GROUND WATER HYDROLOGY OF THE ELIZABETHTOWN AREA, KENTUCKY

U.S. Geological Survey Water-Resources
Investigations Report 84-4057

Prepared in cooperation with the
City of Elizabethtown

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By D. S. Mull and M. A. Lyverse

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Louisville, Kentucky

1984

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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Factors for Converting Inch-Pound Units to International System of Units (SI)

For the convenience of readers who may want to use International System of Units (SI), the data may be converted by using the following factors:

Multiply inch-pound units	By	To obtain SI units
inch (in.)	25.4	millimeter (mm)
feet (ft)	0.3048	meters (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon per minute (gal/min)	0.00309	liters per second (L/s)
gallon per minute per foot (gal/min)/ft	0.207	liter per second per meter (L/s)/m
million gallon per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	3,785	cubic meter per day (m^3/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
micromhos per centimeter at 25° Celsius (umhos/cm at 25°C)	1.000	microsiemens per centimeter at 25° Celsius (uS/cm at 25°C)
degree Fahrenheit (°F)	°C = 5/9 (°F-32)	degree Celsius (°C)

ALTITUDE DATUM

The term "National Geodetic Vertical Datum of 1929" (abbreviation NGVD of 1929) replaces the formerly used term "mean sea level" to describe the datum for altitude measurements. The NGVD of 1929 is derived from a general adjustment of the first-order leveling networks of both the United States and Canada. The NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

Ground water is a principal source of water for municipal, industrial and rural users in an area of 52 square miles surrounding Elizabethtown in Hardin County in north central Kentucky. This report provides detailed information on the occurrence, movement, and quality of ground water in a typical karst terrain underlain by limestone, dolomite, and shale of Mississippian age. The principal aquifer is the St. Louis Limestone. Unconsolidated residuum or surficial deposits of slumped material may store water and recharge the underlying limestone aquifer.

Nearly all ground water originates as precipitation which averages 49 inches annually; of which 32 inches is lost to evapotranspiration, 11 inches to overland flow, and 6 inches recharges ground-water reservoirs. Ground-water recharge occurs as infiltration through soil, leakage from losing streams and drainage of overland flow through sinkholes. Drainage from several sinkholes has been traced to the Elizabethtown spring which is part of the city's water supply.

Discharge measurements in a sinking stream, two karst windows, and three springs indicate that the shallow ground-water velocity ranged from 0.30 to 1.40 feet per second. About 2 million gallons of water per day flows through a 1.8-mile wide section of the aquifer at a point about 1-1/2 miles southwest of the Elizabethtown well field. A water-level contour map indicates that the average hydraulic gradient is approximately 40 feet per mile and that ground-water movement generally is from the northwest, north, and east toward Elizabethtown. Ground water from these three directions is funneled beneath the city and flows out of the area in a southwesterly direction parallel to Valley Creek.

The water-level contour map shows the effects of three of four major faults on regional ground-water flow. The contours tend to form an ovate pattern around the faults suggesting abutment or ponding of ground water flow on the upthrown side of the faults. Comparison between the present map and one made about 10 years ago shows that pumping of city supply wells has not lowered water levels in the city well field.

Caliper logs of 18 wells indicate that shallow ground-water flow probably occurs in horizontal sheet-like openings within 100 feet of land surface. The openings range in height from 1 inch or less to more than 6 feet and appear to be well developed in the area of the city well field south of Elizabethtown. A test well 146 feet deep penetrated 5 zones of horizontal openings. The well was pumped from 280 to 510 gallons per minute. The specific capacity of the well ranged from 11.5 to 12.1 gallons per minute per foot of drawdown after 12 and 72 hours of pumping.

Based on 108 well depths, 85 percent of the wells are 150 feet deep or less. Water levels in 65 percent of the wells were 50 feet or less below land surface.

Raw water from 28 sampled wells and springs meets most drinking water standards and generally is a very hard calcium bicarbonate type. Coliform bacteria varied widely in samples from rural wells and the city springs. Samples from seven wells had no coliform bacteria. Heavily pumped industrial and public-supply wells tend to yield water with higher values of specific conductance and larger concentrations of sulfate when compared to nearby less heavily pumped domestic wells.

INTRODUCTION

Future economic growth and development in the Elizabethtown area is dependent in part on a reliable source of good quality water. Elizabethtown presently uses both surface and ground water for its municipal water supply. Because the principal aquifers are carbonate rocks, ground water is especially susceptible to degradation from the effects of urban growth such as runoff, sewage and garbage disposal, leakage from sewers and septic tank effluent. An additional source of potential ground-water degradation is toxic spills that could originate from traffic on the major transportation arteries that traverse the area. The interest of water managers in developing and protecting their water supply has emphasized the need for more detailed information on the occurrence, movement, and quality of ground water in the Elizabethtown area.

Purpose and Scope

During the summer of 1982, the U.S. Geological Survey, in cooperation with the city of Elizabethtown, began a 1-year study of ground water in the Elizabethtown area. The principal objective of the study was to provide data on ground-water movement and quality. These data will aid managers and water planners in making decisions concerning land and water use that could impact upon the quality and quantity of the ground-water resource.

Location and Extent of Area

The Elizabethtown area, as used in this report, consists of 52 square miles located mostly in Hardin County in north-central Kentucky (fig. 1). The area is about 40 miles south of Louisville and is the hub for interstate highways, toll roads, and railroads. The boundary of the study area is generally the drainage divide of Valley Creek. The northern boundary is the trace of the Colesburg and Rineyville faults. The area includes parts of four 7-1/2 minute quadrangle maps. Most of the area lies within the Cecilia and Elizabethtown quadrangles, except for the northern part which lies within the Vine Grove and Colesburg quadrangles. All the Cecilia and Elizabethtown quadrangles are included on plates 1 and 2 to show selected data outside the defined study area.

Previous Investigations

A number of published reports discuss the geology and water resources of the Elizabethtown area. Most recently, Lambert (1979) described the ground-water and surface-water resources in a 240 square mile area around Elizabethtown. Similar discussions are in reports by Brown and Lambert (1963)

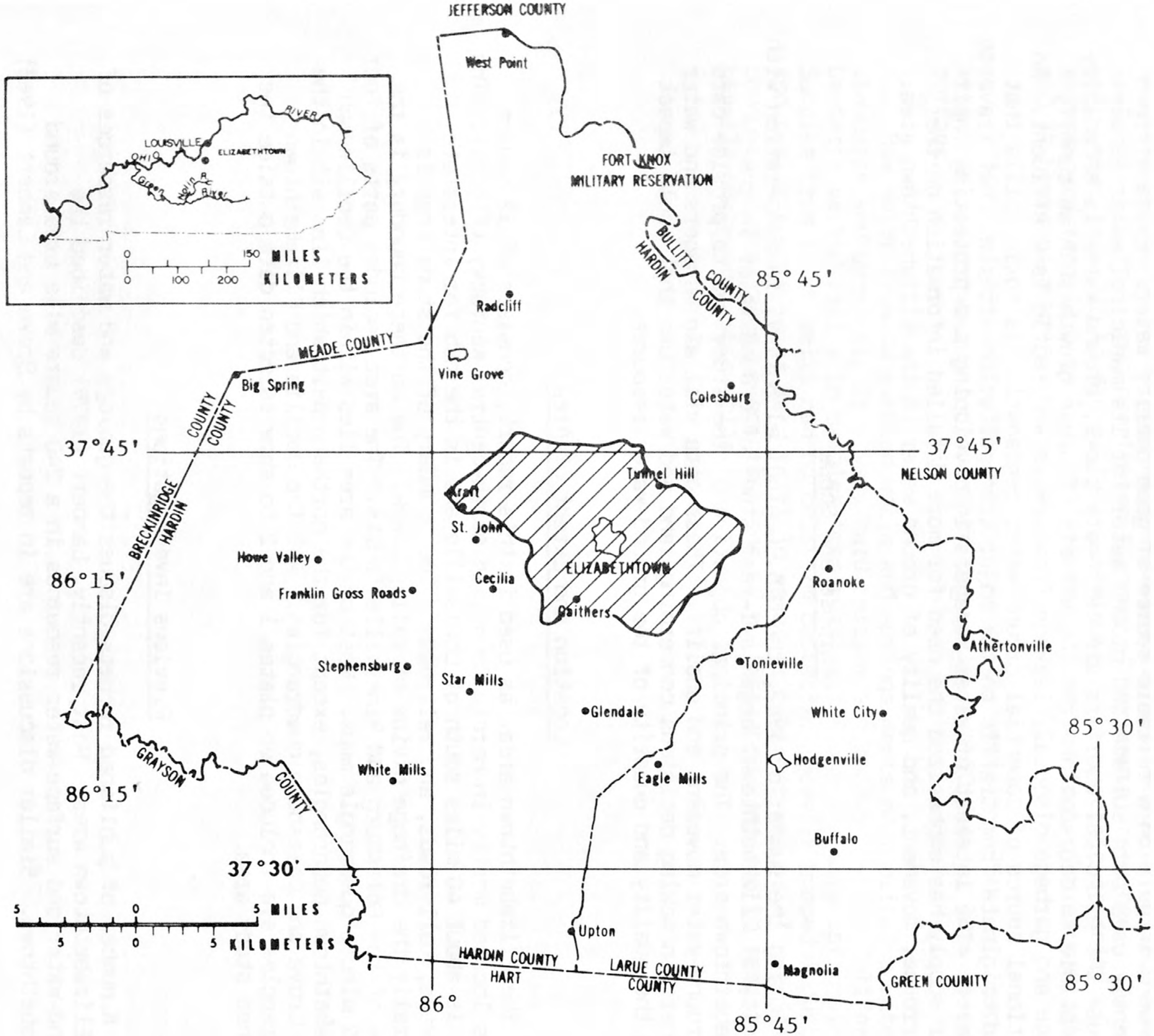


Figure 1.-- Location and extent of Elizabethtown study area.

and Otton (1948). The fresh-saline water interface is shown on a map of Kentucky at a scale of 1:500,000 (Hopkins, 1966). The U.S. Geological Survey published detailed geologic maps at the scale of 1:24,000 for the Cecilia (Kepferle, 1963), Elizabethtown (Kepferle, 1966), Colesburg (Kepferle, 1967a) and Vine Grove (Kepferle, 1967b) quadrangles. McFarlan (1943) discussed the geologic and mineral resources of Kentucky, including the Elizabethtown area.

Methods of Investigations

Following a review of existing data, wells that were accessible for depth and water-level measurements and springs were inventoried. Inventoried sites were selected so that the distance between sites did not exceed 1 mile. The altitude at each site was determined by open-end leveling. Water levels were measured in selected wells during a 2-week dry period in late fall of 1982. Repeat measurements were made during wet weather in April and May 1983.

Caliper and gamma radiation logs were run in 6 wells adjacent to the city well field and in 12 other wells throughout the area. The temperature, pH, and specific conductance of water in the well bore were measured in the same wells. Continuous water-level records were obtained from five observation wells in the Elizabethtown well field. Low-flow discharge measurements were made at four springs and at eight sites on Valley Creek and its tributaries. Temperature and specific conductance measurements were made in all streams during low-flow conditions.

Water from 25 wells and 3 springs was sampled for physical properties and common and trace constituents analyses. Samples were collected from 15 wells and springs for fecal coliform and fecal streptococci determinations. Water from one well and two springs was sampled for an organics scan.

Acknowledgments

The authors are grateful to the many individuals who provided information and granted access to their wells and springs. Representatives of the Gates Rubber Company and Phelps Dodge Corporation contributed information on well yield and quality of water from their wells. Reynolds Supply, Inc., Louisville office, and Angelo George, Consulting Geologist, provided driller's logs and results of test pumping the wells drilled for Elizabethtown at the beginning of this study. Mr. Charles Bryant, City Engineer, and Mr. Robert W. Best, Superintendent of Water Treatment Plant, and their staffs, provided helpful information and valuable assistance during the investigation.

HYDROGEOLOGIC FRAMEWORK

Geology

Because nearly all ground water in the Elizabethtown area is obtained from depths of 300 feet or less, only the near surface geology is discussed in this report. The geology is described in some detail in reports by Lambert (1979), Brown and Lambert (1963), Otton (1948), and McFarlan (1943). Detailed stratigraphic columns, lithologic descriptions and structural features are shown on the 7-1/2 minute geologic quandrangle maps of the area. These maps are listed in the references. A generalized description of the geology and hydrologic characteristics of the unconsolidated sediments and bedrock underlying the Elizabethtown area is shown in table 1. In the following section the discussion proceeds from younger or uppermost geologic units to successively older and deeper units.

Alluvial deposits of Quaternary age that border Valley Creek and its tributaries are the youngest unconsolidated sediments in the Elizabethtown area. The alluvium ranges from 0 to 20 feet in thickness and consists of poorly sorted sand, silt, and gravel, interbedded with clay.

In much of the Elizabethtown area, bedrock is overlain by unconsolidated residuum or surficial deposits of slumped material. The residuum is not mapped, but it may be as much as 70 feet thick in places. It consists of clay and insoluble chert derived from weathered limestone and rests on an irregular karst surface of the underlying limestone. Chert is generally more abundant near the base and is called the "boulder zone" by drillers. This zone was reported in wells 68 and 69 (plate 1) as abundant iron-stained chert and limestone gravel, 1/2 to 3 inches in diameter. The zone was about 2 feet thick in both wells and was underlain by limestone bedrock.

Surficial deposits of slumped material overlie bedrock or residuum only in relatively broad areas south and west of Elizabethtown and ranges from 0 to 330 feet in thickness. The major areas of occurrence are shown on plates 1 and 2. Lambert (1979), suggests that these deposits may be more extensive because they occur irregularly and tend to be masked by a thin veneer of loess. The deposits consist of poorly indurated sand and clay intermixed with scattered boulders of limestone. The deposits were derived from rocks overlying the Ste. Genevieve and St. Louis Limestones, probably during an early cycle of karst erosion (Kepferle, 1966).

The consolidated rocks underlying the Elizabethtown area are of Mississippian age and consist primarily of limestone and dolomite, with some siltstone and shale. The St. Louis and the overlying Ste. Genevieve Limestones are the most widespread rock units exposed at the surface. In this report the

Table 1.--Geology and water-bearing characteristics of units exposed at land surface in the Elizabethtown area

Geologic unit	Thickness (ft)	Physical character	Water-bearing characteristics
Alluvium	0 - 20	Sand, silt, clay and gravel.	Probably contains little water except along major streams.
Loess	0 - 30	Silt.	Contains little or no water.
Surfical deposits of slumped material	0 - 300+	Silt, sand, sandstone, shale, and limestone. Derived from eroded rocks from an early cycle of karst erosion.	An aquifer in places. Where relatively thick may store water and recharges underlying limestone aquifer. Sand and silt troublesome in some wells.
Residuum	0 - 85±	Silt, clay, and sand. Chert and limestone gravel in basal part, "boulder zone" of drillers.	Supplies water to wells where saturated thickness is adequate. Recharges underlying limestone aquifers.
Ste. Genevieve Limestone	80±	Limestone, dolomite, and shale. Limestone characteristically oolitic. Dolomite very fine grained, massive. Weathers to reddish, cherty, clay.	Not a major aquifer in study area because it occurs mostly above drainage.
Lost River Chert of Elrod (1899)	10±	Limestone, medium bedded. Contains very coarse fossil fragments generally silicified in beds 0.1 to 1.5 feet in thickness.	Not an aquifer. May retard downward movement of ground water.
St. Louis Limestone	180 - 300	Limestone, dolomite, shale, and siltstone. Thin to thick bedded, massive. Basal 15 to 30 feet intertongues with underlying Salem Limestone.	Major aquifer in study area. Yields from less than 5 gal/min in area of outcrop to 500 gal/min or more along Valley Creek southwest of Elizabethtown. Lower part of unit is major producing zone.
Salem Limestone	90 - 130	Limestone, shale, and dolomite, very thin to thick-bedded. Shaly sequence in lower part as much as 50 feet in thickness but is discontinuous.	Potential yield unknown in study area. Yields water with a high sulfate concentration in outcrop area. Shale tends to retard downward movement of ground water.

Lost River Chert of Elrod (1899) is assumed to separate the two formations. The Lost River Chert is a 10-foot zone of limestone containing coarse fossil fragments and abundant chert. The unit is commonly marked by rough-weathered blocks and slabs of chert which litter the surface.

The Ste. Genevieve Limestone crops out south and west of Elizabethtown and averages about 80 feet in thickness. The formation is mostly limestone and dolomite but is locally shaly. The characteristically oolitic limestone occurs in beds 0.5 to 4.0 feet thick.

The St. Louis Limestone is the major bedrock unit in the study area. The formation crops out north and east of Elizabethtown and ranges from 200 to 310 feet in thickness. Limestone and dolomite are the predominate rock types, and shale occurs as scattered thin beds. The limestone is thin- to thick-bedded and has weathered to a mature karst topography. In nearby areas, core holes penetrated about 50 feet of interbedded limestone, gypsum, and anhydrite in the lower part of the St. Louis Limestone (Kepferle and Peterson, 1964; Moore, 1964; McGrain and Helton, 1964). George, (1982) reported gypsum nodules in the lower part of the St. Louis Limestones and the upper part of the underlying Salem Limestone.

