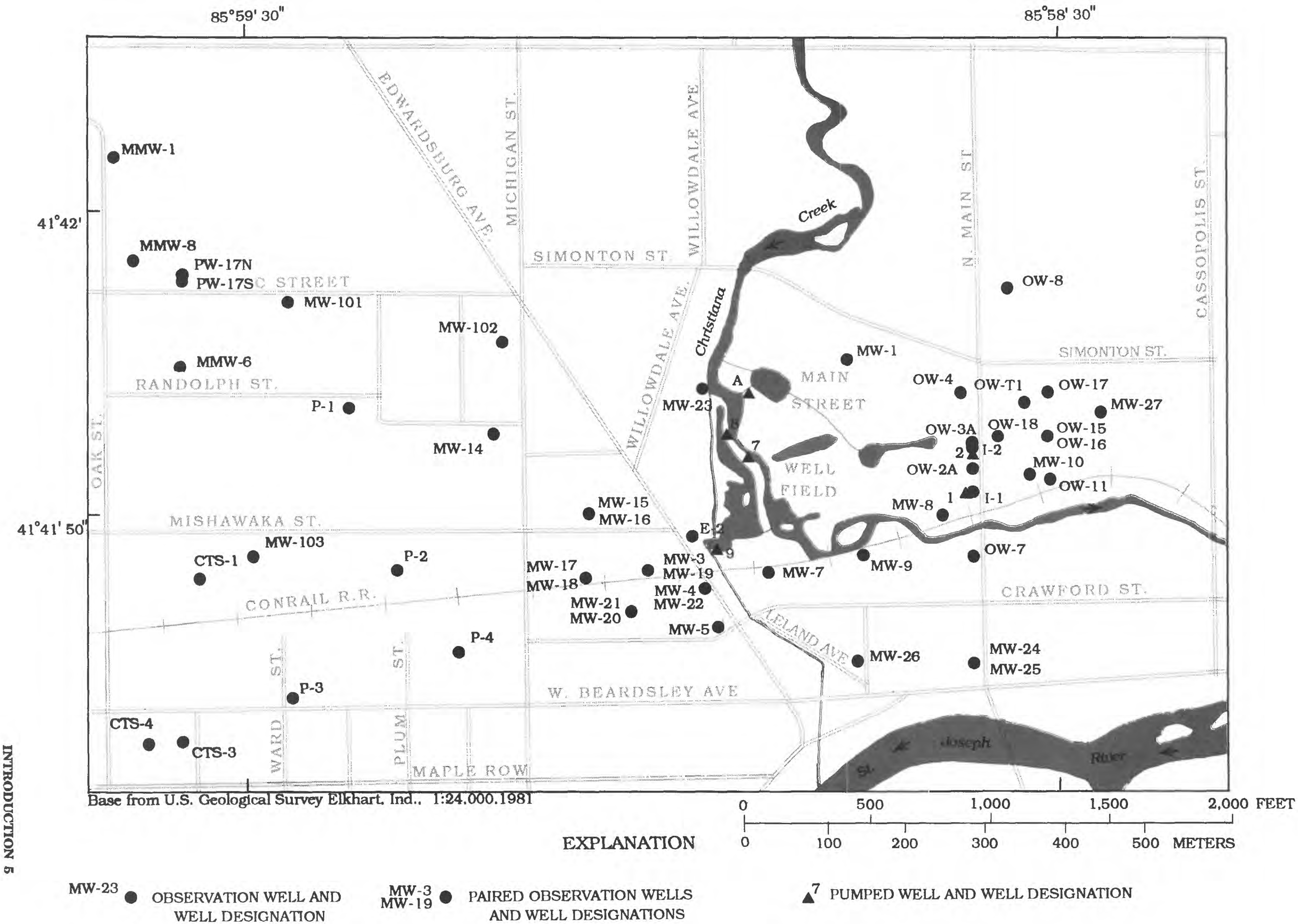


Figure 3. Location of observation and pumped wells in the vicinity of the Main Street well field.

Physiography and Climate

The study area is located in the Northern Moraine and Lake Region described by Malott (1922, p. 112) and Schneider (1966, p. 50). Land surface is nearly flat and land-surface altitudes range from about 745 ft above sea level near the St. Joseph River to about 760 ft above sea level in the northern part of the study area.

Elkhart County has a temperate climate, with a mean annual temperature of 49.6 °F and a mean annual precipitation of 33.7 in. During 1951-80, the mean monthly temperature ranged from 23.4 °F in January to 72.9 °F in July, and the mean monthly precipitation ranged from 1.58 in. in February to 3.66 in. in August (National Oceanic and Atmospheric Administration, 1982).

Geology

The study area is underlain by Devonian and Mississippian shale bedrock (Johnson and Keller, 1972). Lithologic logs of drilled wells show that the average depth to bedrock in the study area is about 175 ft. The bedrock dips about 30 ft/mi to the northeast (Indiana Department of Natural Resources, 1987, p. 15). Overlying the bedrock are unconsolidated deposits of glacial origin, primarily valley-train-outwash deposits. These deposits range in thickness from about 140 to 215 ft and contain thick layers of sand and gravel with interbedded silt and clay (Camp Dresser & McKee Inc. and others, 1989, section 4, p. 6).

At the well field, the bedrock is overlain by about 100 to 150 ft of silty clay; the clay is overlain by about 50 ft of sand and gravel. The surface of the silty-clay layer ranges from about 675 to 715 ft above sea level and slopes gently toward the south. West of the well field, a lower sand and gravel layer is present within the silty-clay layer. This lower sand and gravel layer ranges from about 50 to 75 ft in thickness (Imbrigiotta and Martin, 1981, p. 20).

Hydrology

The St. Joseph River is the principal surface-water feature in Elkhart County (fig. 1). The average discharge of the St. Joseph River at Elkhart is 3,218 ft^3/s for the 42-year period, August 1947 through September 1989. The maximum instantaneous discharge during that period was 18,800 ft^3/s in February 1985, and the minimum daily discharge was 336 ft^3/s in August 1964 (Thompson and Nell, 1990, p. 203). The drainage area of the St. Joseph River at Elkhart is 3,370 mi^2.

Christiana Creek enters the well field from the north (fig. 2), flows southerly near the western boundary, easterly near the southern boundary, and leaves the well field near the southeastern corner. Six recharge ponds were dug at the well field in the mid-1950's (Camp Dresser & McKee Inc. and others, 1989, section 1, p. 6). A series of low-head dams diverts water from Christiana Creek to the ponds and controls surface-water flow at the well field. Water in the ponds percolates downward and recharges the aquifer. This recharge reduces the size of the cone of depression caused by pumping at the well field. The ponds generally are an open, flow-through system; excess water is returned to Christiana Creek.

Two layers of sand and gravel separated by a layer of silt and clay that averages 20 ft in thickness underlie most of northwestern Elkhart County (Imbrigiotta and Martin, 1981, p. 15). The silt and clay layer divides the glacial deposits into an upper unconfined aquifer and a lower confined aquifer. The lower confined aquifer is absent at the Main Street well field but is present in the western part of the study area. Imbrigiotta and Martin (1981, p. 24) calculated the average horizontal hydraulic conductivity of the aquifer materials in northwestern Elkhart County to be 80 ft/d in sand and 400 ft/d in sand and gravel.

Conditions During the Study

Climatic and hydrologic conditions in the study area were generally stable before and during the 5 days when water levels were measured. Temperatures, measured at Goshen, Indiana, about 10 mi southeast of the study area (fig. 1) ranged from -9.9 °F to 21.0 °F during the 5 days preceding the study, and from -16.1 °F to 21.9 °F during the study. Precipitation, in depth of snowfall, was 1.5 in. during the 5 days preceding the study and 2.0 in. during the study (National Oceanic and Atmospheric Administration, 1989). The daily temperature records indicate that little or no snow would have melted to provide runoff to the streams or to infiltrate the ground to recharge the aquifer.

During the study, a total of six production wells were pumped at the Main Street well field (table 1 and fig. 2). Five wells were pumped during December 18-20 and on December 22. Six wells were pumped on December 21. Although pumping rates and pumpage volumes from individual wells are not known, total withdrawals for the 5 days ranged from about 4.6 to 5.2 Mgal/d (Donald Snyder, Elkhart Water Works, oral commun., 1991).

Acknowledgments

Access to privately owned wells located at CTS Corporation, Durakool, Inc., Elkhart Water Works, Excel Industries, Inc., and Miles Inc., was greatly appreciated.

Table 1. *Number of hours pumped and total pumpage from the Main Street well field, Elkhart, Indiana, December 18-22, 1989*

[Total pumpage in million gallons (Elkhart Water Works, written commun., 1990)]

December 18		December 19		December 20		December 21		December 22	
Well number	Hours pumped	Well number	Hours pumped	Well number	Hours pumped	Well number	Hours pumped	Well number	Hours pumped
2	24	2	24	2	24	1	9	1	23
A	21.5	A	23	A	23	2	24	2	24
7	21.5	7	23	7	23	A	13	7	23
8	21.5	8	23	8	23	7	22.5	8	23
9	24	9	24	9	24	8	22.5	9	24
						9	24		
Total hours pumped	112.5	Total hours pumped	117.0	Total hours pumped	117.0	Total hours pumped	115.0	Total hours pumped	117.0
Total pumpage	4.55	Total pumpage	5.24	Total pumpage	5.11	Total pumpage	5.17	Total pumpage	5.05

METHODS OF INVESTIGATION

Data-Collection Network

The data-collection network consisted of 51 observation wells screened in the unconfined sand and gravel aquifer near the well field (fig. 3). The network included 37 single wells and 7 sets of paired wells. Paired wells are sites where there are two wells screened at different depths in the aquifer. Well depths range from about 17 to 71 ft below land surface. Most of the wells used in this study were installed during previous studies; the well numbers from those studies were retained for this report. None of the wells measured for this study was a production or pumped well. Measuring-point altitudes for the wells were provided by the USEPA and were determined by leveling from benchmarks to each observation well. Descriptions of the observation wells are listed in table 2.

Table 2. *Description of observation wells in the vicinity of the Main Street well field*

[--, data not available; A, auger; <, less than; SS, stainless steel; PVC, polyvinyl chloride]

Well number	Date installed	Method of drilling	Well depth (feet)	Screen length (feet)	Casing diameter (inches)	Casing material	Measuring-point altitude (feet above sea level)	Height of measuring-point above land surface (feet)
CTS-1	--	--	< 51.0	--	--	--	748.31	--
CTS-3	--	--	< 46.0	--	--	--	748.16	--
CTS-4	--	--	< 52.0	--	--	--	748.26	--
E-2	--	--	--	--	--	--	750.67	--
I-1	--	--	--	--	--	--	747.76	--
I-2	--	--	--	--	--	--	747.33	--
MMW-1	--	--	< 42.0	--	--	--	757.34	--
MMW-6	--	--	< 49.0	--	--	--	753.21	--
MMW-8	--	--	< 43.0	--	--	--	755.44	--
MW-1	--	--	45.7	10	--	--	750.47	0.78
MW-3	--	--	70.0	10	--	--	749.83	2.88
MW-4	--	--	71.5	10	--	--	750.00	1.48
MW-5	--	--	57.0	10	--	--	750.66	2.62
MW-7	--	--	71.3	10	--	--	750.89	2.56
MW-8	--	--	47.0	10	--	--	745.39	2.39
MW-9	--	--	48.8	10	--	--	743.48	1.71
MW-10	--	--	38.4	10	--	--	742.06	1.66
MW-14	04/20/88	A	23.0	10	2	SS	748.16	2.07
MW-15	04/15/88	A	62.0	10	2	SS	749.75	3.56
MW-16	04/15/88	A	38.0	10	2	SS	749.09	3.05
MW-17	04/26/88	A	53.0	10	2	SS	749.92	1.50

Table 2. *Description of observation wells in the vicinity of the Main Street well field*--Continued

Well number	Date installed	Method of drilling	Well depth (feet)	Screen length (feet)	Casing diameter (inches)	Casing material	Measuring-point altitude (feet above sea level)	Height of measuring-point above land surface (feet)
MW-18	04/26/88	A	23.0	10	2	SS	750.14	1.83
MW-19	04/20/88	A	33.0	10	2	SS	748.84	1.90
MW-20	04/27/88	A	53.0	10	2	SS	749.60	2.08
MW-21	04/28/88	A	33.0	10	2	SS	749.14	1.74
MW-22	04/17/88	A	43.0	10	2	SS	750.66	1.80
MW-23	04/13/88	A	43.0	10	2	SS	747.80	1.80
MW-24	04/29/88	A	43.0	10	2	SS	750.86	1.46
MW-25	04/29/88	A	38.0	10	2	SS	751.36	1.96
MW-26	04/18/88	A	48.0	10	2	SS	750.56	2.38
MW-27	05/05/88	A	28.0	10	2	SS	749.10	1.61
MW-101	12/10/89	--	22.4	10	2	SS	756.67	2.10
MW-102	12/11/89	--	22.2	10	2	SS	755.44	2.50
MW-103	12/07/89	--	17.1	10	2	SS	748.99	2.20
OW-2A	--	--	< 33.8	--	--	--	748.07	--
OW-3A	--	--	< 33.8	--	--	--	747.01	--
OW-4	--	--	< 24.0	--	--	--	747.00	--
OW-7	--	--	< 23.8	--	--	--	749.54	--
OW-8	--	--	< 29.0	--	--	--	752.56	--
OW-11	--	--	< 23.8	--	--	--	745.66	--
OW-15	--	--	< 24.0	--	--	--	742.30	--
OW-16	--	--	< 25.0	--	--	--	749.03	--
OW-17	--	--	< 24.0	--	--	--	750.00	--
OW-18	--	--	< 18.9	--	--	--	742.70	--
OW-T1	--	--	--	--	--	--	744.45	--
P-1	12/12/89	--	17.6	10	2	PVC	752.51	2.48
P-2	12/09/89	--	19.1	10	2	PVC	749.91	2.53
P-3	11/08/89	--	17.9	10	2	PVC	746.04	2.50
P-4	12/09/89	--	21.2	10	2	PVC	747.76	2.41
PW-17N	--	--	--	--	--	--	755.31	--
PW-17S	--	--	--	--	--	--	754.86	--