Limestone, shale, and dolomite of the Salem Limestone underlie the St. Louis Limestone but crop out only in the headwaters of several streams north of Elizabethtown. The Salem Limestone is about 35 to 110 feet thick, thin-to thick-bedded, and commonly shaly in the lower half. The upper part of the limestone is composed of rounded sand-sized limestone pellets and fossil detritus as much as 1/8-inch in diameter. The shaly sequence may reach a thickness of 50 feet but beds are discontinuous.

Structure

The major structural features in the Elizabethtown area are the Elizabethtown, Gaithers, Colesburg, and Rineyville faults, and the Cecilia and Glendale synclines. The Cecilia syncline is about 5 miles west of Elizabethtown and the Glendale syncline is about 6 miles southwest of Elizabethtown, just south of the study area. These features and structure contours are shown on 7-1/2 minute geologic quadrangle maps listed in the references. Lambert (1979) included a map with structure contours modified from the geologic quadrangle maps. Because the regional dip of bedrock is relatively constant, except in the vicinity of the Cecilia and Glendale synclines, the structure contours are not shown on plate 1. However, all the faults are delineated on plates 1 and 2 because they may influence the rate and direction of ground-water movement. This relation is discussed in detail in a later section.

Although the vertical displacement along the faults is as much as 100 feet, the regional dip of bedrock is relatively unchanged, about 20 to 30 feet per mile to the southwest. The regional dip is a major factor contributing to the high yield from the city's wells and springs and is discussed in a later section.

The bedrock in the Elizabethtown area typically contains near vertical joints. These joints are not limited to the vicinity of known faults but occur throughout the area. According to the geologic quadrangle maps, the joints commonly occur in sets that tend to aline in northwest and northeast directions. Joints can be several feet wide at the top of bedrock and diminish to hairline cracks at depth. They may be open or soil-filled at the surface. Joints are present in all rocks of the Elizabethtown area but are best developed in limestone and dolomite where they have been enlarged by circulating ground water.

In addition to vertical joints, bedrock also has horizontal or sheet-like openings. These openings range from less than 1 inch to more than 6 feet in height and extend for several thousand feet. Sheet-like openings are best developed in carbonate rocks where ground-water circulating along bedding planes has dissolved and removed the carbonate material. Driller's records and geophysical logs show that as many as six zones of horizontal openings are present in some wells in the Elizabethtown area.

Physiography

The Elizabethtown area lies within the Interior Low Plateaus Physiographic province of Fenneman (1938). Except for the crest of the Muldraugh escarpment which forms the northeast boundary of the study area, the major topographic feature is a sinkhole plain named the Pennyroyal (Sauer, 1927 p. 21). The Pennyroyal is a gently rolling broad upland (rough in places) that slopes to the southwest, and is underlain by soluble limestone. Karst features such as sinkholes, sinking streams, springs, and subsurface drainage occur. Sinkholes are especially common in the area south of Elizabethtown. Depressions are fairly common throughout the area, but not all are shown on topographic maps because of the 20-foot contour interval. Sinkholes as deep as 60 feet occur south of Elizabethtown and along Highway 1600 about 3.5 miles northwest of the city.

The lowest altitude, about 1/2 mile south of Gaithers, is about 640 feet above sea level, the highest near Crest, is about 920 feet. The relief in most of the basin is less than 150 feet. The smaller streams usually flow in shallow channels less than 5 feet deep in residuum or alluvium. The main stem and larger tributaries of Valley Creek flow directly on bed rock.

Precipitation and Water Budget

Precipitation is the source of nearly all water in the Elizabethtown area. Based on precipitation records from 1950 to 1982 at St. John Bethlehem Academy, Elizabethtown and Cecilia, the average annual precipitation in the vicinity of Elizabethtown is approximately 49 inches per year. However, precipitation is not evenly distributed throughout the year (fig. 2). In 1982, the wettest month was January; October was the driest month with February, June, and November being the next driest. Precipitation also can vary considerably within fairly short distances. For example, the variation in monthly precipitation between Cecilica and Elizabethtown, an airline distance of approximately 5-1/2 miles, was as much as 4.10 inches in July, 1982, (fig. 2).

Long-term precipitation trends are useful for evaluating water availability. The cyclic nature of precipitation is shown by the cumulative departure curve in figure 3. In addition, the curve shows how much the cumulative precipitation was above or below the average annual precipitation for the period 1950-82. The curve shows that periods between about 1953 and 1969 and 1980-82, were periods of deficit precipitation. The maximum deficit was about 44 inches in 1969. Since 1976, the deficit decreased rapidly until 1979, when there was a surplus of approximately 7.7 inches. Although the cumulative departure curve does not provide quantative predictions, the fact that the city wells did not fail during the "dry period" indicates that the wells are capable of sustained yield during prolonged periods of deficient precipitation.

Volumes of water are expressed in several different ways, but probably are easiest to visualize if expressed in inches. Reference to 1 inch of water is the quantity required to cover the entire study area to a depth of 1 inch.

Only a small part of rainfall is available for mans' use. The 30-year average rainfall and the 1982 streamflow at nearby Nolin River were used to depict a typical water budget for the study area. As shown in the following table of the estimated water budget, only 17 inches of the 49 inches of rainfall is available for use. The other 32 inches of rainfall are lost by evaporation and transpiration.

	Inches	Percent of total
Mean annual rainfall	49	100
Stream discharge	17	35
Base flow	6	13
Overland flow	11	22
*Evaporation-transpiration	32	65

*Evaporation Pan data from Nolin River gage (Farnsworth and Thompson, 1982).

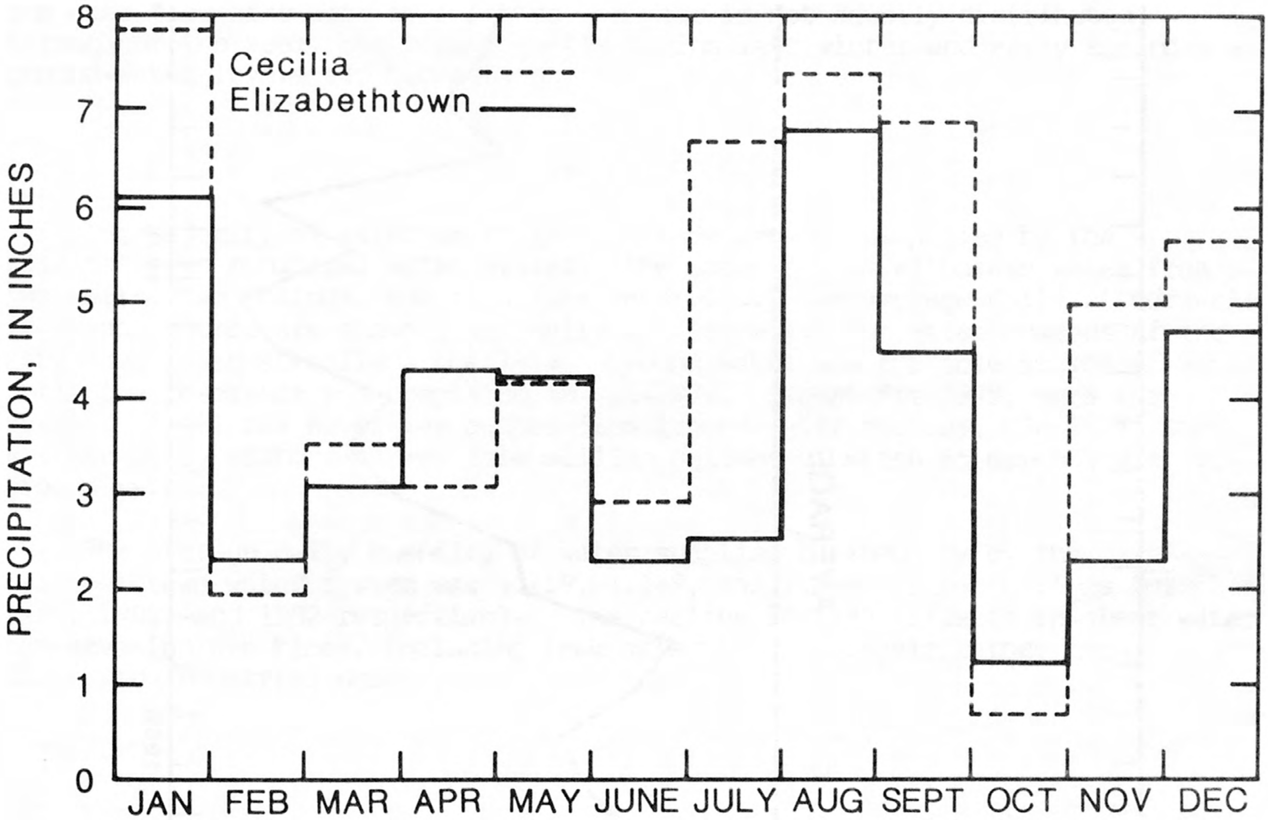


Figure 2.-- Comparison of monthly precipitation at Cecilia and Elizabethtown, 1982.

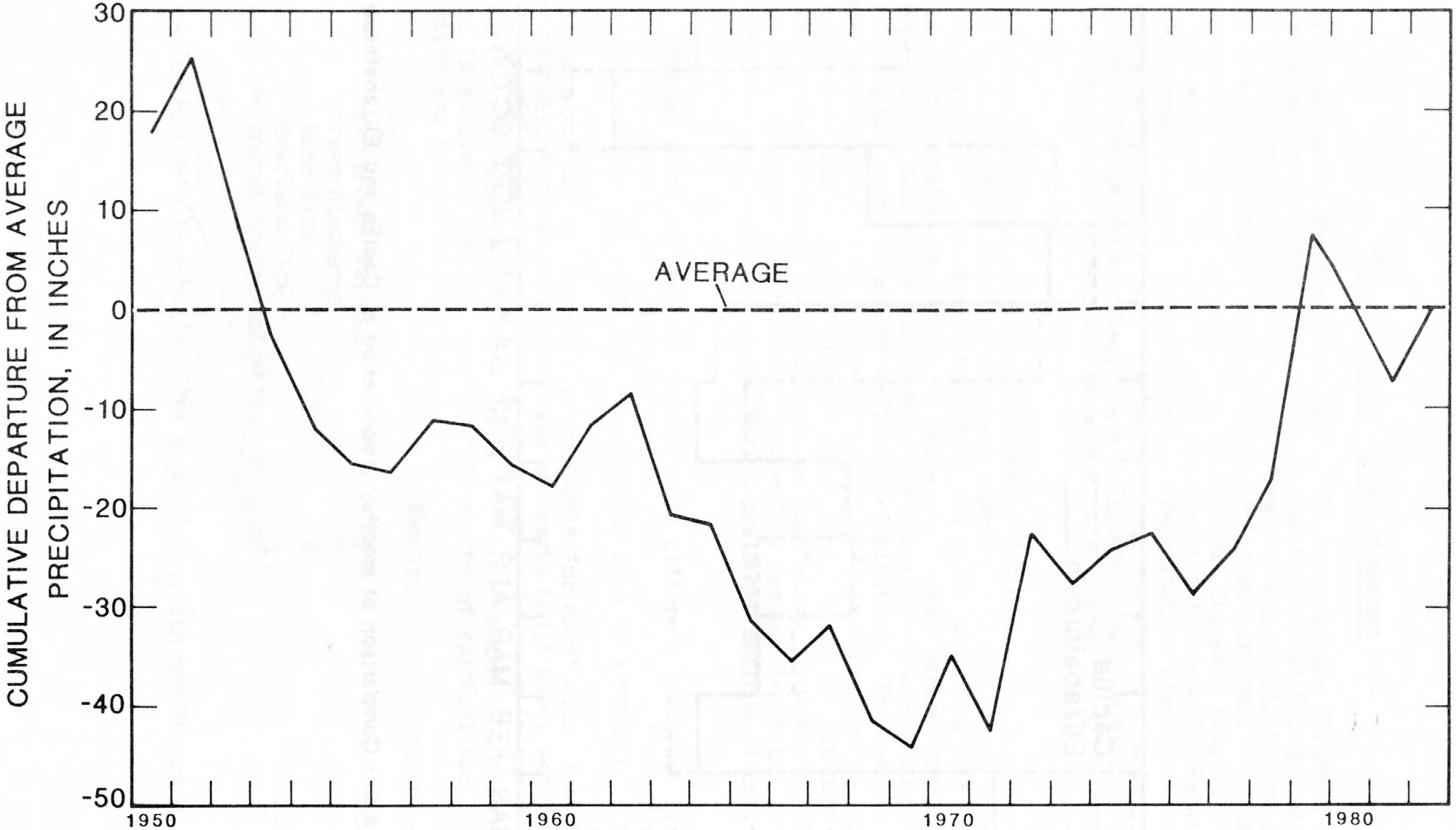


Figure 3.-- Cumulative departure from average precipitation at Elizabethtown, 1950-82.

The 17 inches of streamflow that leave the study area consists of 11 inches of overland flow and 6 inches of base flow which is recharged to and discharged from the aquifer system in a typical year. Base flow and overland flow for the budget were identified by separating the 1982 hydrograph for Nolin River at White Mills, Kentucky, into surface-water and ground-water components.

It is significant to note in the water budget table that the 11 inches of overland flow occurs less than 25 percent of the time and therefore is not available for mans' use unless it is stored or impounded for later use. Also the base flow discharge of 6 inches per year is not equally distributed throughout the year, but occurs mostly during late winter and early spring when ground-water levels are highest.

WATER USE

The majority of water users in the study area are supplied by the Elizabethtown municipal water system. The water system withdraws water from two wells, two springs, and a surface reservoir. The average daily withdrawals from each source are shown graphically in figure 4. The water demands of the city have risen steadily since 1974. Ground water was the sole source of water until the reservoir was completed in mid-1972. Except for 1978, more than 50 percent of all raw water was pumped from ground-water sources. In 1982, the average daily withdrawal was 3.14 million gallons of which 65 percent was from ground water.

The average daily quantity of water supplied to industry by the Elizabethtown water system was 1.119, 1.149, and 1.016 million gallons for 1980, 1981, and 1982 respectively. The decline in 1982 reflects in-plant water conservation practices, including leak detection and repair rather than decreased industrial demand.

OCCURRENCE OF GROUND WATER

Ground water in the Elizabethtown area occurs in both unconsolidated sediments and consolidated bedrock that make up a complex interrelated aquifer system. The following discussion is limited to the relatively shallow aquifers in which most of the usable water occurs. Although water occurs in rocks 600 feet or more below land surface, this water usually is highly mineralized or saline and is seldom reached by municipal or domestic supply wells.

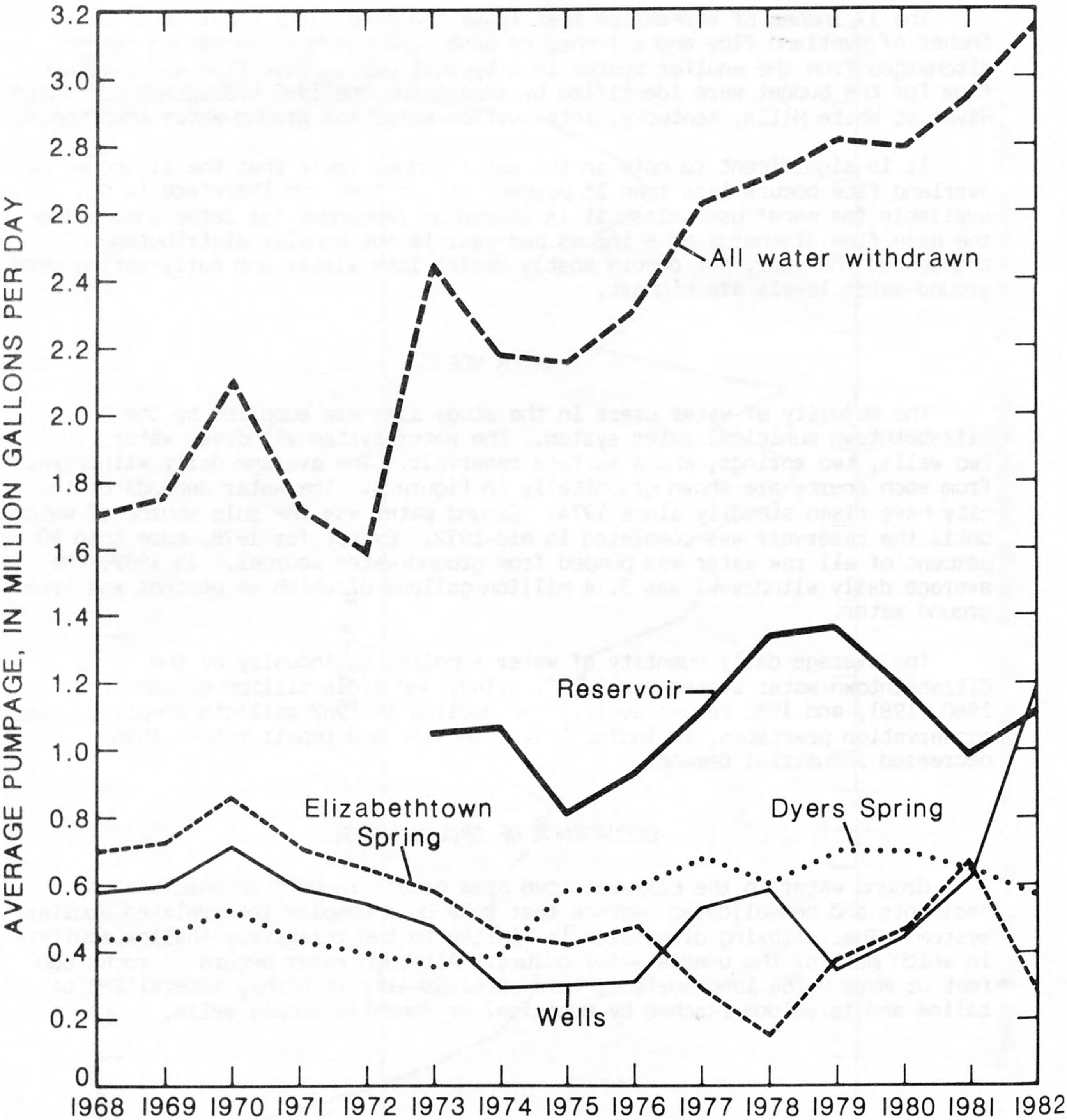


Figure 4.-- Source and amount of water withdrawn by the Elizabethtown municipal water system, 1968-82.

Ground water in the unconsolidated sediments of the residuum and slumped surfical deposits occurs in intergranular (primary) openings. Although few inventoried wells were completed in these deposits, the deposits are hydrologically significant because they act like a sponge that collects and holds rainfall which eventually recharges the underlying bedrock aquifers or is discharged slowly to streams.

Nearly all water derived from limestone in the area occurs in interconnected openings which have been enlarged by circulating water. The circulating water dissolves calcium carbonate and enlarges the openings to allow freer passage of ground water. Except for these openings, the limestone is relatively impervious. The openings may be vertical or horizontal, but horizontal sheet-like openings are most commonly penetrated by water wells in the Elizabethtown area. The occurrence of water in and the abundance of such openings suggests concentrated ground-water flow, especially in the vicinity of the Elizabethtown well field. This is further substantiated by the direction of ground-water flow shown on the water-level contour map in plate 1.

MOVEMENT OF GROUND WATER

Ground-water in the Elizabethtown area moves in response to hydraulic gradients from points of recharge to points of discharge. Movement is primarily through irregular, solutionally enlarged openings along joints and bedding planes in carbonate rock. The contours on plate 1 depict the shape of the water table and are based on the altitude of the water level in wells, springs, and streams in the fall of 1982. The water-level contours connect points of equal water elevation and are based on water-level measurements of approximately 125 wells and springs in the fall of 1982. The contours represent the average seasonal water levels in the Elizabethtown area because the precipitation received during the measuring period was about normal for this time of year. The altitude of the water levels was established by open-end level lines that were run to all wells and springs. Most of the wells used as contour control points tap either the Ste. Genevieve, St. Louis, or Salem limestones. The general direction of ground-water flow can be estimated by drawing flow lines perpendicular to the water-level contours.

According to the water-level contour map (plate 1), ground water moves towards Elizabethtown from the escarpment area to the north, from the Rineyville area to the northwest, and from the rolling topography east of the city. The water from this fan-shaped area is funneled beneath Elizabethtown to the southwest along Valley Creek.

The horizontal gradient of ground-water movement can be determined from the water-level contour map. The horizontal gradient varies throughout the study area but averages approximately 40 feet/mile. The contours indicate that the gradient is steeper in upland areas and relatively flat near major streams. The water concentrates in the vicinity of the Elizabethtown well field, then moves toward the main artery of discharge, Valley Creek southwest of the city.

Because ground-water flow patterns may change with the volume of water in storage, an attempt was made to produce a high-water contour map to identify such changes in the Elizabethtown area. Water levels rose in response to heavy rains; 4.9 inches on April 28-30 and 1.79 inches on May 2, 1983. Water-level measurements were made within 1 to 3 days after the precipitation and are shown on plate 1. The high-water contour map showed little change in flow patterns when compared with the low-water contour map (plate 1) and, thus, was not included in this report. Similarities between maps indicate that the water levels in the aquifers underlying the Elizabethtown area fluctuate in response to precipitation but return to a steady-state equilibrium rather quickly.

Recharge

Ground-water recharge in the Elizabethtown area is described by Lambert (1979) and occurs primarily in three ways: by overland flow into sinkholes in karst areas, by infiltration through the soil and unconsolidated deposits, and by loss of water by streams to the aquifer.

Sinkholes

Sinkholes are depressions that can provide a direct path for surface runoff to drain to the subsurface. They usually are caused by the collapse of rocks above openings that have been enlarged by circulating ground-water in carbonate bedrock. Sinkholes also can develop in thick unconsolidated sediments when the sediments are washed into enlarged crevices in the underlying bedrock.

In the Elizabethtown area sinkholes are abundant to absent, but generally are more numerous than those shown on the 7-1/2 minute quadrangle maps. The 20-foot contour interval prevents the mapping of sinkholes less than 20 feet deep unless the contour intercepts the sinkhole. Sinkholes are circular to irregular in outline, but frequently have a long dimension that trends northwest or northeast, similar to the joint pattern. Groups of sinkholes tend to show similar alinement. Delineation of the alined sinkholes and the long dimension of some sinkholes are shown on plate 1. Alinement of sinkholes suggests solution action of ground water along joints.

In the Elizabethtown area sinkholes are a significant recharge area for ground water. Dye traces are commonly used to define the connection between sinkholes and springs. Although dye traces were not part of this investigation, both an earlier dye trace and a sewer line break confirm the relation between sinkholes, the ground-water flow system, and springs. In 1982, dye was injected into a dry sinkhole located about 2.25 miles south of Elizabethtown and 500 feet west of Highway 31W. The dye was flushed underground with water from several tank trucks and was detected in the Elizabethtown spring (spring 80) about 24 hours later (Robert W. Best, Superintendent of Water Treatment Plant, oral commun., 1983). Further evidence of the relation between sinkholes and ground-water was shown when a broken sewerline under the I-65 interchange south of Elizabethtown was repaired and the coliform content in water from the city spring decreased dramatically (Robert W. Best, Superintendent of Water Treatment Plant, oral commun., 1983).

Sinkholes in the Elizabethtown area can be divided into five types based on their relation to surface runoff and the water table: (1) Relatively shallow depressions that are dry except for brief periods following precipitation. These are well above the water table and do not have a well-developed swallet or drain. (2) Small to medium-sized sinkholes that hold water for long periods of time, are fairly deep, and may intercept the water table. The water levels in the pond may reflect changes in the position of the water table if it is interconnected. This type sinkhole is relatively uncommon in the Elizabethtown area. (3) Sinkholes that are above the water table and have a well-developed swallet that forms the drainage point for a sinking stream. Three sinkholes with sinking streams are identified on plate 1. These sinkholes vary in size and usually have flow into them, except in extended dry periods. Normally, all streamflow drains into the swallet. However, heavy rains may cause streamflow to exceed the capacity of the swallet, flood and sometimes overflow the sinkhole. This condition was observed at a sinkhole (S-1) east of Highway 1031 southeast of Elizabethtown and at two sinkholes (S-2 and S-3) located about 1 mile southwest of Highway 1600 and about 3 miles northwest of Elizabethtown (see plate 1). In March 1982, estimated flow into these sinkholes was about 100 gal/min at each site. After heavy rains in May 1983, water had overflowed each sinkhole and was ponded in nearby fields. Eventually, enough water drained into the sinkholes to allow the streams to return to their channels and empty all flow into the sinkhole. Sinkholes of this type provide a direct path for surface runoff to reach the subsurface. Obviously, any contaminant in the surface runoff has a direct path to the ground-water system. (4) Large, irregular-shaped sinkholes that are dry except after precipitation, but have incised stream channels that terminate in one or more well-developed swallets. Several sinkholes of this type were identified in the cluster of sinks near I-65 south of Elizabethtown. The sinkholes are as deep as 60 feet below the surrounding area and have stream channels cut 15 feet or more into the unconsolidated sediment in the bottom of the sinkhole. The drain characteristics of this type of sinkhole are similar to those with sinking streams. That is, rapid runoff can exceed the drain capacity of the swallets, flood the sinkholes, and eventually overflow onto the adjacent area. Unless the swallet becomes plugged, drainage continues until the sinkhole is dry. (5) An unusual type of sinkhole that is rare in the Elizabethtown area is a collapsed sinkhole or "karst window," (Monroe, 1970) with a stream flowing across its floor. Two karst windows are known in the Elizabethtown area and are shown as springs 33 and 58 on plates 1 and 2. In both cases a spring or stream emerges at the upper end of each sinkhole, flows about 250 feet and drains into a swallet at the lower end of the sinkhole. The two sinkholes receive relatively little runoff because of the small area that drains directly into the sinkhole. Thus, they are less important as points of subsurface recharge than other types of sinkholes previously discussed. However, the karst windows are hydrologically significant because the streams in each sinkhole offer a direct path to the subsurface for any contaminant deposited in or near the sinkhole. This is especially important in the case of spring 58 which is located about 0.5 mile east of Dyers Spring (spring 48). It is likely that flow in spring 58 reappears as part of the discharge of Dyers Spring, which is part of Elizabethtown's water supply.

Infiltration

A second, slower type of recharge to the aquifer occurs by downward percolation of water through soil and the surficial deposits of the clayey and cherty regolith. If the underlying limestone is relatively impervious, water may be perched on top of the bedrock. If downward percolation intercepts fractures or solution openings, then lateral movement to discharge areas occurs. Vertical infiltration through the regolith is the principal method of recharge to the aquifer in much of the study area except in areas where sinkholes are abundant.

Losing Streams

Losing streams are those having streambeds above the water table and are contributing water to the zone of saturation. Streams may lose either a part or all of their flow to the ground-water system at points along their course usually through fractures or other openings below the streambed. Although recharge to the aquifer by losing streams is difficult to quantify, this may constitute a major portion of the total ground-water inflow in the project area.

Losing streams or segments of losing streams may be identified on the contour map (plate 1) by noting the point where a ground-water contour line falls below the estimated elevation of the streambed, assuming that the streambed is permeable. Streams may either lose or gain at different times of the year, depending on the changing water table. Lambert (1979) reported losing streams north of Hodgenville and Tonieville, southeast of the Elizabethtown area. Although losing streams were not observed in the Elizabethtown area, sinking streams do occur (plate 1). The major distinction between a sinking stream and a losing stream is that all flow from a sinking stream is lost underground for most of the year. Streamflow is usually lost in one or more well developed swallets in the stream bed. Streamflow lost underground freqeuently does not reappear in the same stream but may become part of the ground-water discharge in springs or seeps. It also may leave the basin through interbasin transfer. This is common in limestone terrain where ground-water divides do not necessarily coincide with the topographic divides.

Discharge

Most ground-water from the Elizabethtown study area is discharged to the major streams and springs by seepage from the St. Louis or Ste. Genevieve Limestones. Discharge generally is to the alluvium, which in turn feeds water to the stream. Water-level contours indicate that Valley Creek probably is the major ground-water discharge outlet in the study area. Ground water also is discharged to wells and to the atmosphere by evapotranspiration.

Discharge to Streams

Ground-water discharge to streams is not constant, but varies seasonally depending on the quantity of precipitation in the area, losses to evapotranspiration, and changes in ground-water storage during the year. Ground water flows from the limestone bedrock through the valley alluvium to Valley Creek (plate 1) and contributes much of the gain in flow in this stream as it crosses the study area. Results of low-flow measurements along Valley Creek in the fall of 1982, and in August 1983, show an overall gain in streamflow between the measured reaches (see table 2). Discharge in Valley Creek ranged from 0.33 ft^3/s at the bridge on Middle Creek Road to 6.93 ft^3/s at the bridge on Gaithers Station Road in the fall of 1982. Noticeable increases in streamflow occurred in two reaches of Valley Creek. Streamflow increased from 1.99 to 2.57 ft^3/s from the bridge on Highway 61 to the bridge on Highway 62, a stream distance of about 0.5 mile. Gains in flow in each reach do not accurately represent discharge from the aquifer because of the changes in the ability of the valley alluvium to transmit water between the individual reaches. However, the changes balance out somewhat over the length of Valley Creek and increases in streamflow may be used as a rough estimate of discharge from the aquifer to the stream in the study area.

Table 2.--Miscellaneous stream discharge measurements, Elizabethtown area

Stream	Map or station number[1]	Date	Discharge (ft^3/s)	Temperature (°C)	Specific conductance (micromhos per centimeter)
Valley Creek at Middle Creek Road near Elizabethtown 37°40'33"N85°48'36"	8	Oct. 27, 1982	0.33	5.5	-
Valley Creek at State Highway 567 at Elizabethtown 37°40'38"N85°49'27"	7	Oct. 27, 1982	.80	8	-
Valley Creek at Pierce Street at Elizabethtown 37°41'17"N85°51'00"	6	Oct. 28, 1982	1.35	11	-
Valley Creek at State Highway 61 at Elizabethtown 37°41'31"N85°51'22"	5	Oct. 27, 1982	1.99	5.5	
		Aug. 4, 1983	1.01	26	360
		Aug. 10, 1983	1.81	25.5	360
Valley Creek at U.S. Highway 62 at Elizabethtown 37°51'50"N85°41'31"	4	Oct. 28, 1982	2.57	8.5	
		Nov. 1, 1982	2.52	17	
		Aug. 4, 1983	1.25	24	400
		Aug. 10, 1983	1.17	24.5	390
Freeman Creek at State Highway 251 at Elizabethtown 37°41'32"N85°52'24"	3	Oct. 27, 1982	1.37	10	
		Nov. 1, 1982	1.34	18.5	
		Aug. 4, 1983	2.06	24.5	380
		Aug. 10, 1983	.74	24.5	370
Valley Creek at Elizabethtown 37°40'49"N85°52'34"	2	Oct. 27, 1982	3.20	11	
	03310210	Nov. 1, 1982	4.01	18.5	
		Aug. 4, 1983	1.69	22	420
		Aug. 10, 1983	1.85	27	390
Valley Creek at Gaithers Road near Elizabethtown 37°40'28"N85°53'13"	1	Oct. 28, 1982	6.93	11	
		Aug. 5, 1983	3.12	23.5	460

[1]Refers to plate 1.

Discharge to Springs

A spring is a natural point of discharge from the ground-water reservoir where the land surface intersects the water table or water-bearing cavities. Springs in the Elizabethtown area range from "wet weather seeps" that flow only during or shortly after a rainy period, to springs that issue from cave-like limestone fractures and generally are perennial. None of the wet-weather springs were measured during this investigation.

The largest springs in the area, Elizabethtown (80) and Dyers Springs (48), are fed by a subsurface drainage system that can be considered as a large branching pattern of solution openings that collect water over an extensive area, funnel the water to the main trunk of the spring, and thence to the surface. Drainage from sinkholes is a major source of recharge to this "pipe-like" system. All large springs in the area are developed in the St. Louis Limestone. This formation contains massive beds of limestone with well-developed solution openings along fractures and bedding planes which form the pipes for ground water movement.

Although no gaging stations are maintained on springs in the Elizabethtown area, miscellaneous springflow measurements have been made over the years and are listed in the report by Lambert (1979). Because the utility of springflow is largely dependent on the magnitude and occurrence of low flow, only low-flow measurements were made during this investigation. The discharge of six springs was measured during dry periods in April and August, 1983. The measurements are listed in table 3 and the spring locations are shown on plate 1.

The low, base-flow measurements of April and August, 1983, were greater than the record low flows of either spring. For example, flow from Dyers Spring (spring 48) was 0.76 ft^3/s on August 4, 1983, but was 0.42 ft^3/s on November 16, 1953. Similarly, discharge from Elizabethtown Spring (spring 80) was 2.61 ft^3/s on August 4, 1983 and was 1.50 ft^3/s on September 21, 1972,.

These springs are part of the Elizabethtown water supply. At the time of the measurements in August 1983, virtually all the flow from each spring was being taken by the city. Based on the 7-day low-flow frequency graph for the Elizabethtown Spring (Lambert, 1979) spring flow equal to or less than 2.0 ft^3/s can be expected to occur almost every year. Although this rate has partially met the water needs of the city, extended dry periods would likely cause more frequent occurrence of lower spring flows which could endanger this part of the Elizabethtown water supply.

Table 3.--Miscellaneous spring discharge measurements
(Type of opening: D, depression; T, tubular; K, karst window)

Latitude longitude (map number)[1]	Type of opening	Date	Discharge (ft^3/s)	Temperature (°C)	Specific conductance (micromhos per centimeter)
Mike Pirtle 374156N0855022 (33)	K	Apr. 21, 1983	0.93	10.5	235
		Aug. 4, 1983	.08	13.5	440
Joe Villatoe 374152N0855034 (104)	T	Apr. 21, 1983	.03	12	315
Dyers Spring 373929N0855404 (48)	D	Apr. 21, 1983	4.49	13	415
		Aug. 4, 1983	.76	13.5	380
Unnamed spring at Gaithers 373924N0855327 (58)	K	Apr. 21, 1983	2.52	13	400
		Aug. 5, 1983	1.03	13	390
Elizabethtown Spring 374043N0855230 (80)	T	Apr. 21, 1983	6.38	12	345
		Aug. 4, 1983	2.61	13	360
Unused spring at Elizabethtown 374045N0855529 (80-A)	T	Apr. 21, 1983	.86	12	470
		Aug. 4, 1983	.11	13	560

[1]Refers to plate 1

Discharge to Wells

Ground water is discharged to numerous wells drilled to obtain water for domestic, stock, municipal, and industrial use. Some wells are used for irrigation at various times throughout the year. Discharge to industrial and municipal supply wells in the vicinity of the city well field averages 1.1 million gallons per day. Although the quantity of water pumped from these wells remains relatively constant from year to year, except for the increased pumpage for municipal purposes by the city of Elizabethtown, future discharge to wells may be increased in response to industrial or municipal supply demands.