Water-Level Measurements

Water levels were measured with an electrical water-level indicator that has a measuring tape graduated in 0.05-ft increments. Visual interpolation was made for each measurement, and the depth to water was recorded to 0.01 ft. The tape was rinsed with deionized water after each measurement to reduce the risk of cross-contaminating the wells. Water-level altitudes were determined by subtracting the depth to water from the measuring-point altitude.

Surface-water levels in Christiana Creek and the recharge ponds were not measured during the test but were measured August 14 and 15, 1990. Because the overflow structures of dams that control the stage in the ponds have fixed altitudes, pond stage does not fluctuate greatly except during times of extreme low flow in Christiana Creek (Donald Snyder, Elkhart Water Works, oral commun., 1991). The surface-water levels measured in August are assumed to be similar to those during the test.

GROUND-WATER LEVELS AND DIRECTIONS OF FLOW

During the 5-day study, measured ground-water levels ranged from about 7.5 ft below land surface in well MW-10 on December 22 to about 30 ft below land surface in well I-2 on December 18. The average measured depth to water throughout the study area was about 15 ft. Calculated ground-water altitudes ranged from about 717 to 742 ft above sea level. The measured depths to water and calculated water-level altitudes are listed in table 3 at back of report.

Ground-water altitudes were plotted and contoured on maps to determine the distribution of water levels and direction of flow in the unconfined aquifer near the Main Street well field. Maps were drawn for each of the 5 days when water levels were measured. The maps were compared to determine if changes in water levels or flow direction had occurred during the aquifer test. No substantial differences in flow direction were found; however, minor differences in water levels were noted.

Water levels in the unconfined aquifer on December 18 are shown in figure 4. Ground-water levels are highest north and northwest of the Main Street well field and lowest in the eastern part of the Main Street well field and near the St. Joseph River. The direction of ground-water flow is perpendicular to the contour lines and, in the study area, is generally toward the south or southeast and the St. Joseph River. River stage was determined by using the average daily gage height, determined from records at the USGS streamflow-gaging station. The station (number 04101000) is located on the St. Joseph River approximately 200 ft downstream from the mouth of the Elkhart River and approximately 1,800 ft southeast of the Main Street well field. Ground-water levels near the river are higher than the stage of the river, indicating that ground water discharges to the river.

Three cones of depression in the water table are shown in figure 4. The cones of depression, shown by water-level contours that bend around the pumped wells, indicate areas in which the water table is lowered by pumping. The small cone of depression in the northwestern part of the mapped area is caused by industrial pumping. The small cone of depression at the Main Street well field is located near interceptor/production well 2 in the eastern part of the well field (fig. 2). The large cone of depression at the Main Street well field is located near production wells A, 7, 8, and 9 in the western part of the well field. Water levels were not measured in the production or pumped wells; therefore, the maximum drawdown is not known.

Ground-water levels at the Main Street well field indicate that pumping lowers the water table below the level of the bottom of the recharge ponds. Water levels in the recharge ponds and Christiana Creek, measured August 14-15, 1990, ranged from about 745 ft above sea level near the upstream end of the ponds to about 740 ft above sea level near the downstream end. The depth of water in the ponds is variable, but averages about 6 ft (Donald Snyder, Elkhart Water Works, oral commun., 1991). Measured ground-water levels at the well field ranged from about 717 ft above sea level at well I-2, an observation well located about 2 ft from interceptor/production well 2, to about 733 ft above sea level at well MW-9 (table 3 and fig. 3).

Determination of the volume of water that seeps from the ponds to recharge the aquifer is beyond the scope of this report. However, because ground-water levels are below the altitudes of the pond bottoms, there is no direct hydraulic connection between the ponds and the ground water; the rate of seepage is independent of the water level in the aquifer. The rate of seepage is controlled by the water level in the ponds and the vertical hydraulic conductivity of the sediment on the pond bottoms. The Elkhart Water Works periodically drains and cleans the ponds to prevent build up of silt and organic material that would lower the vertical hydraulic conductivity. Pond water that recharges the aquifer is captured by the pumped wells, thereby reducing expansion of the cone of depression.

Water levels in the unconfined aquifer during December 19-22 (figs. 5-8) show the same general trends as those on the water-level map for December 18. Regional ground-water flow is toward the south or southeast; three cones of depression are indicated on the maps. During the 5-day study, water levels increased in the eastern part of the mapped area near the Main Street well field and decreased in the western part of the mapped area. The largest increases in water level were 2.7 ft at well OW-2A and 2.5 ft at well MW-8 in the eastern part of the well field. Water-level decreases ranged from 0.10 to 0.20 ft.

Because little or no recharge of the aquifer by precipitation or snowmelt occurred, the rise in water levels is related to a decrease in pumpage at the well field. Although pumpage from individual wells is not known, total pumpage from the well field was fairly constant for the 5 days during which water levels were measured. Therefore, the rise in water levels indicates that pumpage rates at the well field were larger before the study than during the study.

Horizontal hydraulic gradients are variable in the mapped area but were not calculated. Horizontal gradients are largest where contour lines (figs. 4-8) are closely spaced and smallest where contour lines are widely spaced. Inspection of the water-level maps indicates the horizontal hydraulic gradients are largest in the eastern part of the Main Street well field and near the St. Joseph River.

Water levels were measured in seven sets of paired wells (table 3) to determine vertical hydraulic gradients. The data indicate little or no difference in water levels for paired wells at the same location. The majority of water-level differences for the paired wells are less than or equal to 0.04 ft, within the range of error for the method of measurement. The largest difference between water levels is at well pair MW-4 and MW-22 where the shallow well, MW-4, had water levels ranging from 0.06 to 0.11 ft higher than the water level in the deep well, MW-22. The higher water level in the shallow well compared to that in the deep well indicates downward flow related to pumping near this site.

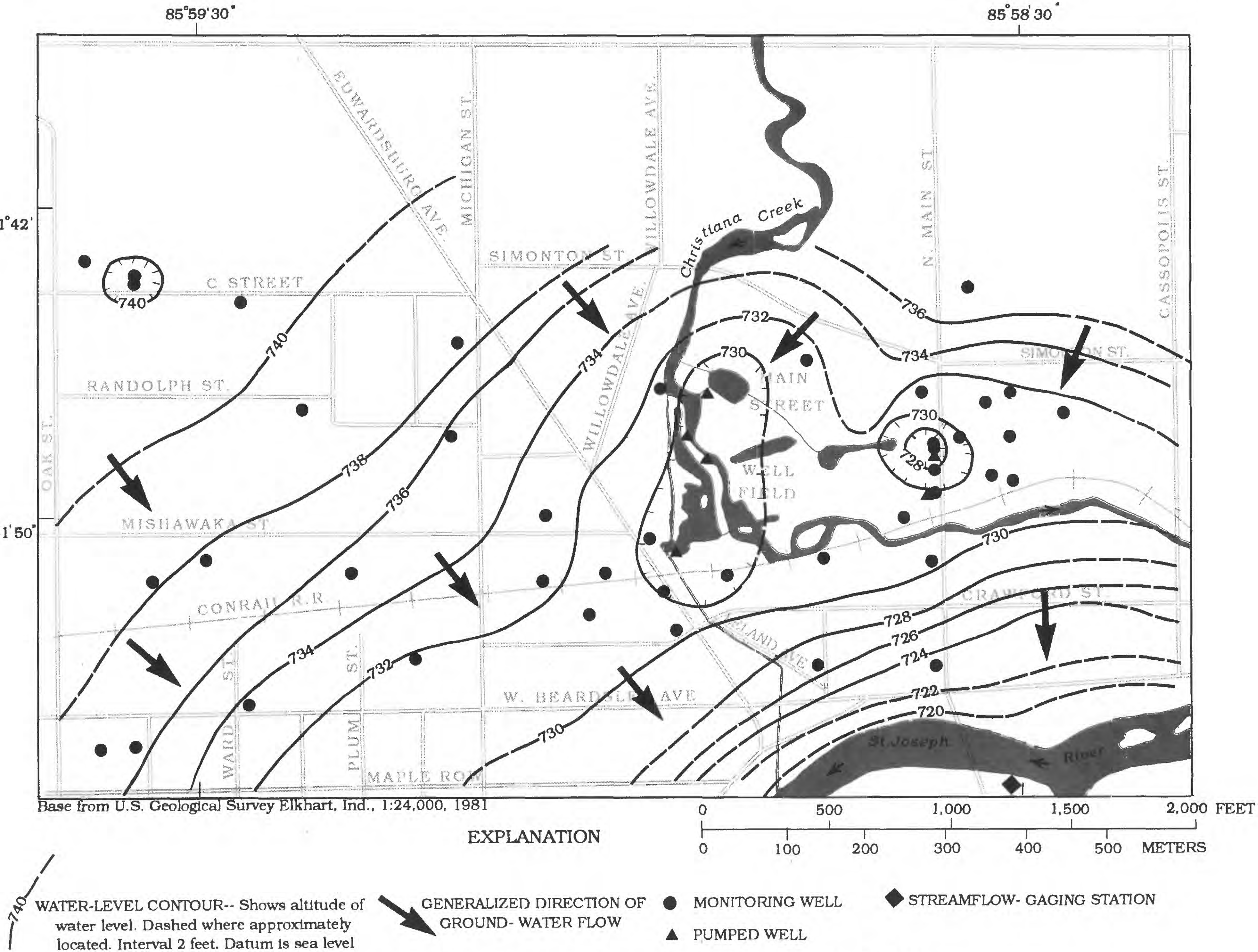
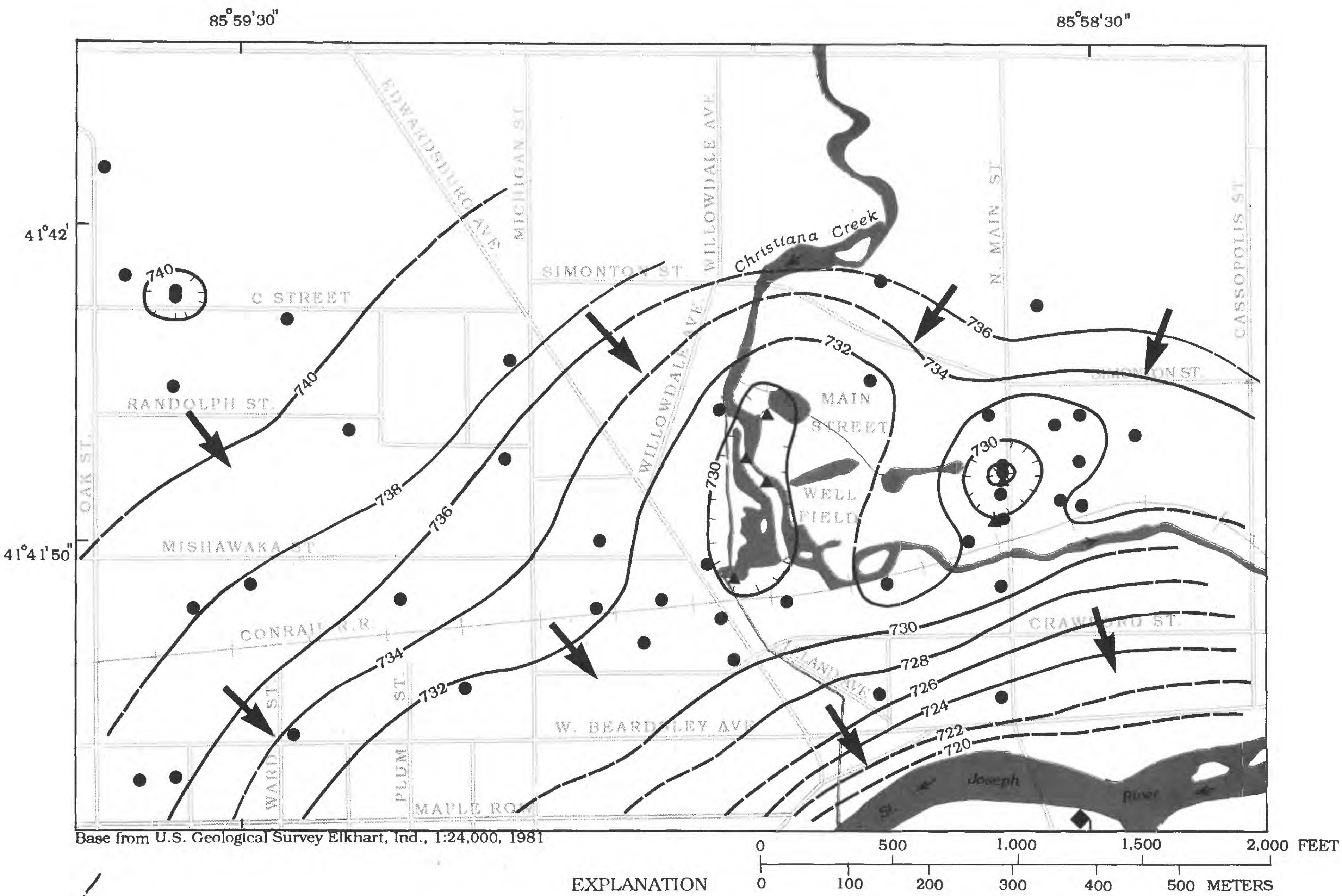