Evapotranspiration

In the Elizabethtown area water is discharged to the atmosphere by evaporation from soil moisture and ground-water, and by transpiration through vegetation. Estimates of as much as 63 percent of the precipitation received in the area is discharged to the atmosphere by evapotranspiration. The quantity of water discharged varies inversely with the depth to water with areas of highest evapotranspiration being those where the water table is less than 5 feet below land surface.

RATE AND QUANTITY OF GROUND-WATER MOVEMENT

The rate of ground-water movement is important to the understanding and solution of many problems, but especially to those related to pollution in the ground-water system. For example, if a pollutant enters the ground-water system up gradient from a supply well, it becomes a matter of considerable urgency to be able to predict when the pollutant will reach the well.

The movement of ground water in limestone in the Elizabethtown area occurs primarily in two zones. Rapid movement is characteristic of the upper zone where water moves through solution openings. Slow movement is characteristic of the lower zone where a large reservoir of water moves through small openings.

Although the study area is not a complete hydrologic unit and available data are not adequate to assess all variables, most wells and springs probably tap the upper zone rather than the lower zone. This is suggested both by the rapid increase in spring discharge and by rising water levels in wells within a few hours following a rain. For example, the discharge from Dyers Spring (spring 48) and the Elizabethtown Spring (spring 80) became muddy and increased considerably during heavy rains on the morning of June 2, 1983. This rapid response to precipitation is facilitated by the many sinkholes in the study area which provide a direct path for rapid movement of recharge to the upper ground-water zone.

Based on discharge measurements at springs and karst windows, velocities of ground water ranged from 0.3 to 1.40 feet per second. At these rates water movement of 5 to 23 miles per day is possible. However, reported results from a dye injection into a sinkhole south of the city indicated that movement from that site to the Elizabethtown spring (spring 80) was about 1.5 to 2 miles per day. (Robert W. Best, Superintendent of Water Treatment Plant, oral commun., 1983). The slower movement in this case probably does not reflect the true velocity because the test was only intended to verify a connection between the sinkhole and the spring rather than define the travel time. Thus, the presence of the dye in the spring was verified but the leading edge of the dye or the shortest travel time between the sinkhole and the spring was not measured.

Flow nets are an effective means for illustrating conditions in ground-water systems and not only show the direction of ground-water movement, but may also be used to estimate the quantity of water in transit through the aquifer. The quantity of water moving through the aquifer southwest of Elizabethtown was calculated by using a flow-net analysis (fig. 5) of the area at A-A' on plate 1. The nets consist of two sets of lines, equipotential lines connecting points of equal head and flow lines which depict the idealized paths followed by particles of water as they move through the aquifer.

There are an infinite number of equipotential lines and flow lines. However, for purposes of flow-net calculations, it is necessary to draw only a few sets of lines. Equipotential lines are drawn so that the drop in head is the same between adjacent pairs of lines and flow lines are drawn so that the flow is equally divided between adjacent pairs of lines. Together, equipotential lines and flow lines form a series of "squares" in which total flow through a section may be calculated by adding the flows of each "square" in the section. According to Darcy's law the flow through any given "square" is:

$$q = T\, w\, \frac{dh}{dl} \qquad (1)$$

T is transmissivity or the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient.
w is the distance between flow lines
dh is the difference in head between equipotential lines, and
dl is the distance between equipotential lines.

A transmissivity value of 3,500 ft^2/d was assumed for this calculation. This value was calculated by George (1982) from aquifer tests at the well field about 1-1/2 miles to the northeast during early November 1982.

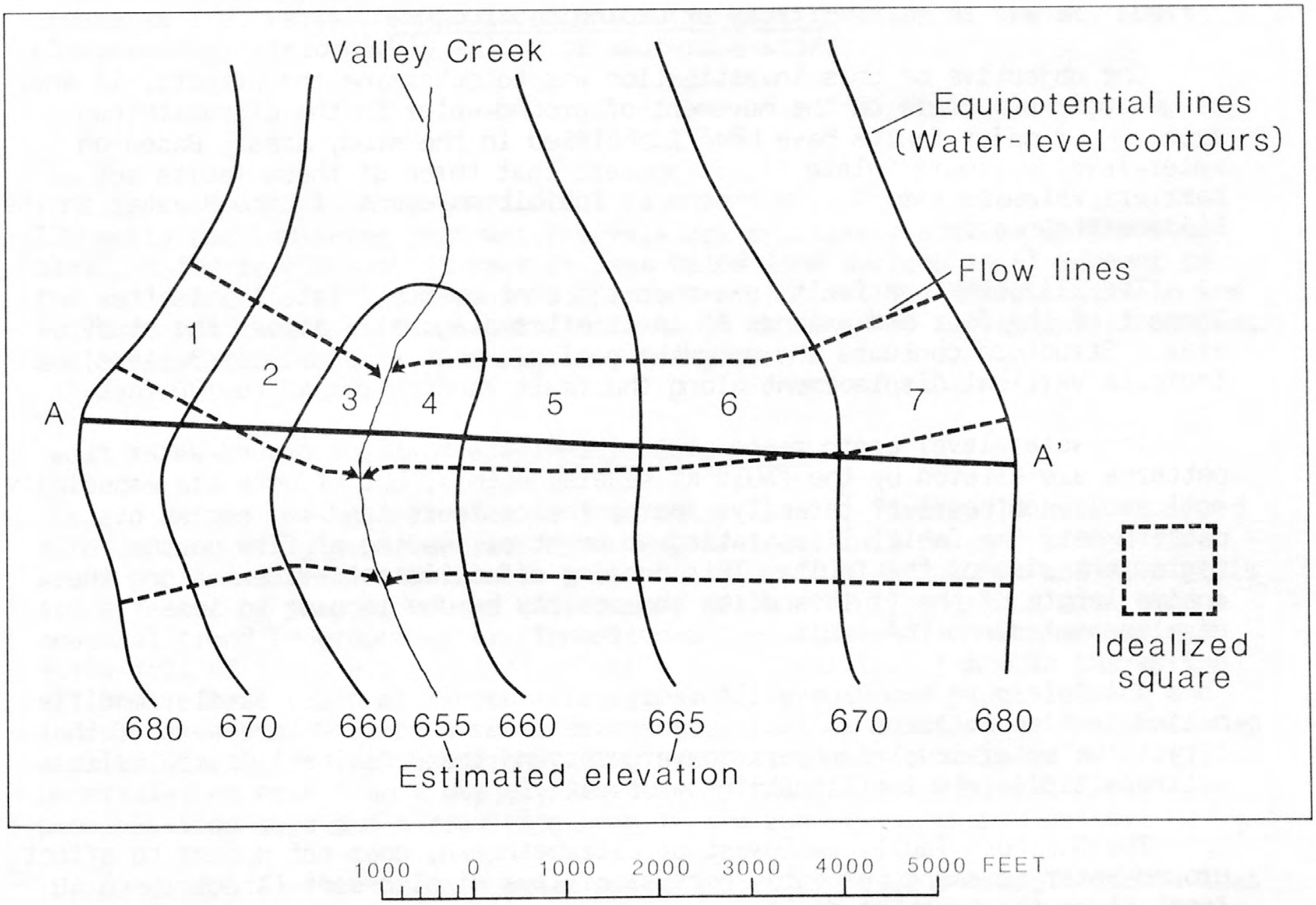


Figure 5.-- Diagram illustrating ground-water flow net analysis at A to A' on plate 1.

Assuming that water moving through "squares" 1-7 (fig. 5) represents water moving through the aquifer at A-A', the quantity moving through each "square" can be calculated and summed to get the total flow. Based on this technique, about 2 million gallons per day move through the aquifer at A-A'. This value should be considered an estimate because of inaccuracies in the flow net ("squares") and the uncertainity of the actual value for transmissivity at the site.

Effects of Geologic Structure

One objective of this investigation was to determine the effects, if any, of geologic structure on the movement of ground-water in the Elizabethtown area. Four major faults have been identified in the study area. Based on water-level contours (plate 1), it appears that three of these faults act as barriers which to some degree impede or inhibit movement of ground water in the Elizabethtown area.

The Elizabethtown fault, shown on the contour map (plate 1), is the longest of the four and extends 10 to 12 miles diagonally across the study area. Structure contours shown on the geologic maps (Kepferle 1963, 1966) indicate vertical displacement along the fault ranges from 40 to 100 feet.

The water-level contours on plate 1 indicate that the ground-water flow patterns are altered by the fault at several points, but effects are especially noticeable southeast of the city. Here, the contours tend to form an ovate pattern near the fault, illustrating abutment or ponding of flow on the upgradient side of the fault. This ponding effect is not evident along the entire length of the fault and its absence may be due in part to less displacement along the fault to the northwest.

The Colesburg and Rineyville faults also appear to cause similar modification in flow patterns in their respective areas north and northwest of the city. The water-level contours converge around these faults in circular patterns similar to the Elizabethtown fault.

The Gaithers fault, southwest of Elizabethtown, does not appear to affect ground-water movement, probably because of less displacement (about 20 to 40 feet) along the Gaithers fault.

Other structural features having a local effect on the ground-water flow system are the occurrence of anticlines and synclines. Lambert (1979) describes such features in the Elizabethtown area and presents a plate in his report depicting their location. Typically, he points out, synclinal areas and the downthrown side of faults are the best places to find water and generally produce the better yielding wells.

DEPTHS OF WELLS

A cumulative curve based on 108 well depths shows that most wells in the study area are completed at relatively shallow depths (fig. 6). About 65 percent of the wells are 100 feet deep or less and about 85 percent are 150 feet deep or less. Two factors account for the shallow depths. First, percolation is impeded or prevented from reaching greater depths in the aquifer by shale in the basal part of the Salem Limestone. Second, deeper wells are more likely to penetrate zones containing poor quality water. Lambert (1979) indicates that wells located in or below the basal portion of the St. Louis Limestone may yield highly saline or sulfurous water.

WATER LEVELS

The cumulative curve in figure 7 was derived from water levels in 108 wells and indicates that water levels are relatively shallow in the study area. Water levels were 50 feet or less below land surface in 65 percent of the wells and 95 feet or less in 95 percent of the wells. Water levels in the wells do not remain constant but fluctuate in response to variations in pumping and natural ground-water discharge and recharge.

Seasonal Fluctuations

To define seasonal fluctuations of water levels, five wells were equipped with continuous water-level recorders. Water-level data in each of the five wells and local precipitation are shown in figure 8. Although these five wells are affected by pumping of the city supply wells, the hydrographs also show a seasonal trend in ground-water fluctations. Water levels in late summer and early fall of 1982, were typically 2 to 4 feet lower than those in the spring of 1983. These seasonal fluctuations reflect lower summer precipitation and losses to evapotranspiration and natural ground-water discharges. As mentioned earlier, the hydrographs show that the system responds quickly to rainfall. Generally, no more than 1 day elapsed between rainfall at the well field precipitation gage and a resulting peak in the recorder-equipped wells.

Seasonal fluctuations in wells not affected by heavy pumping indicate that wide areal variation in water levels exists in the area. The range of water-level fluctuations was determined by measuring water levels in wells throughout the project area during the dry period, October and November, 1982, and again in early May 1983, when water levels were high. The high and low water-level measurements are shown on plate 1. Differences between high and low water levels at various locations ranged from 0 to 50 feet. A water-level contour map was drawn based on the high water level measurements. By contouring the

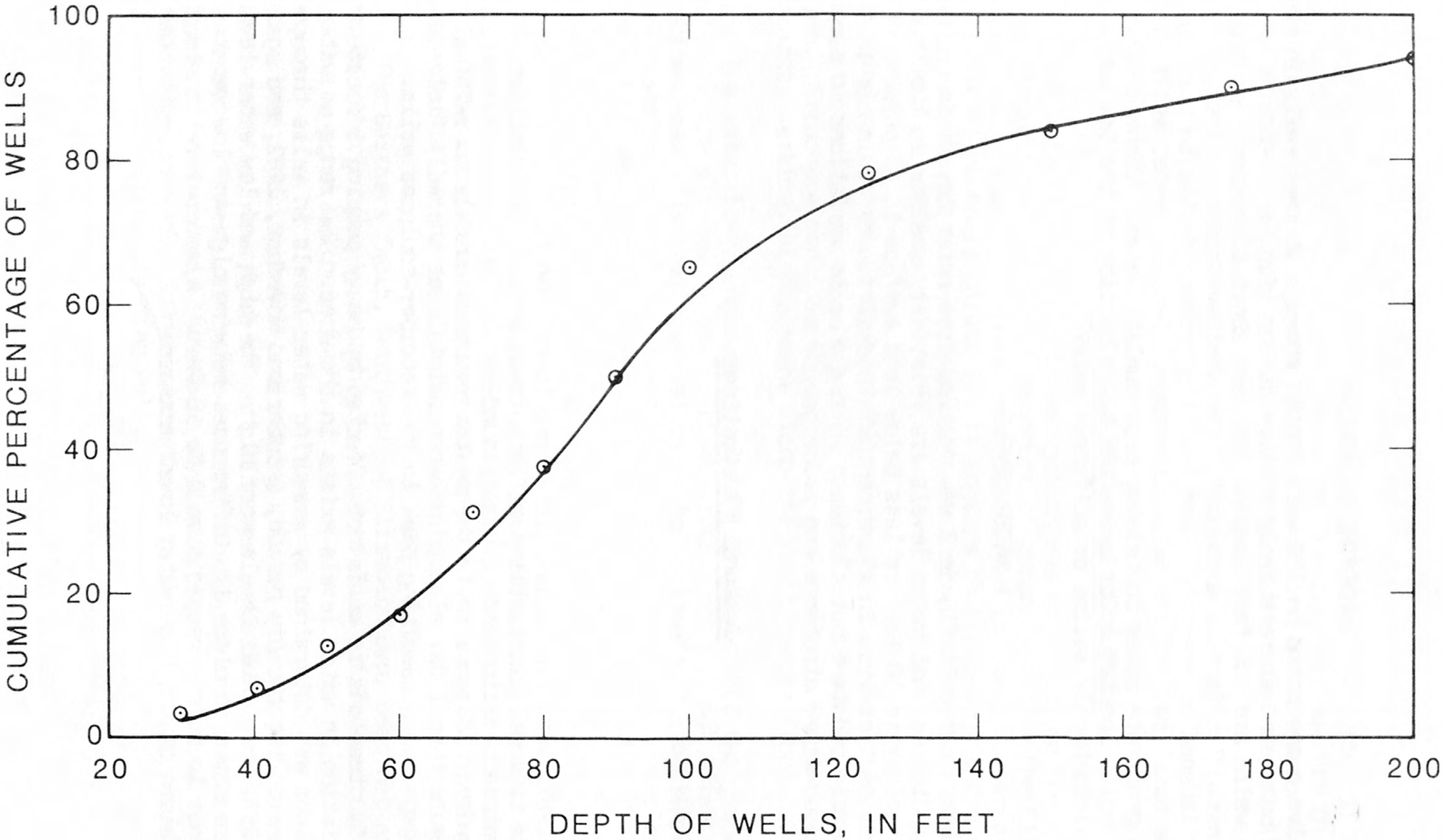


Figure 6.-- Cumulative distribution by depth of 108 drilled wells. Curve indicates percent of wells having depth equal to or less than indicated amount.