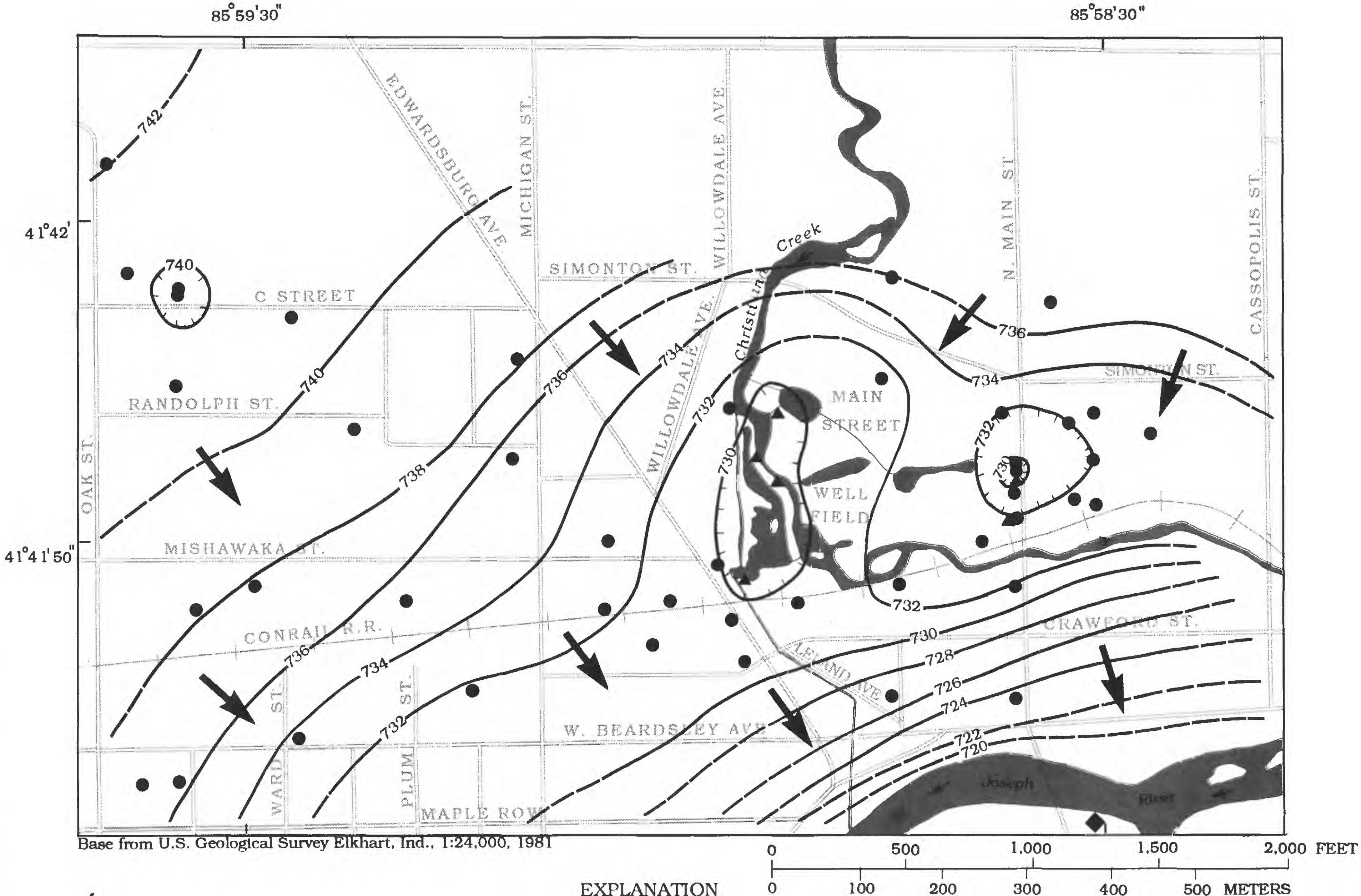
Figure 4. Water levels and flow directions in the unconfined aquifer, December 18, 1989.



EXPLANATION

- WATER-LEVEL CONTOUR--Shows altitude of water level. Dashed where approximately located. Interval 2 feet. Datum is sea level (740)
- GENERALIZED DIRECTION OF GROUND-WATER FLOW
- ● MONITORING WELL
- ▲ PUMPED WELL
- ◆ STREAMFLOW-GAGING STATION

Figure 5. Water levels and flow directions in the unconfined aquifer, December 19, 1989.



EXPLANATION

- WATER-LEVEL CONTOUR--Shows altitude of water level. Dashed where approximately located. Interval 2 feet. Datum is sea level (740)
- GENERALIZED DIRECTION OF GROUND-WATER FLOW
- ● MONITORING WELL
- ▲ PUMPED WELL
- ◆ STREAMFLOW-GAGING STATION

Figure 6. Water levels and flow directions in the unconfined aquifer, December 20, 1989.

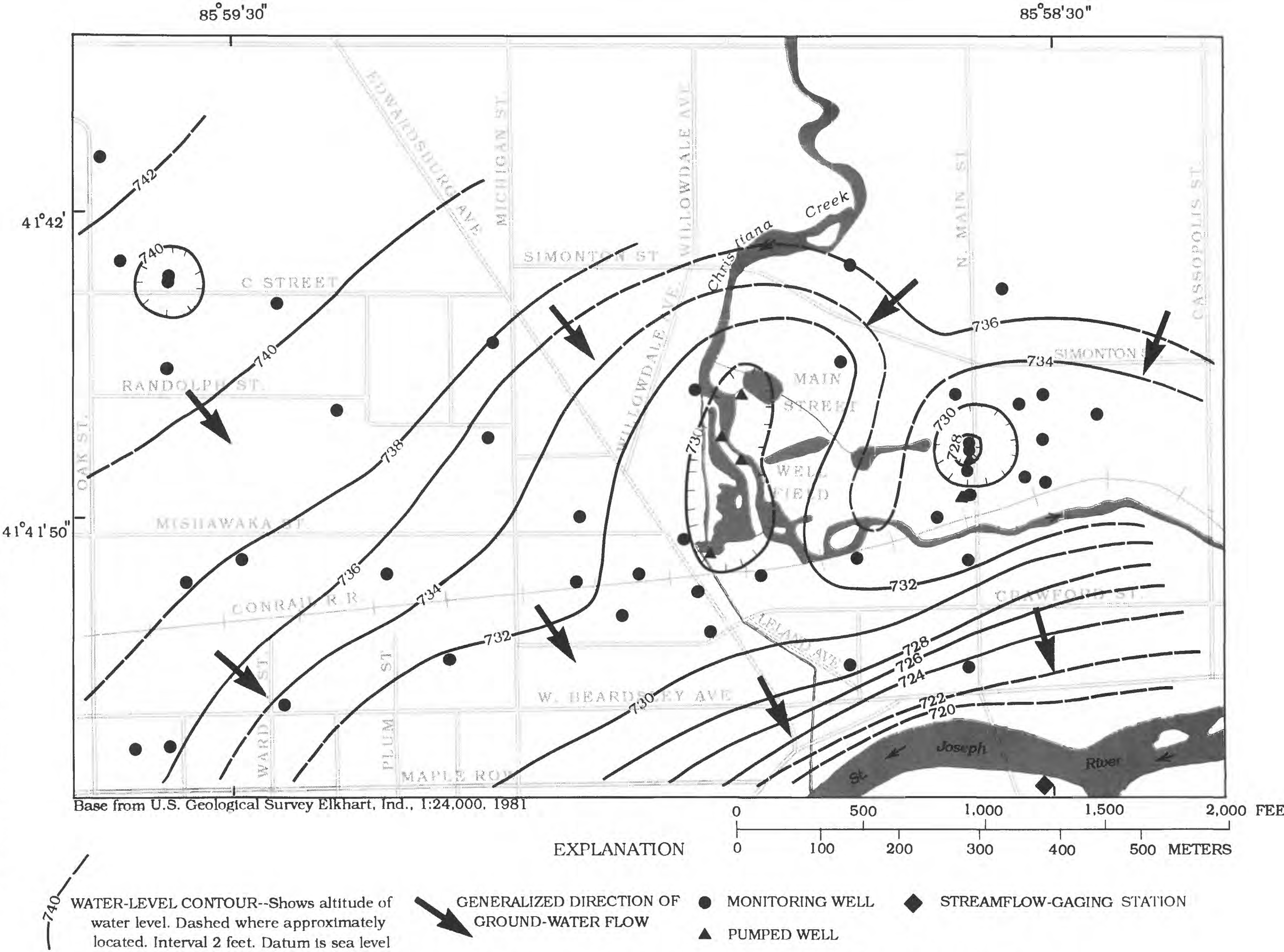


Figure 7. Water levels and flow directions in the unconfined aquifer, December 21, 1989.

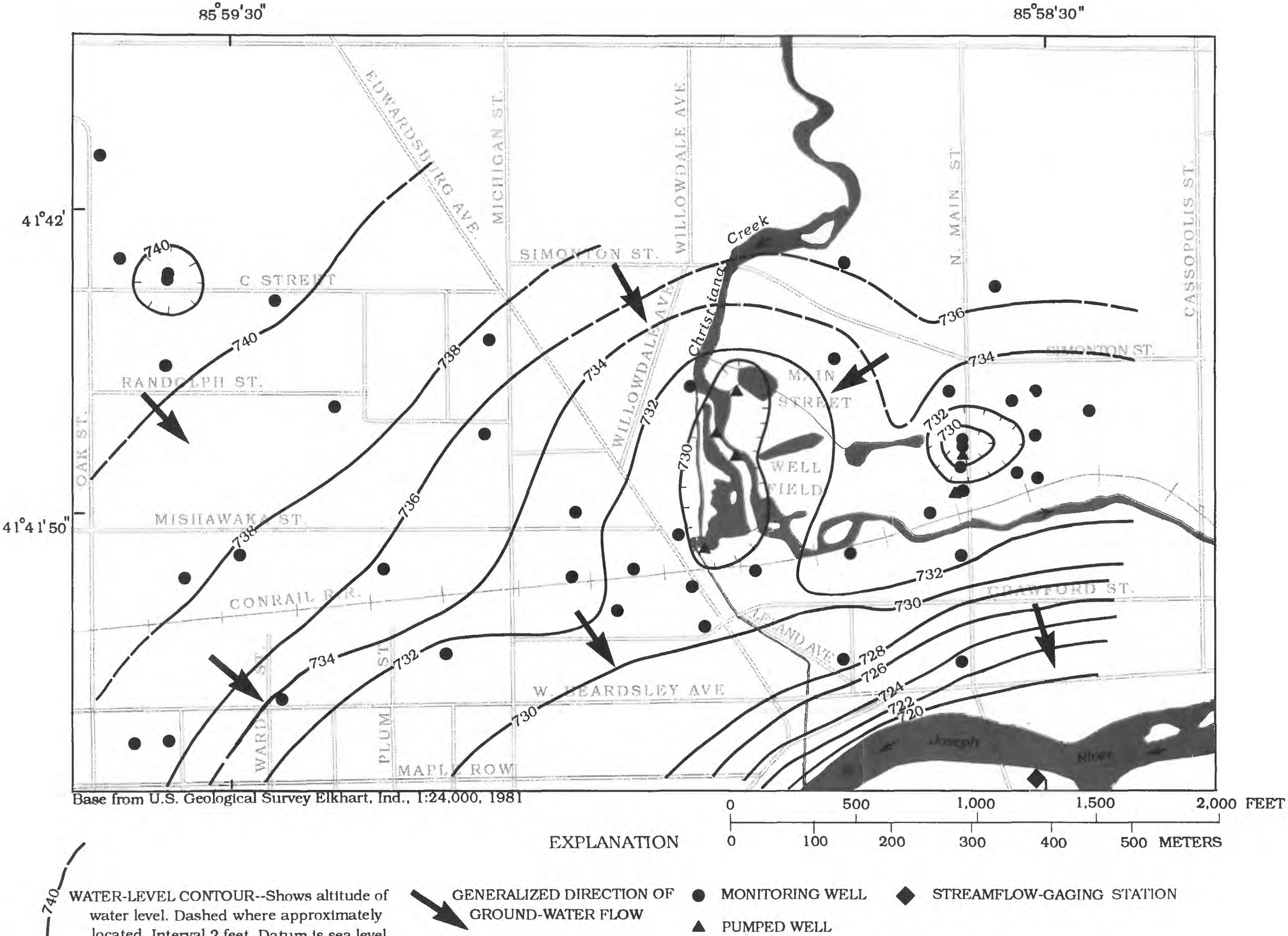


Figure 8. Water levels and flow directions in the unconfined aquifer, December 22, 1989.