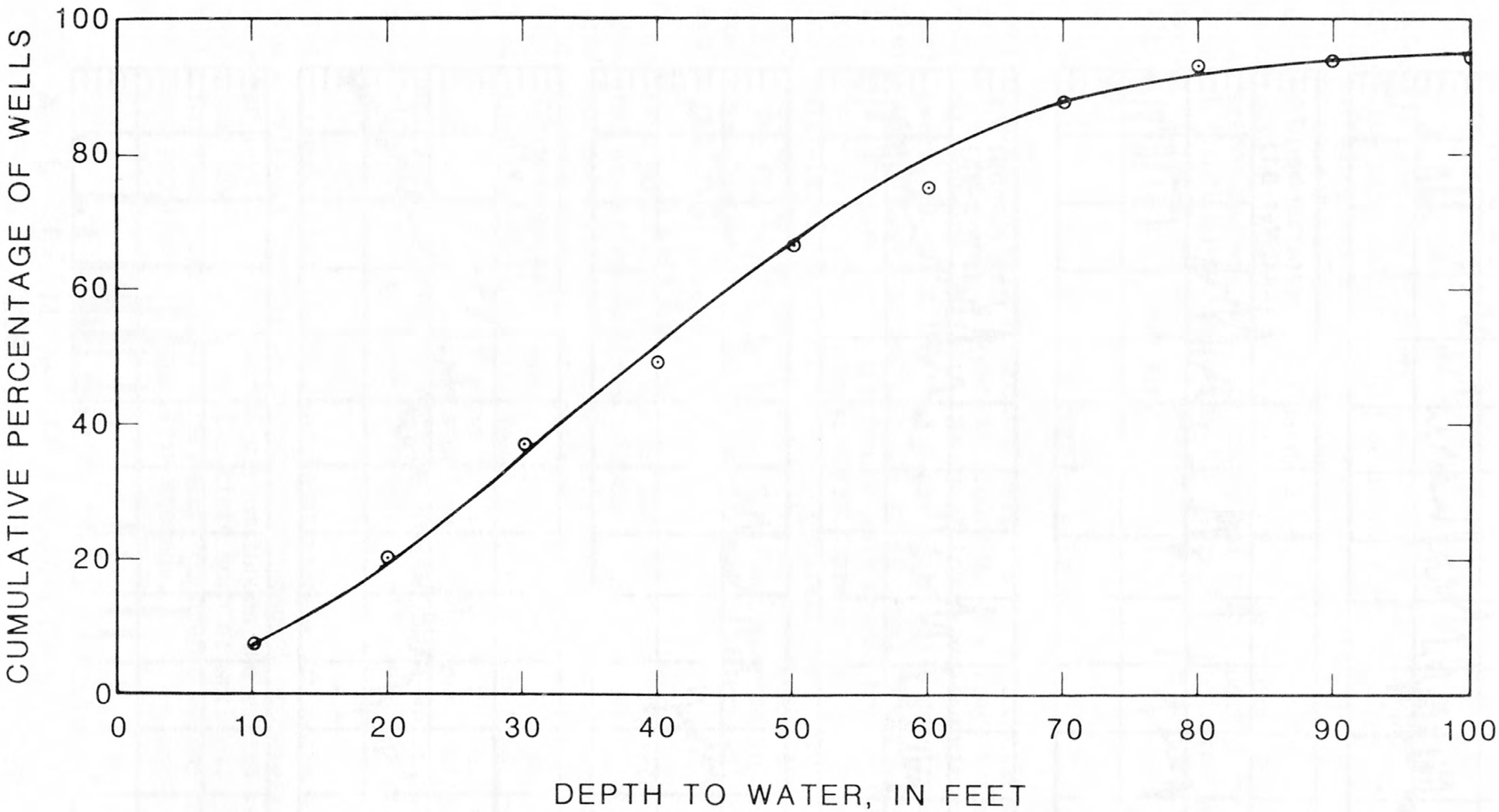


Figure 7.-- Cumulative distribution of 108 water-level measurements. Curve indicates percent of water levels having depth below land surface equal to or less than indicated amount.

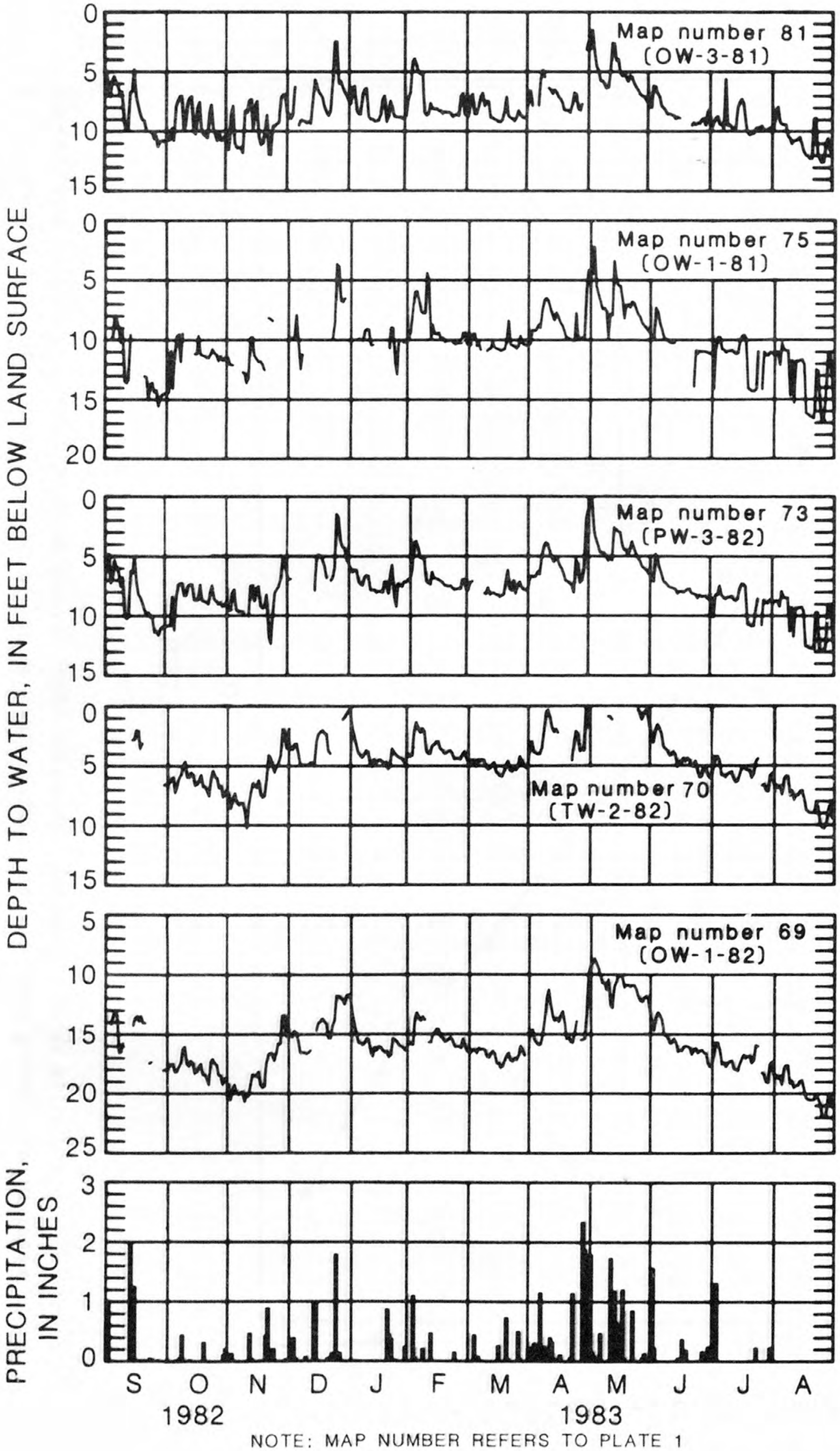


Figure 8.-- Maximum daily water levels in five wells and precipitation at Elizabethtown.

difference between the high and low water levels it was anticipated that regions of low permeability could be identified and might in turn identity zones of differing water quality. However, the aquifers underlying the project area do not appear to lend themselves to regional analysis of this kind, because the wide differences in water levels did not seem to correlate with known geologic or hydrologic features. For this reason, the seasonal water-level difference map was not reproduced for this report. The wide range of water-level fluctuations indicates the overall predominance and haphazard occurrence of fractures and solution openings in the carbonate aquifers underlying the Elizabethtown area.

Pumping Effects

A hydrograph of well 75 located near the city production well and tapping the St. Louis Limestone is shown in figure 9. The trace shows short-term drawdown and recovery (April 15-22) resulting from intermittent pumping of the city well (well 76) about 100 feet away. Both wells penetrated the same system of interconnected openings because the water level in the observation well rose swiftly each time pumping in the nearby well ceased and fell correspondingly when pumping began. These pumping effects are superimposed on the natural seasonal water-level fluctuations which generally declined in the summer and fall and rose during the winter and spring months during the period of record (fig. 8). The fluctuations in figure 8 reflect changes in ground water storage and are caused by normal seasonal changes and by withdrawal of water from storage by pumping.

Long-term pumping effects can be seen by comparing water-level contour maps prepared at different times. Lambert (1979) shows a water-contour map prepared from data acquired in the early 1970's. A comparison of Lambert's map and plate 1 shows that the city pumpage over the past few years has not had a noticeable effect on water levels in the vicinity of the well field. Lambert's map shows that the average water level near the water treatment plant was approximately 670 to 680 feet above sea level about 10 years ago. The water-contour map drawn for this study (plate 1) shows similar water levels, which is especially noteworthy because annual ground-water pumpage has increased since 1979, and exceeded reservoir withdrawals in 1982 (see fig. 4).

This suggests that the aquifer is at or near its optimum capacity. Recharge usually is greatly in excess of the amount necessary to maintain normal water levels. Under normal circumstances the excess recharge is discharged rapidly through natural outlets such as springs. Any deficiencies caused by increased pumping will be partly countered by the diversion of some of the excess recharge to longer-term storage.

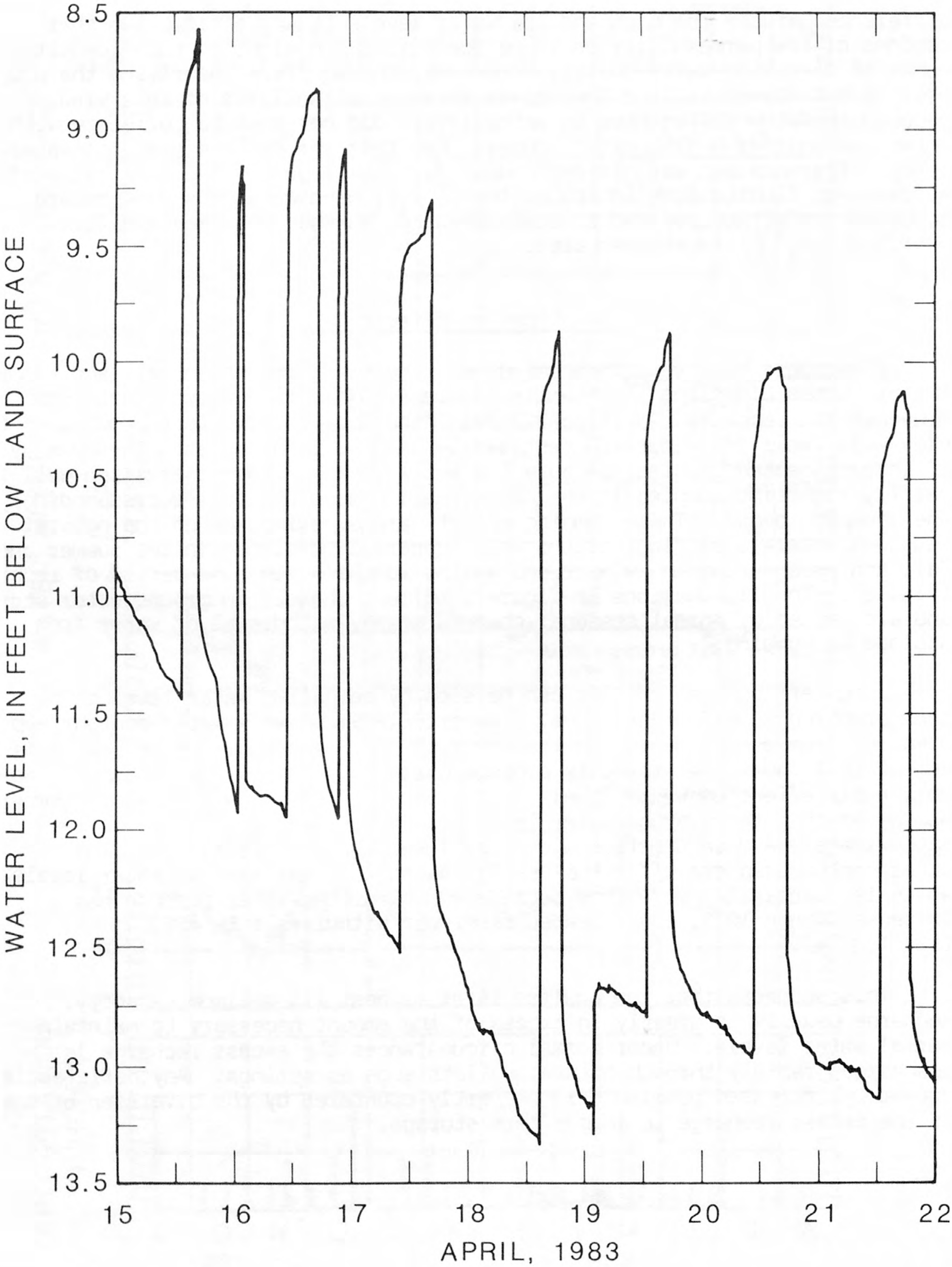


Figure 9.-- Fluctuation of water levels in well 75 caused principally by pumping from Elizabethtown well 76 about 100 feet away.

GEOPHYSICAL LOGS

To determine the presence and size of openings and the lithology of the rocks penetrated by a well, caliper logs were run in 18 open wells and gamma logs were run in 12 of the same wells in the Elizabethtown area.

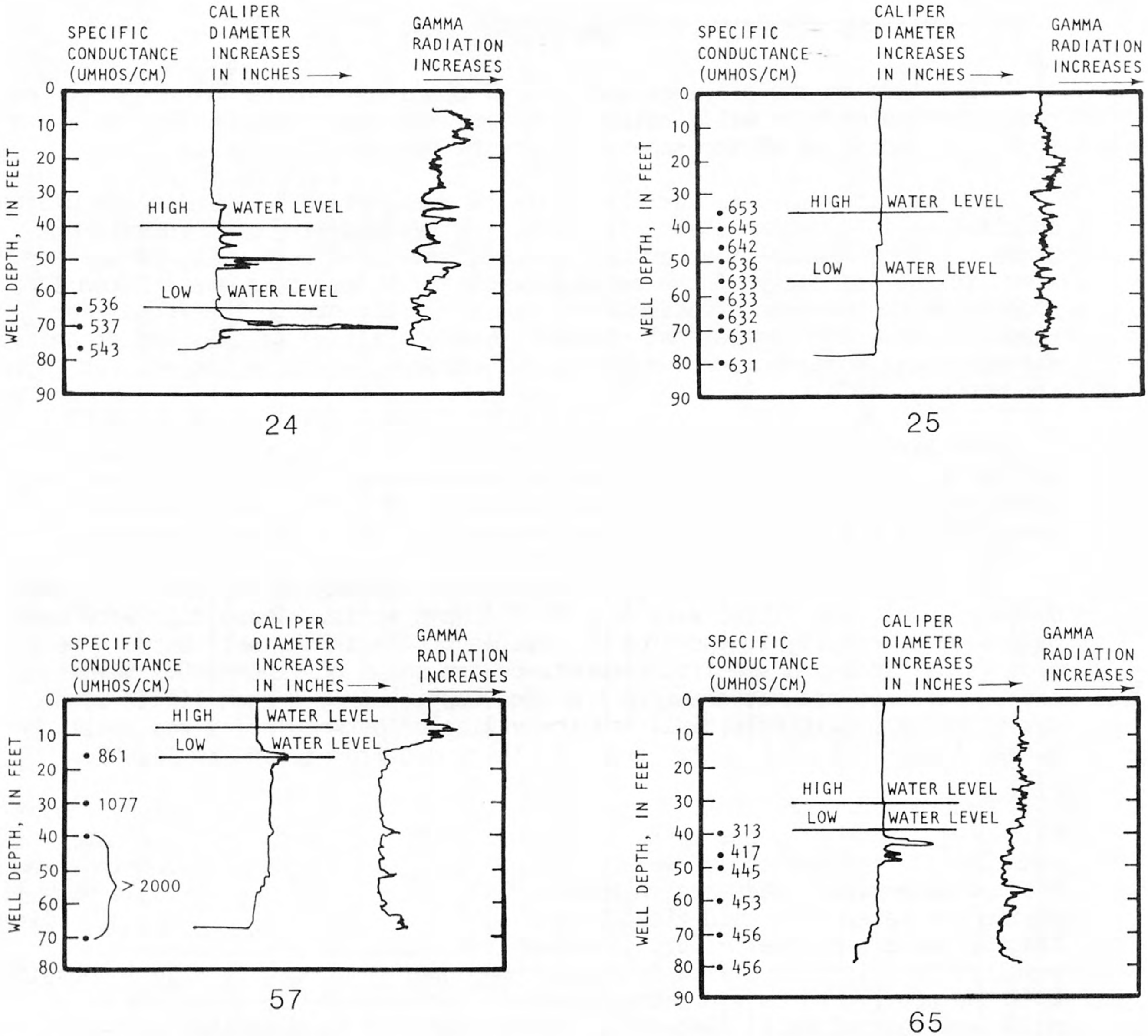
Caliper logs measure variations in the diameter of a borehole and provide qualitative information on the lithology and permeability of a formation. Gamma-ray logs measure the natural radioactivity of a rock unit and are used to identify the lithology of the rocks penetrated. Gamma rays are emitted in proportion to the concentration of radioactive elements in the rock. For example, shaly carbonates that contain large quantities of clay and organic materials are more radioactive than other carbonates within the aquifer (Keys and MacCary, 1971).

The average depth of the wells logged was 90 feet. Most wells were drilled approximately 30 feet below the lowest observed fracture or bedding plane opening. Although well 68 was drilled to a depth of 146 feet, the hole was subsequently bridged at 120 feet and was not logged below that point.

In addition to the logging, downhole measurements of pH, specific conductance, and temperature were made in the same wells. These data were used to define water quality in openings at various depths in the well bore. The geophysical logs and specific conductance are shown on figure 10. Values of pH and temperature are not shown on the logs because they showed little or no variation in a particular well and the variation between wells was small; pH ranged from 6.2 to 7.6 units; temperature ranged from 12.1°C to 14.5°C.

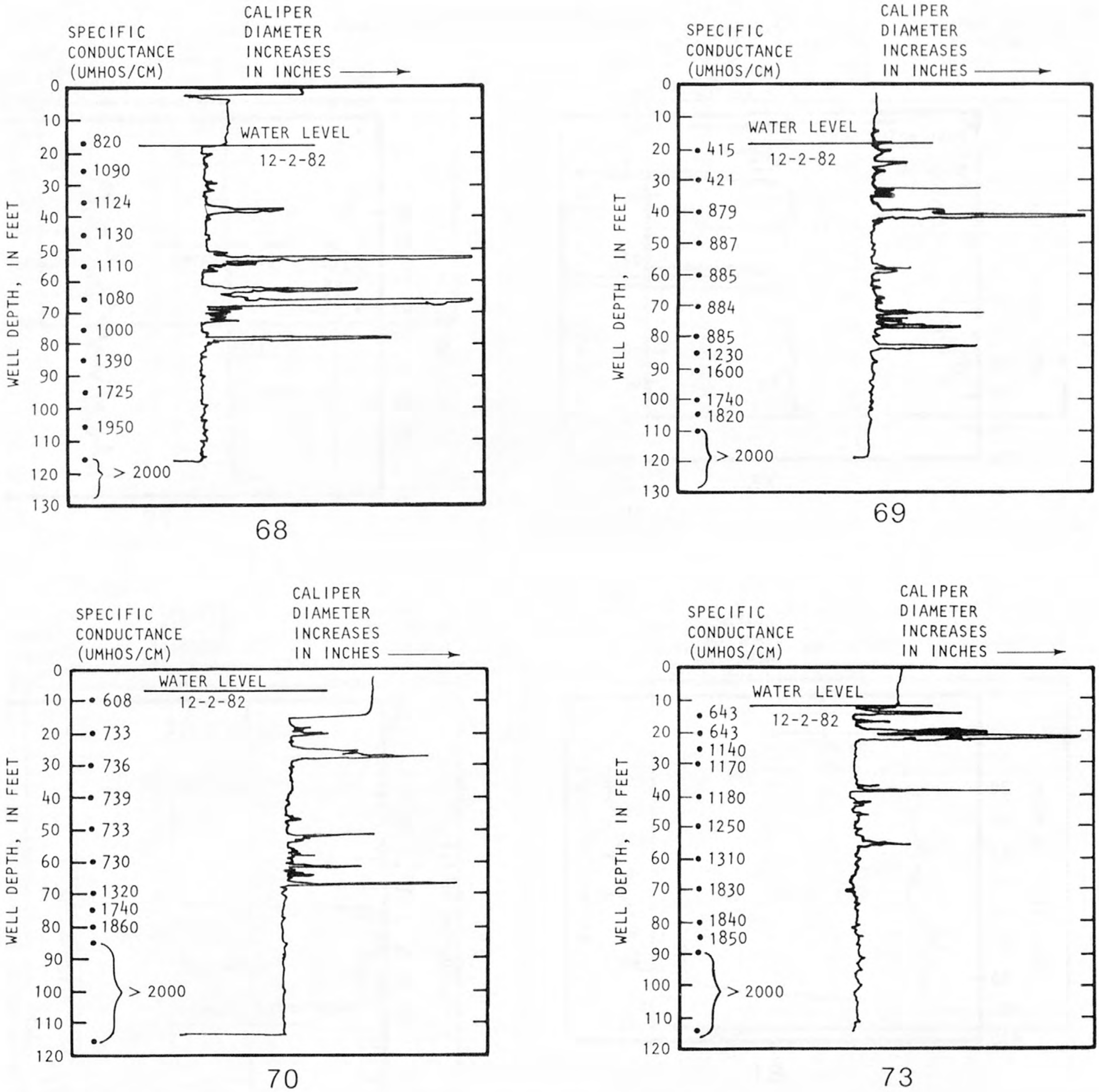
Fracture or solutionally enlarged openings were found at various depths (fig. 10). Some of these openings were water bearing and some were not. For example, the caliper log of well 24 showed an extensive zone of openings above the low-water level measured in October 1982. When measured during a high-flow period the water level had risen 22 feet and the previously non-water bearing fracture zone was under water. Although the higher water level may have resulted from increased flow from only the lower openings, it also is possible that the upper zone is a direct connection for recharge to enter the well quickly after rainfall. Generally, there seemed to be a greater difference between low and high water level measurements in wells having numerous fractures or solution openings as opposed to those with few openings. These fractures and solution-enlarged channels have increased the capacity of the aquifer to drain by gravity and to transmit water.

Openings observed on caliper logs from the city wells (wells 68, 69, 70, 73, and 75) appear at the same stratigraphic level in wells 88, 100, and 120 southeast of Elizabethtown (fig. 11) if the well logs are adjusted to the same datum. The presence of the Elizabethtown fault is evident between wells 120



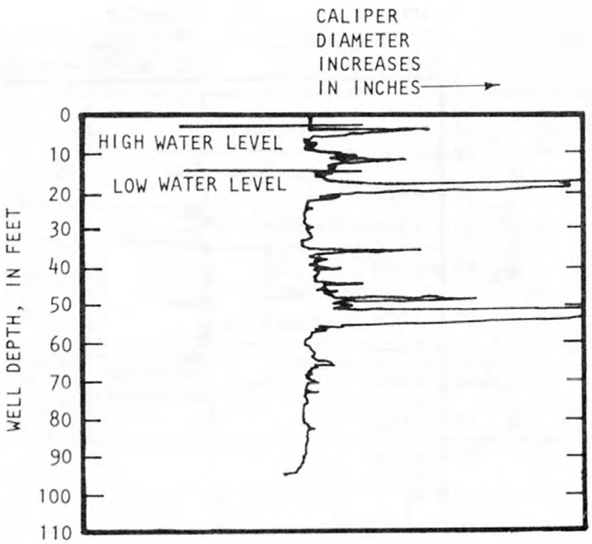
Well numbers refer to plate 1.

Figure 10.-- Geophysical logs with specific conductance and water levels for wells in the Elizabethtown area. Low water measured fall 1982. High water measured May 1983.



Well numbers refer to plate 1.

Figure 10.-- Geophysical logs with specific conductance and water levels for wells in the Elizabethtown area--Continued.



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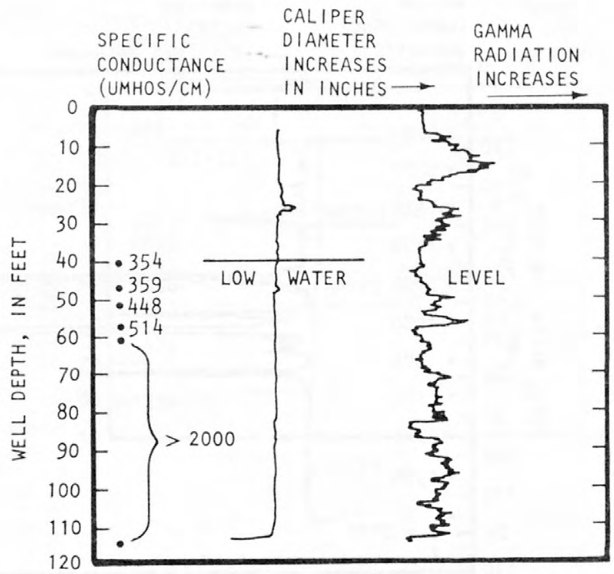

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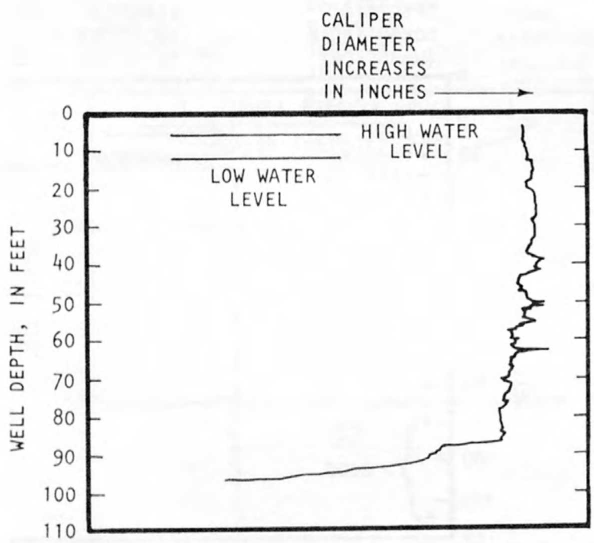

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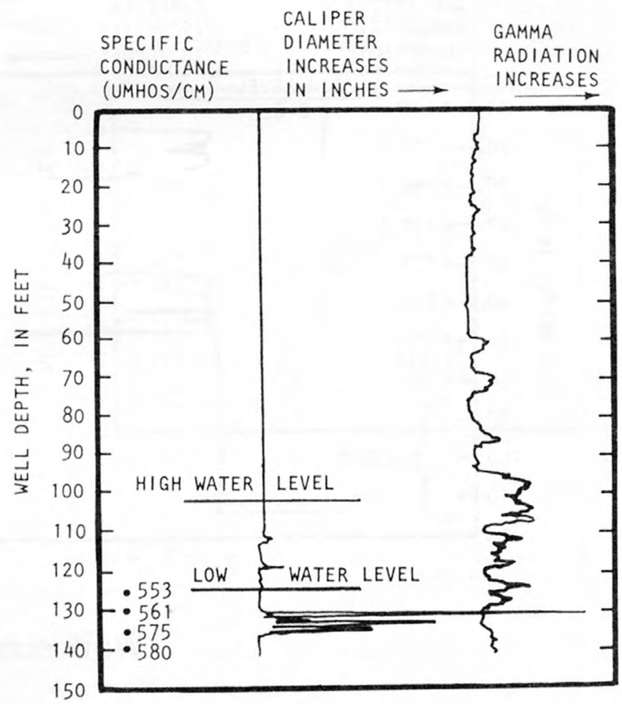
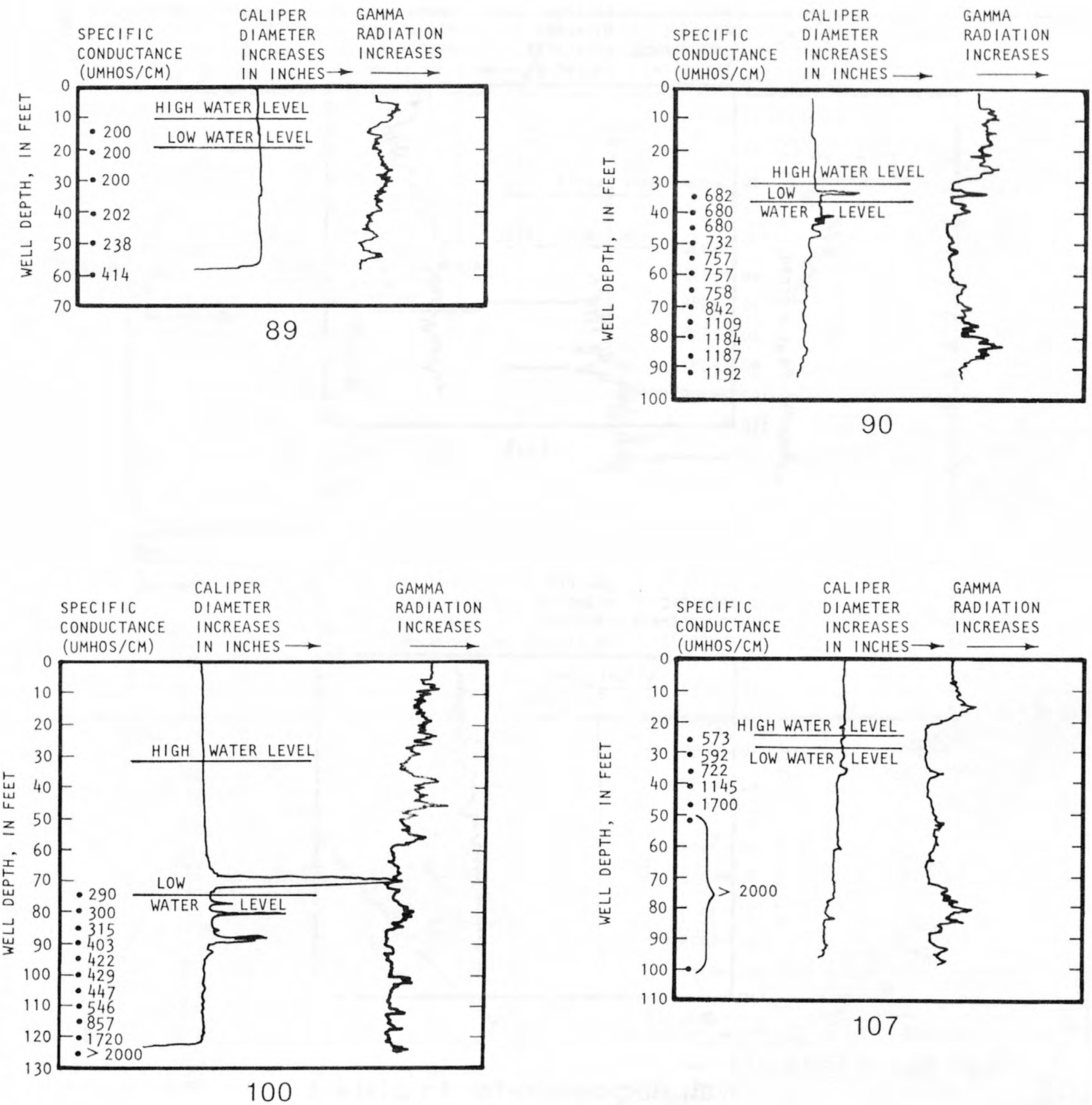


88

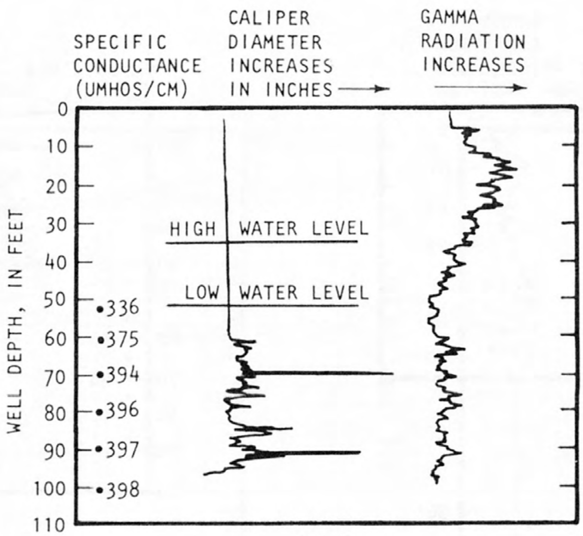
Well numbers refer to plate 1.

Figure 10.-- Geophysical logs with specific conductance and water levels for wells in the Elizabethtown area--Continued.



Well numbers refer to plate 1.

Figure 10.-- Geophysical logs with specific conductance and water levels for wells in the Elizabethtown area--Continued.



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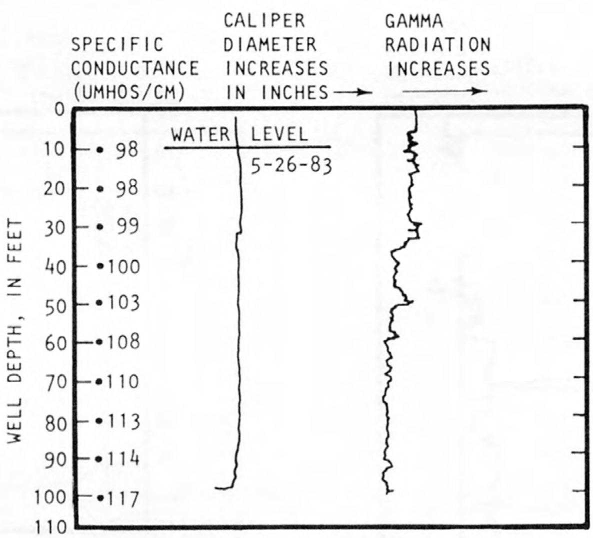
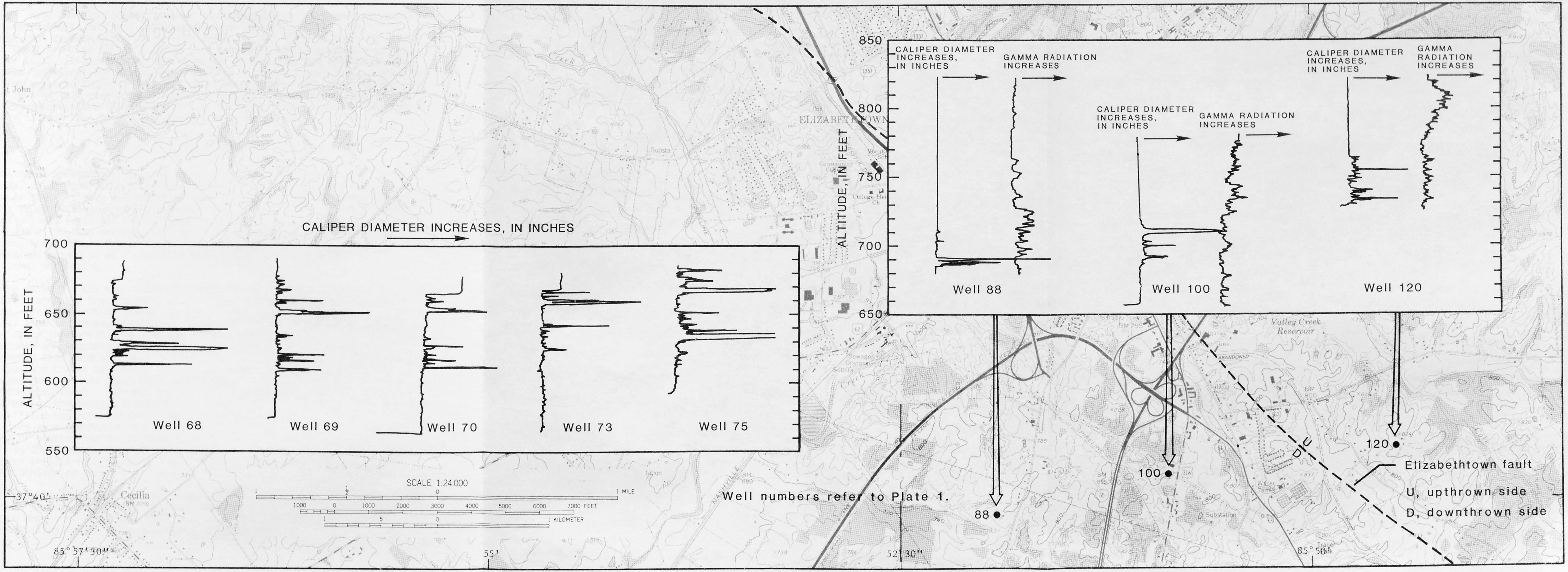


122-A

Well numbers refer to plate 1.