SUMMARY

The city of Elkhart, Indiana, obtains its public water supply from well fields screened in sand-and-gravel outwash deposits. Water quality at the Main Street well field, in northwestern Elkhart, has changed as a result of commercial and industrial activities in adjacent areas. Water levels were measured in 51 wells in the vicinity of the well field during the 5-day period, December 18-22, 1989, to determine the ground-water levels and directions of flow. During the 5 days, there was normal pumping at the well field and little or no ground-water recharge from precipitation.

Measured ground-water levels ranged from about 7.5 to 30 ft below land surface during the study. The average measured depth to water was about 15 ft. Ground-water altitudes ranged from about 717 to 742 ft above sea level. Water-level maps were drawn for each of the 5 days and compared to determine whether changes in water levels or directions of flow had occurred during the study. No substantial differences in flow direction were noted; however, water levels near the well field rose during the study. The rise in water levels indicates that pumpage rates at the well field were larger before the study than during the study.

Ground-water levels are highest north and northwest of the Main Street well field and lowest in the eastern part of the Main Street well field and near the St. Joseph River. Ground-water flow is generally toward the south or southeast. Ground-water levels near the river are higher than the river stage, indicating that ground water discharges to the river.

Three cones of depression have formed in the water table because of pumping. A small cone of depression in the northwestern part of the study area is a result of industrial pumping. Two cones of depression have formed at the Main Street well field--one in the eastern part of the well field and one in the western part of the well field.

Horizontal hydraulic gradients are steepest near the well field and the St. Joseph River. Vertical hydraulic gradients generally were not detected by measurements at sites where there are two wells screened at different depths. The one exception was near an area of pumping in the southwestern part of the well field where a downward gradient was measured.

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Table 3. *Ground-water levels measured in the vicinity of the Main Street well field, Elkhart, Indiana, December 18-22, 1989*

[Time in military notation, depth to water in feet below measuring point, water-level altitude in feet above sea level, --- indicates no data]

	Well								
	CTS-1	CTS-3	CTS-4	E-2	I-1	I-2	MMW-1	MMW-6	MMW-8
12/18/1989									
Time	1403	1356	1354	1237	0921	0915	---	---	1452
Depth to water	9.83	11.28	11.08	20.94	17.51	30.33	---	---	14.70
Water-level altitude	738.48	736.88	737.18	729.73	730.25	717.00	---	---	740.74
12/19/1989									
Time	1054	1045	1042	1135	0825	0816	1355	1535	1349
Depth to water	9.87	11.28	11.08	20.69	16.63	29.58	15.60	12.68	14.70
Water-level altitude	738.44	736.88	737.18	729.98	731.13	717.75	741.74	740.53	740.74
12/20/1989									
Time	1029	1019	1017	1145	0815	0810	1332	1317	1327
Depth to water	9.87	11.31	11.10	20.46	15.99	28.98	15.30	12.71	14.72
Water-level altitude	738.44	736.85	737.16	730.21	731.77	718.35	742.04	740.50	740.72
12/21/1989									
Time	1002	0954	0950	1057	0829	0819	1159	1148	1155
Depth to water	9.90	11.32	11.12	20.26	15.53	28.56	14.93	12.79	14.75
Water-level altitude	738.41	736.84	737.14	730.41	732.23	718.77	742.41	740.42	740.69
12/22/1989									
Time	0934	0922	0920	1027	0712	0704	1130	1119	1126
Depth to water	9.95	11.36	11.14	20.27	15.32	28.33	15.52	12.88	14.77
Water-level altitude	738.36	736.80	737.12	730.40	732.44	719.00	741.82	740.33	740.67

Table 3. *Ground-water levels measured in the vicinity of the Main Street well field, Elkhart, Indiana, December 18-22, 1989*--Continued

	Well									
	MW-1	MW-3[1]	MW-4[2]	MW-5	MW-7	MW-8	MW-9	MW-10	MW-14	MW-15[3]
12/18/1989										
Time	0909	1254	1232	1227	1225	0925	1037	1027	1512	1249
Depth to water	19.15	18.52	20.10	20.58	21.09	14.80	12.48	10.66	12.73	17.42
Water-level altitude	731.32	731.31	729.90	730.08	729.80	730.59	731.00	731.40	735.43	732.33
12/19/1989										
Time	0809	1123	1142	1145	1150	0828	0932	0907	1403	1117
Depth to water	19.05	18.42	19.78	20.34	20.46	13.70	11.14	10.03	12.76	17.38
Water-level altitude	731.42	731.41	730.22	730.32	730.43	731.69	732.34	732.03	735.40	732.37
12/20/1989										
Time	0803	1105	1122	1129	1155	0820	0925	0855	1342	1058
Depth to water	18.96	18.28	19.48	20.07	19.95	12.92	10.27	9.56	12.79	17.34
Water-level altitude	731.51	731.55	730.52	730.59	730.94	732.47	733.21	732.50	735.37	732.41
12/21/1989										
Time	0811	1021	1053	1049	1106	0833	0925	0908	1205	1018
Depth to water	18.79	18.16	19.21	19.82	19.60	12.40	9.84	9.28	12.81	17.27
Water-level altitude	731.68	731.67	730.79	730.84	731.29	732.99	733.64	732.78	735.35	732.48
12/22/1989										
Time	0655	1002	1018	1022	1025	0716	1045	0758	1138	1014
Depth to water	18.35	18.08	19.17	19.70	19.75	12.30	10.30	9.18	12.82	17.21
Water-level altitude	732.12	731.75	730.83	730.96	731.14	733.09	733.18	732.88	735.34	732.54

Table 3. *Ground-water levels measured in the vicinity of the Main Street well field, Elkhart, Indiana, December 18-22, 1989*--Continued