Figure 10.-- Geophysical logs with specific conductance and water levels for wells in the Elizabethtown area--Continued.



Base from:
U.S. Geological Survey 7.5' quadrangles, scale 1:24,000,
Cecilia (1967), Elizabethtown (1967, photorevised 1982).

Figure 11.-- Comparison of geophysical logs from five City wells with logs from three wells southeast of Elizabethtown.

and 100. Here the displacement between the upthrown and downthrown sides is approximately 40 to 50 feet. Although the water-level contours (plate 1) indicate that ground-water flow between wells 120 and 100 is somewhat modified by the fault and flow on the upthrown side generally moves eastward away from the city wells, it appears that the conduits in this area are similar and may provide a "pipeline" for ground-water movement. Although openings are shown on logs from wells to the north and west of Elizabethtown, these openings are not as numerous or well developed as those in logs from wells southeast of the city. Therefore, flow through the aquifer and yield from wells in these areas probably is less than in the southeastern part of the area.

TEST DRILLING

Although knowledge of geology and detailed well records can suggest the potential yield from wells in a specific area, ultimately, well yield must be proved by test drilling and properly conducted aquifer tests. At the beginning of this study, arrangements had been made for the drilling and testing of a new production well (well 68) and two observation wells (wells 69 and 70) in an area about 2,100 feet southwest of the city's water treatment plant. In addition, one production well (well 73) was enlarged from 6 to 12 inches in diameter and served as an observation well during test pumping and subsequent water-level monitoring.

The sites for the test wells were selected by a consultant on the basis of fracture traces and the proximity of the sites to the water-treatment plant (George, 1982). Fracture traces are the surface manifestation of subsurface vertical fracture zones, usually less than one mile in length. Fracture traces are detected in low altitude photographs as a variation in soil tonal color, topographic and vegetation alinements, alined gaps in ridges, linear topographic sags, and alinement of sinkholes. The yield of wells drilled on or near fracture traces is greatly enhanced because the fractures are avenues of preferred ground-water flow, capable of transmitting large volumes of ground water (George, 1982). However, George (1982) reports that the test wells did not penetrate the typical fracture-trace conditions below land surface such as gravel-filled crevices and deeper regolith-bedrock interface. Instead conditions were similar to that of adjacent non-fracture trace localities. Perhaps of greater importance than fracture traces in the area of the well field, is the presence of horizontal sheet-like openings that are discussed elsewhere in this report. Also, the sites were selected in the area of ground water discharge as shown on the water-level contour map of Lambert (1979).

The wells, 6 to 12 inches in diameter, were drilled with an air rotary rig to depths ranging from 117 to 146 feet below land surface. The wells were cased to depths of 14 to 19.5 feet. Well-construction data and physical characteristics of the wells are summarized in table 4.

Table 4.--Physical characteristics of test wells

Map number (Local number)	Date drilled	Depth (feet)			Diameter (inches)		Depth (feet) to first major opening	Number of major openings penetrated	Altitude of land surface (feet above sea level)
		To bedrock	Of casing	Of well	Casing	Well			
68 (TW-1-82)	07-01-82	7	19.5	146	12	12	36	5	690.55
69 (OW-1-82)	08-01-82	10	14	120	8	6	32	6	692.25
70 (TW-2-82)	09-01-82	11	14.2	118	8	6	16	6	680.84
73 (PW-3-81)	08-01-82	8	14.3	117.5	12	12	14	5	683.19

The test wells were drilled in the lower part of the St. Louis Limestone, the principal aquifer in the area. The wells penetrated from 7 to 11 feet of regolith overlying bedrock. All wells penetrated horizontal openings that probably have been solutionally enlarged along bedding planes. Caliper logs showed that the openings ranged in height from a few inches to as much as 6 feet. No large openings were found below 82 feet. The openings are fairly extensive and extend at least 2,100 feet in one direction in the vicinity of the well field. The possibility that the openings extend for several miles is dicussed in the section on geophysical logs.

DESCRIPTION OF PUMPING TEST

The drilling of a test well was undertaken to locate an additional water-supply well for the city. The well was test pumped to evaluate its potential as a water-supply well. The design and implementation of the test pumping was directed by consulting geologist, Angelo I. George. The aquifer test data are summarized in table 5. The U.S. Geological Survey's partici-ptation in the test was limited to the installation and maintenance of continuous-record water level recorders on wells 69, 70, 73, 75, and 81 (plate 1) and field testing of water samples for pH, temperature and specific conductance.

The test well (well 68) was pumped at varying rates for various periods of time while drawdown and recovery were measured in the pumped well and observation wells. The observation wells were spaced 213 to 2,920 feet, generally in a northeasterly direction, from the pumped well (well 68). After each period of pumping, water levels were allowed to recover to near prepumping level before the next pumping began. To lessen the cyclical effects of pumping from the city's production wells (wells 74 and 76), pumping from these wells began on September 9, and continued for the duration of test pumping and recovery. The combined yield from these wells was estimated to be nearly 1,000 gallons per minute. The first test began at 1300 hours on September 20, 1982. The pumping rate was 280 gal/min for 10 hours. The total drawdown in well 68 was 23.20 feet or 40.03 feet below land surface. The specific capacity was 12.1 (gal/min)/ft at the end of the first pumping period. After pumping ceased, water rose 3.29 feet in the first minute and 12.79 feet in the first 60 minutes. After 10 hours the water level was 2.91 feet below the prepumping level of 16.83 feet below land surface.

Drawdown in well 69 was 18.77 feet or 34.70 feet below land surface. At the end of the recovery period, the water in this well was almost 3 feet below the prepumping level of 15.93 feet below land surface.

Table 5.--Summary of aquifer test data

Map number[1] (Local number)	68 (TW-1-82)	69 (OW-1-82)	70 (TW-2-82)	73 (PW-3-82)	75 (OW-1-81)	81 (OW-3-81)
Distance from pumping well, in feet	(pumping well)	213	538	1,850	2,060	2,920
Test 1, pre-pumping water level in feet above sea level	673.72	676.32	676.15	673.69	672.80	673.36
Drawdown, 280 gal/min for 18 hours	23.20	18.77	13.26	1.70	1.5	1.06
Test 2, pre-pumping level, in feet above sea level	672.45	675.00	674.97	673.44	672.57	672.94
Drawdown, 510 gal/min (average) for 12 hours	46.40	30.56	20.76	2.78	2.73	1.37
Test 3, pre-pumping level, in feet above sea level	672.45	674.90	674.87	672.86	672.08	672.49
Drawdown, 448 gal/min for 72 hours	39.1	28.58	19.84	3.60	4.03	2.22
Recovery, in feet 1 hour after pump off, Step 3	24.61	13.99	7.59	.68	.84	.05

[1]Refers to plate 1.

The next test began at 1000 hours on September 22, 1982. The discharge rate was constant at 584 gal/min for the first 2 hours but varied from 524 to 488 gal/min in the next 10 hours. The time-weighted average discharge rate for the 12-hour period was 510 gal/min. This test produced the maximum drawdown in the pumped well; 46.40 feet below pre-pumping level or 64.50 feet below land surface. Based on the average pumping rate of 510 gal/min the specific capacity was almost 11 (gal/min)/ft. Water level recovered 12.25 feet in the first minute and 14.33 feet in the first hour after pumping ceased. The water level was 1.39 feet below original static 13 hours and 20 minutes after recovery began. Drawdown in well 69 was 30.56 feet or 47.81 feet below land surface.

The third test began at 1030 hours on September 24, 1982, and was intended to be a 72-hour test. Based on the results of the earlier tests, the pumping rate was 448 gal/min and remained constant throughout the test. After 72 hours of pumping, drawdown in the pumped well (well 68) was 39.1 feet below the pre-pumping level or 57.2 feet below land surface. The specific capacity was 11.5 (gal/min)/ft. One minute after pumping stopped, water had risen 6 feet; one hour later, water had risen 14.49 feet and was 32.59 feet below land surface. Recovery was monitored for 72 hours at which time the water level was only 0.82 feet below the pre-pumping level.

Drawdown in well 69 totaled 28.58 feet below original static or 45.83 feet below land surface. Water level in this well recovered to 0.75 feet below the pre-pumping level or 18.10 feet below land surface 72 hours after pumping ceased. Discharge rate, distance from the pumped well, and drawdown and recovery in the pumped well and observation wells are shown in table 5.

Based on these data, George (1982) derived a transmissivity value of 3,500 ft^2/d and a storage coefficient of 0.00016 for the pumped well (well 68). He recommended an on-line pumping rate of 500 gal/min for well 68. He estimates that pumping at this rate, for 1, 10, and 30 days should produce drawdowns of 22, 32, and 36 feet, respectively. The pumping levels would be about 58, 63, and 65 feet below land surface.

WATER QUALITY

Comprehensive chemical analyses of water from 25 wells and 3 springs indicate that ground water in the Elizabethtown area is a very hard calcium bicarbonate type. Figure 12 shows the relative proportions of the major mineral constituents. The values are means of the concentrations determined in samples from the wells. The mean value and statistical comparison of analyses of water from wells and springs in the Elizabethtown area are listed in table 6.

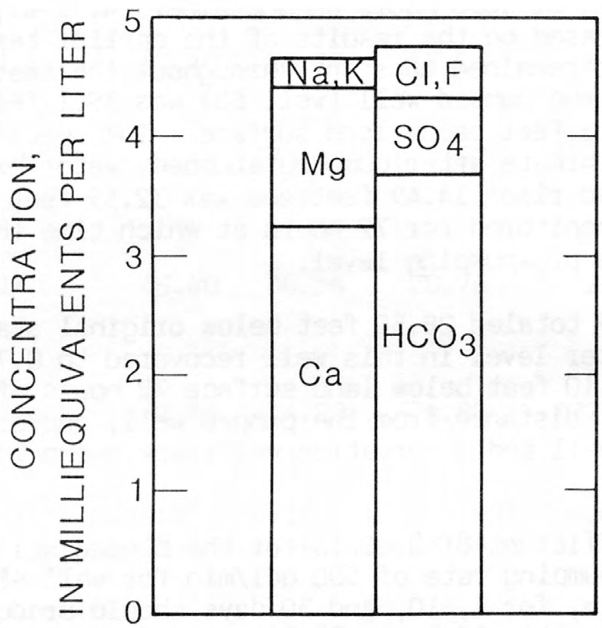


Figure 12.-- Major dissolved constituents in ground water in 25 wells and 3 springs in the Elizabethtown area. Values are the mean of analyses.

Table 6.--Mean values and statistical comparison of analyses of water from wells and springs in the Elizabethtown area with standards for maximum levels of constituents in finished drinking water

Label	Number of samples	Mean	Maximum value	Minimum value	Standard error of mean	Standard deviation	National drinking-water regulations[1]: Primary maximum contaminant level[2]	National drinking-water regulations[1]: Secondary maximum contaminant level[3]	Kentucky water-quality standards[6]
Alkalinity, laboratory (mg/L as $CaCO_3$)	28	188	259	121	6.20	32.8	-	-	-
Barium, dissolved (ug/L as Ba)	28	71	220	29	8	41	1,000	-	1,000
Beryllium, dissolved (ug/L as Be)	28	1	1	1	1	0	0	-	-
Cadmium, dissolved (ug/L as Cd)	28	1	3	1	0	1	10	-	-
Calcium, dissolved (mg/L as Ca)	28	63	92	41	2.5	13	-	-	-
Chloride, dissolved (mg/L as Cl)	28	11	120	.80	4.2	22	-	250	250
Chromium, dissolved (ug/L as Cr)	27	11	20	10	1	3	50	-	50
Cobalt, dissolved (ug/L as Co)	28	3	3	3	0	0	-	1,000	-
Copper, dissolved (ug/L as Cu)	28	10	10	10	0	0	-	1,000	1,000
Fluoride, dissolved (mg/L as F)	28	0.4	1.6	0.1	0.1	0.5	-	[4]1.8	-
Hardness (mg/L as $CaCO_3$)	28	209	300	130	9.0	47	-	-	-
Hardness, noncarbonate (mg/L as $CaCO_3$)	28	23	100	0	6	33	-	-	-
Iron, dissolved (ug/L as Fe)	28	22	71	3	3.8	20	-	300	-
Lead, dissolved (ug/L as Pb)	28	11	20	10	1	32	50	-	50
Lithium, dissolved (ug/L as Li)	28	6	18	4	1	3	-	-	-
Magnesium, dissolved (mg/L as Mg)	28	11.7	30	2.60	1.5	8.2	-	-	-
Manganese, dissolved (ug/L as Mn)	28	17	320	1	11	60	-	50	50
Molybdenum, dissolved (ug/L as Mo)	28	11	30	10	1	4	-	-	-
pH (units)	43	7.2	7.6	6.8	-	-	-	6.5-8.5	-
Potassium, dissolved (mg/L as K)	28	0.6	2.80	0.10	0.1	0.7	-	20	-
Solids, dissolved, residue at 180°C	27	245	456	157	15	79	-	500	750
Silica, dissolved (mg/L as SiO_2)	28	10	13	8	0.26	1.40	-	-	-
Sodium, dissolved (mg/L as Na)	28	7	64	1.8	2.2	12	-	250	-
Percent sodium	26	6.7	36	1.9	1.3	6.4	-	-	-
Specific conductance (micromhos)	55	480	2,900	260	48	354	-	-	-
Strontium, dissolved (ug/L as Sr)	28	2,824	25,000	58	1,192	6,309	-	-	-
Sulfate, dissolved (mg/L as SO_4)	28	22	110	1.7	6.0	31.5	-	250	-
Turbidity (NTU)	28	2.12	16	[5]1	.72	3.79	1	-	-
Vanadium, dissolved (ug/L as V)	28	6	6	6	0	0	-	-	-
Temperature (°C)	37	14.3	16	13	.11	.66	-	-	-
Zinc, dissolved (ug/L as Zn)	28	226	2,200	4	87.5	463	-	-	-
Carbon, organic total (mg/L as C)	25	.98	6.6	0.1	.26	1.3	-	-	-
Nitrogen, nitrite dissolved (mg/L as N)	24	0.02	0.25	0.01	0.01	0.05	-	-	-
Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	24	1.8	10	0.10	0.51	2.5	10	10	10
Nitrogen, ammonia dissolved (mg/L as N)	24	0.02	0.05	0.01	0	0	-	-	-
Nitrogen, ammonia + organic dissolved (mg/L as N)	24	0.24	0.60	0.10	0.03	0.17	-	-	-
Nitrogen, ammonia dissolved (mg/L as NH_4)	24	0.02	0.06	0.01	0	0	-	-	-
Phosphorus, ortho dissolved (mg/L as P)	24	0.01	0.04	0.01	0	0	-	-	-
Phosphorus, dissolved (mg/L as P)	24	0.02	0.05	0.01	0	0	-	-	-

[1]U.S. Environmental Protection Agency, 1975, 1979.

[2]Applies to all systems providing piped water for human consumption if such systems have at least 15 service connections or regularly serves at least 25 individuals.

[3]These are not Federally enforceable and are intended as guidelines.

[4]At average maximum daily temperature of 69°F.

[5]A value of five or fewer turbidity units is allowed if it does not interfere with disinfection or microbiological determinations.

[6]Kentucky Administrative Regulation 401, Chapter 5.

Ground water sampled from the domestic wells is suitable for most uses including drinking water. Only one of the samples tested had a secondary constituent exceeding recommended U.S. Environmental Protection Agency (1979) concentrations as shown in table 6. This water sample had a dissolved manganese content of 320 ug/L (micrograms per liter), exceeding the recommended maximum of 50 ug/L. This isolated value is no cause for concern. Water from only one other domestic well sampled, approached the recommended maximum value. Manganese is one of the most common elements in the earths crust and is widely distributed in rocks and soils in the Elizabethtown area. Manganese is readily leached from rocks and soils by circulating ground water.

Suspended sediment content is probably the most objectionable water-quality constituent in ground water in the Elizabethtown area. Many residents reported that their well water was muddy for various lengths of time after heavy rains. Although this condition is objectionable, the condition is temporary and the water generally clears in 1 or 2 days. There are several possible explanations for the turbid water in the wells. An improperly sealed casing may allow surface runoff to drain into the well or the aquifer may be recharged with muddy water from surface runoff. This is common in the Elizabethtown area because the ground water system is recharged directly by drainage through sinkholes and sinking or losing streams.

Water from wells can also be muddy in dry weather. This is most likely to occur in heavily pumped wells where the combination of lower water levels and turbulence caused by pumping can dislodge sediment, which was previously equilibrated with the ground-water flow system, resulting in turbid discharges from the wells. This situation apparently occurred in the city supply well in August 1983. The discharge from well 76 was very muddy on August 10, although the last rainfall was on August 5.

Areal variation in water quality is shown by the pie diagrams for each sampled site plotted on plate 2. The diagrams show concentrations in milliequivalents per liter for selected cations and anions. The radius of the circle is proportional to the ionic concentration of the sample.

The diagrams of ionic concentrations indicate a slight zonation of water quality near the Elizabethtown fault (see plate 2). The samples from the upthrown side of the fault tend to have higher concentrations of dissolved minerals (larger circles) than those samples from the downthrown side. Many of the wells on the upthrown side of the fault tap the deeper St. Louis and underlying upper Salem limestones which generally yield water with higher mineral concentrations. This difference in water quality attenuates toward the northwestern end of the Elizabethtown fault and may reflect a gradual lessening in displacement along the fault in that direction.

Heavy pumping of wells seems to affect water quality in the Elizabethtown area. Samples from three heavily pumped wells had large concentrations of sulfate or high specific conductances when compared to samples from nearby domestic supply wells. The industrial supply well (well 60) is routinely pumped at approximately 100 gal/min for about 16 to 24 hours daily; the city supply well (well 76) yields about 500 gal/min for 19 to 20 hours per day. Samples from these two wells showed sulfate concentrations of 403 mg/L and 73 mg/L respectively. Specific conductance was 1,200 umhos and 600 umhos in water from wells 60 and 76, respectively. These analyses illustrate the potential water-quality problems related to prolonged or heavy pumping. George (1982) noted the increase in conductance, sulfates and dissolved solids during testing of well 68 in November of 1982. Specific conductance was 1,150 umhos at the beginning of the 72-hour pumping test on September 24, 1982, but increased to 1,725 umhos at the end of the test. During the same test sulfate increased from 620 to 775 mg/L.

In addition to sampling for laboratory analysis, the physical properties were checked by a three-parameter downhole sampler. Specific conductance, temperature, and pH were measured in 18 open wells ranging in depth from 59 to 142 feet. Five of the wells were at the city well field and the others are located in the Elizabethtown area. The down-hole testing provided evidence of stratification of water quality and showed water-quality changes that seem to be related to solution openings. Overall, pH and temperature varied in a narrow range of values, but specific conductance values varied widely.

Specific conductance is a measure of the capacity of water to conduct an electric current and is an indicator of the dissolved solids in solution. The larger the specific conductance value, the larger the concentration of dissolved solids.

Specific conductance is compared with the caliper logs on figure 10. The graphs show strong correlation of conductance with zones of openings in the city well field. In these zones of openings, specific conductance values usually increased by approximately 50 percent and in some wells a distinct layering of water quality was noted. This zonation of specific conductance and the relation to conduits was less noticeable in wells outside the city well field. Even in wells southwest of Elizabethtown, that had similar openings, the specific conductance values were in the low to medium range (300 to 600 umhos) and fairly uniform throughout the vertical section sampled.

The stratification of specific conductances at the well field is partially due to differences in mineral composition of the aquifer and to pumping rates. The presence of higher conductance values at depth suggests some mixing of highly mineralized water from deeper aquifers or higher mineralization resulting from the slower movement of water and increased contact-time in the less permeable part of the aquifer.

Further analysis of the conductance and caliper logs in the city well field indicates that nearly all the water pumped at the present time is derived from the upper 25 feet of the aquifer. Horizontal openings are abundant in this part of the aquifer and conductance values range from 400 to 1,000 umhos. Specific conductance of the water from the city supply well (well 76) was 460 umhos which agrees with the assumption that most of the water is presently coming from the upper fractured part of the aquifer.

Specific conductance was measured at each inventoried well or spring where possible (see plate 2). The field measurements of specific conductance of water from the St. Louis Limestone in the Elizabethtown area ranged from 340 to 950 umhos per centimeter. The average value was 430 umhos and the median was 400 umhos. Water from the underlying Salem Limestone has specific conductance values exceedings 1,000 umhos. Lower conductance values occur in areas overlain by surficial deposits of slumped material. Water draining from this clayey material has lower dissolved solids than water in the underlying limestone aquifer. Thus, water in the limestone tends to be diluted by the less mineralized water from above.

Specific conductance measured in streams throughout the Elizabethtown area during low base flow on March 15-16, 1983, ranged from 230 to 520 umhos per centimeter. Generally, the lowest values were in streams draining the surficial deposits of slumped material (plate 2).

Specific conductance is a simple and inexpensive method of monitoring water quality. The specific conductance values shown on plate 2 provide a base level for measuring future quality changes in water from streams, wells, or springs.

Nutrients

Dissolved nitrogen, in the form of nitrate (NO_3), is the most common nutrient contaminant identified in most ground water systems. This contaminant is becoming increasingly wide-spread because of agricultural activities. Although NO_3 is the main form in which nitrogen occurs in ground water, dissolved nitrogen also occurs in the form of ammonium (NH_4+), ammonia (NH_3), nitrite (NO_2), nitrogen (N_2), nitrous oxide (N_2O), and organic nitrogen. Organic nitrogen is nitrogen that is incorporated in organic substances. Given time, however, most of the nitrogen in the form of ammonia and nitrite will oxidize to nitrate.

A large concentration of phosphorus generally is an indication of ground water contamination. Phosphate is available for solution in water from several of man's activities, primarily the application of fertilizers. Because phosphorus is an element essential in metabolism, it is always present in animal metabolic waste and a component of sewage.

Analysis of the ground-water samples from the Elizabethtown area in November and December 1982, indicates that nitrogen is primarily in the form of nitrate and the phosphorous concentrations are relatively small. The maximum nitrate concentration of 10 mg/L for 24 samples falls below the recommended U.S. Environmental Protection Agency limit of 45 mg/L, which indicates that nitrate should not be viewed at the present time as a hazard to water use in and around the study area.

Although detection of nutrient concentrations was low for all wells sampled in the study area, the potential exists for contamination of some wells by nitrogen and phosphorous from fertilized fields or locations with concentrations of livestock. In such situations, nutrients could be easily introduced into the ground-water system by surface runoff draining into improperly sealed wells or by direct inflow of surface runoff from pastures and fields.

Trace Constituents

Substances that typically occur in concentrations below 1,000 ug/L are generally considered as being in the trace constituent category. Analyses for minor element constituents are not considered routine. However, recent discoveries indicate that some supposedly insignificant minor constituents are important to human and plant physiology. In addition, minor elements may serve as indicators of pollution from industrial and municipal wastes.

Analyses of trace constituents in water from 28 sites in the Elizabethtown area are summarized in table 6 along with the recommended allowable content for drinking water. Industrial pollution typically produces trace constituent concentrations far in excess of the recommended content for drinking water. The recommended trace constituent concentration was exceeded only for manganese in water from one well. None of the other trace constituents exceeded the recommended drinking water-quality standards (U.S. Environmental Protection Agency, 1979) during this investigation.

Organic Compounds

Organic compounds in ground water occur naturally and also as a product of man's activities. Because of the potential effects on health, considerable emphasis has been placed on the detection and identification of man-made organic compounds in public water supplies. Because of the vast array of organic compounds that may be in ground water, the detection and identification of specific compounds is costly and complex. Therefore, a broad spectrum analysis is frequently used to provide an overall picture of the organic constitutents present in a sample.

A relatively new analytic technique for detecting organic carbon pollution in ground water was used by the U.S. Geological Survey water-quality laboratory on three samples from the Elizabethtown area. Samples from Dyers (spring 48) and Elizabethtown (spring 80) springs and well 76 were analyzed using a gas chromatographic flame ionization detector (GCFID). The GCFID scan is a general screening method and has a greater sensitivity for determining levels of carbon pollutants than the more routine total organic carbon (TOC) analysis which yields only a gross measurement of the organic carbon content of a water sample. As much as 95 percent of the carbon detected may be from natural sources such as humic materials, algae, leaves, detritus, or other plant and animal materials. The TOC technique is not a direct indicator of pollution unless abnormally high levels are indicated by the analysis. Total organic carbon in 25 samples from the Elizabethtown area ranged from 0.1 to 6.6 mg/L and is not considered high.

Results of the GCFID scan on three samples from the study area showed almost no traces of organic pollutants and virtually no difference in the organic characteristics of the water sampled. Although the scan is not compound specific, not enough organic pollutants were detected to warrant further analysis on the three samples.

Bacteria

Because of the nature of ground-water movement in carbonate rocks, the introduction and relatively widespread distribution of contaminants, such as bacteria, is possible. Thus, bacterial pollution could become a serious problem in ground water supplies developed in carbonate rocks underlying the Elizabethtown area.

The coliform group of bacteria is a commonly used indicator of pollution. Although coliform bacteria are derived from many sources and general occurrence is not unusual, high numbers are indicative of pollution. In addition, the ratio of fecal coliform to fecal streptococci is frequently used to indicate whether the source of bacteria is animal or human wastes. For example, if the ratio of fecal coliform to fecal streptococci is 4.0 or greater, the pollution is derived from human waste; if the ratio is 0.7 or less the source of the pollution is animal wastes.

Samples for bacterial analysis were collected from 10 wells, 1 spring and 1 sinking stream on April 25-27, 1982, after 1.14 inches of rainfall on April 23. Sampling after a heavy rain was considered the most likely time for high bacteria counts. The samples were analyzed using the membrane filter method described by Greeson and others (1977). The results of these analyses are shown in table 7. If the number of colonies per plate was non-ideal (20 to 60 colonies of fecal coliform or 20 to 100 colonies of fecal streptococci) the colony count nearest the ideal was used to calculate the bacteria concentration per 100 mL of water. The non-ideal numbers of colonies are identified in table 7. Samples from seven wells had no fecal coliform but fecal streptococci ranged from 12 to 330 colonies per 100 mL of water. One well had no fecal coliform or fecal streptococci colonies. On April 25 well 42 had 2,580 fecal coliform colonies and 513 fecal streptococci colonies per 100 mL of water. The well was resampled on April 27 and had 100 fecal coliform colonies and 40 fecal streptococci colonies per 100 mL of water. The ratio of fecal coliform to fecal streptococci changed from 5.1 on April 25 to 2.5 on April 27. Although the specific reason for this fluctuation in the bacteria count is not known, the fluctation indicates how quickly the bacteria count can change in a limestone aquifer.

Technicians at the city's wastewater-treatment plant have monitored the content and species of bacteria in raw water from the Elizabethtown Spring and Dyers Spring since February 4, 1982. Their analyses, shown in table 8, show wide variations in bacteria concentration. The largest concentration occurred on August 19, 1982, and was apparently caused by a broken sewerline under the I-65 interchange south of the city. After the break was repaired the bacteria concentration decreased noticeably.

The variation in bacteria concentration in water from the springs is likely related to precipitation, temperature, and the numerous sinkholes that occur in the vicinity of each spring. Because sinkholes provide a direct connection between land surface and ground water, the quality of water reaching the shallow ground-water reservoir is virtually unchanged from conditions at the surface. Thus, if runoff contains bacteria, bacteria-laden ground water can be expected in karst areas underlain by carbonate rocks such as the Elizabethtown area.

Table 7.--Bacterial analysis of raw water samples from the Elizabethtown area

Map number (Refers to Plate 1)	Date sampled	Fecal coliform (colonies/100 mL)	Fecal streptococci (colonies/100 mL)	Ratio fecal coliform to fecal streptococci
61	4-25-83	1,080	[1]TNTC	-
29	4-25-83	0	290	-
42	4-25-83	[2]2,580	513	5.0
42	4-27-83	[2]100	40	2.5
15	4-25-83	0	212	-
22	4-25-83	280	2,495	.1
62	4-25-83	0	[2]16	-
113	4-27-83	0	0	-
87	4-27-83	0	[2]8	-
124	4-27-83	0	330	-
111	4-27-83	[2]12	80	.15
101-A	4-27-83	0	100	-
S-1	4-27-83	[2]60	320	.19

[1]Colonies too numerous to count.
[2]Non-ideal number of colonies per plate.

Table 8.--Bacterial analysis of raw water from water-supply springs in the Elizabethtown area (Analyses by David W. Pedigo, Chief Laboratory Technician for Elizabethtown)

Site (map number)	Date sampled	Fecal coliform (colonies/100 mL)	Fecal streptococci (colonies/100 mL)	Ratio fecal coliform to fecal streptococci
Elizabethtown Spring (80)	2- 3-82	50	210	0.24
	2-22-82	510	30	17.0
	3- 9-82	300	110	2.7
	4-13-82	1,400	160	8.8
	5-18-82	5,200	310	16.8
	6-22-82	1,800	300	6.0
	7- 7-82	90	56	1.6
	7-12-82	2,500	2,300	1.1
	8-17-82	7,600	20,000	.38
	9-21-82	100	300	.30
	10-26-82	1	5	.20
	11-16-82	10	36	.28
	11-22-82	220	940	.23
	12- 7-83	100	260	.38
	1- 4-83	4	16	.25
	2-16-83	18	30	.60
	4-21-83	80	63	1.3
	5-16-83	66	96	.69
	6- 7-83	280	580	.48
	7-26-83	13	380	.03
	8- 9-83	26	40	.65
	9-13-83	1	3	.30
Dyers Spring (48)	2- 3-82	30	60	.5
	6-22-82	52	100	.52
	9-21-82	550	400	1.4
	10-26-82	7	6	1.2
	12- 7-82	40	280	.14
	2-16-83	6	16	.38
	4-21-83	40	36	1.1
	5-16-83	54	37	1.5
	6- 7-83	250	180	1.4
	7-26-83	25	110	.23
	8- 9-83	110	350	.31
	9-13-83	1	140	.01

SUMMARY

1. The St. Louis Limestone is the principal aquifer. Unconsolidated residuum or surficial deposits of slumped material may store water and recharge the underlying limestone aquifer.

2. Most ground water derived from carbonate rocks in the area, occurs in openings that have been enlarged by circulating water. Horizontal sheet-like openings range in height from 1 inch or less to 6 feet. These openings are best developed in the area of ground-water discharge southwest of Elizabethtown and parallel to Valley Creek. Although wells in this area penetrated as many as 5 zones of horizontal openings, most ground water is withdrawn from the upper zones near land surface.

3. The major source of ground-water recharge is infiltration through soil and unconsolidated deposits, overland flow into sinkholes, and percolation through stream beds. Sinkholes are abundant in parts of the area. Because sinkholes provide direct paths for runoff to drain to the subsurface, they are potential sources of ground water contamination.

4. Average ground-water recharge is 6 inches per year. The rate of shallow ground water-movement ranges from about 1.5 to 23 miles per day. About 2 million gallons of water per day flows through a 1.8 mile wide section of the aquifer about 1-1/2 miles southwest of the city well field. The ground-water flow pattern is modified by three of four faults. The faults form barriers that impede ground-water movement.

5. A test well produced from 280 to 510 gal/min. Specific capacity ranged from 11.5 to 12.1 (gal/min)/ft of drawdown after 12 and 72 hours of pumping. Drawdown was 2.2 feet in an observation well 2,920 feet from the pumped well indicating that the wells penetrated an extensive system of interconnected openings.

6. Seasonal differences in water levels ranged from 0 to 50 feet. Water levels near the city well field are about the same as they were about 10 years ago, about 670 to 680 feet above sea level.

7. Ground water generally is a very hard calcium bicarbonate type. Only one constituent exceeded recommendations for finished drinking water; manganese was 320 ug/L in one water sample. Suspended sediment is a problem in some areas. Heavily pumped wells tend to yield water with higher specific conductance and larger concentrations of sulfate than nearby domestic wells. Specific conductance increases with depth and varies with the horizontal

openings in wells. Specific conductance usually increased about 50 percent and showed a stratification of water quality around the zones of openings. Specific conductance was 400 to 1,000 umhos in the upper 25 feet of aquifer but generally exceeded 2,000 umhos in deeper zones, especially in wells near the Elizabethtown well field. The sulfate concentration increased from 620 to 775 mg/L during 72 hours of pumping at 448 gal/min.

8. Organic pollutants were not detected in significant amounts in samples from the city springs or wells.

9. Of samples collected for bacterial analysis from 10 wells, 1 spring, and 1 sinking stream, samples from 7 wells had no fecal coliform but fecal streptococci ranged from 12 to 330 colonies per 100 mL of water. Samples from one well had no fecal coliform or fecal streptococci bacteria. The fecal-coliform count in one well decreased from 2,500 colonies to 100 colonies per 100 mL of water in 2 days and illustrates how quickly the bacteria count can change in a limestone aquifer.