	Well									
	MW-16	MW-17[4]	MW-18	MW-19	MW-20[5]	MW-21	MW-22	MW-23	MW-24	MW-25[6]
12/18/1989										
Time	1248	1303	1302	1253	1256	1257	1234	1242	1050	1046
Depth to water	16.77	17.55	17.79	17.51	18.03	17.57	20.65	17.30	27.78	28.31
Water-level altitude	732.32	732.37	732.35	731.33	731.57	731.57	730.01	730.50	723.08	723.05
12/19/1989										
Time	1118	1128	1127	1124	1421	1419	1143	1305	1157	1158
Depth to water	16.72	17.50	17.73	17.39	17.93	17.45	20.37	17.25	27.70	28.22
Water-level altitude	732.37	732.42	732.41	731.45	731.67	731.69	730.29	730.55	723.16	723.14
12/20/1989										
Time	1059	1115	1112	1107	1135	1137	1123	1150	1206	1205
Depth to water	16.67	17.44	17.67	17.27	17.84	17.37	20.08	17.48	27.54	28.08
Water-level altitude	732.42	732.48	732.47	731.57	731.76	731.77	730.58	730.32	723.32	723.28
12/21/1989										
Time	1016	1027	1025	1022	1046	1045	1054	1059	1117	1115
Depth to water	16.61	17.37	17.61	17.14	17.73	17.26	19.81	17.48	27.35	27.89
Water-level altitude	732.48	732.55	732.53	731.70	731.87	731.88	730.85	730.32	723.51	723.47
12/22/1989										
Time	1012	1007	1009	1004	0957	0954	1016	1030	1104	1102
Depth to water	16.55	17.32	17.56	17.07	17.65	17.91	19.77	16.68	27.13	27.67
Water-level altitude	732.54	732.60	732.58	731.77	731.95	731.23	730.89	731.12	723.73	723.69

Table 3. *Ground-water levels measured in the vicinity of the Main Street well field, Elkhart, Indiana, December 18-22, 1989*--Continued

	Well									
	MW-26	MW-27	MW-101	MW-102	MW-103	OW-2A	OW-3A	OW-4	OW-7	OW-8
12/18/1989										
Time	1057	1118	1435	1427	1335	0918	0852	0855	1043	1005
Depth to water	23.27	17.37	16.17	17.29	11.24	19.51	19.67	15.72	18.93	14.82
Water-level altitude	727.29	731.73	740.50	738.15	737.75	728.56	727.34	731.28	730.61	737.74
12/19/1989										
Time	1155	0854	1340	1325	1058	0820	0745	0802	0945	0902
Depth to water	22.97	16.95	16.19	17.34	11.28	18.62	18.80	15.39	18.13	14.82
Water-level altitude	727.59	732.15	740.48	738.10	737.71	729.45	728.21	731.61	731.41	737.74
12/20/1989										
Time	1200	0845	1315	1309	1037	0812	0745	0755	0930	0848
Depth to water	22.62	16.60	16.22	17.41	11.30	17.85	18.13	15.02	17.55	14.80
Water-level altitude	727.94	732.50	740.45	738.03	737.69	730.22	728.88	731.98	731.99	737.76
12/21/1989										
Time	1109	0902	1145	1139	1005	0824	0800	0803	0938	0857
Depth to water	22.26	16.34	16.25	17.45	11.34	17.24	17.62	14.65	17.14	14.78
Water-level altitude	728.30	732.76	740.42	737.99	737.65	730.83	729.39	732.35	732.40	737.78
12/22/1989										
Time	1055	0744	1115	1112	0942	0709	0645	0650	1052	0750
Depth to water	21.96	16.19	16.30	17.50	11.40	16.85	17.36	14.36	16.97	14.75
Water-level altitude	728.60	732.91	740.37	737.94	737.59	731.22	729.65	732.64	732.57	737.81

Table 3. *Ground-water levels measured in the vicinity of the Main Street well field, Elkhart, Indiana, December 18-22, 1989*--Continued

	Well					
	OW-11	OW-15[7]	OW-16	OW-17	OW-18	OW-T1
12/18/1989						
Time	1110	0952	0950	0948	1023	1013
Depth to water	13.97	11.27	17.97	18.72	13.72	13.52
Water-level altitude	731.69	731.03	731.06	731.28	728.98	730.93
12/19/1989						
Time	0920	0847	0845	0842	0912	0838
Depth to water	13.41	10.69	17.40	18.17	13.58	12.92
Water-level altitude	732.25	731.61	731.63	731.83	729.12	731.53
12/20/1989						
Time	0944	0835	0834	0831	0858	0829
Depth to water	13.00	10.25	16.96	17.73	13.49	12.45
Water-level altitude	732.66	732.05	732.07	732.27	729.21	732.00
12/21/1989						
Time	0920	0850	0847	0844	0912	0842
Depth to water	12.78	9.95	16.65	17.42	13.35	12.10
Water-level altitude	732.88	732.35	732.38	732.58	729.35	732.35
12/22/1989						
Time	0812	0738	0736	0734	0802	0730
Depth to water	12.73	9.78	16.48	17.22	13.20	11.90
Water-level altitude	732.93	732.52	732.55	732.78	729.50	732.55

Table 3. *Ground-water levels measured in the vicinity of the Main Street well field, Elkhart, Indiana, December 18-22, 1989*--Continued

	Well					
	P-1	P-2	P-3	P-4	PW-17N	PW-17S
12/18/1989						
Time	1516	1309	1329	1312	1440	1438
Depth to water	13.97	14.28	13.10	15.95	15.66	15.13
Water-level altitude	738.54	735.63	732.94	731.81	739.65	739.73
12/19/1989						
Time	1400	1110	1104	1106	1345	1346
Depth to water	13.98	14.30	13.11	15.97	15.67	15.02
Water-level altitude	738.53	735.61	732.93	731.79	739.64	739.84
12/20/1989						
Time	1337	1045	1042	1052	1324	1323
Depth to water	14.01	14.32	13.13	15.97	15.70	15.18
Water-level altitude	738.50	735.59	732.91	731.79	739.61	739.68
12/21/1989						
Time	1203	1035	0955	1037	1153	1152
Depth to water	14.07	14.33	13.15	15.96	15.72	15.20
Water-level altitude	738.44	735.58	732.89	731.80	739.59	739.66
12/22/1989						
Time	1135	0950	0929	0952	1123	1122
Depth to water	14.15	14.36	13.18	15.96	15.77	15.25
Water elevation	738.36	735.55	732.86	731.80	739.54	739.61

[1] Not used for water-level map, paired with well MW-19.
[2] Not used for water-level map, paired with well MW-22.
[3] Not used for water-level map, paired with well MW-16.
[4] Not used for water-level map, paired with well MW-18.
[5] Not used for water-level map, paired with well MW-21.
[6] Not used for water-level map, paired with well MW-24.
[7] Not used for water-level map, paired with well OW-15.

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