POTENTIOMETRIC SURFACE AND WATER QUALITY IN THE PRINCIPAL AQUIFER, MISSISSIPPIAN PLATEAUS REGION, KENTUCKY

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CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
gallon per minute (gal/min)	0.0630	liter per second (L/s)
inch (in.)	25.40	millimeter (mm)
inch per year (in/yr)	25.40	millimeter per year (mm/yr)
mile (mi)	1.609	kilometer (km)
micromho per centimeter at 25° Celsius (umho/cm at 25°C)	1.000	microsiemens per centimeter at 25° Celsius (uS/cm at 25°C)

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°C = (°F-32)/1.8$$

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level, is referred to as sea level in this report.

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ABSTRACT

The Mississippian Plateaus region is the outcrop area of rocks of Mississippian age which extends as a broad arcuate band around the Western Coal Field in west-central Kentucky. Much of the area is characterized by plains of low relief containing numerous sinkholes, subsurface drainage, and a low density of surface streams. The principal aquifer consists of 1,000 to 2,000 feet of limestones extending downward stratigraphically from the base of the Chesterian Series to the black shales at the top of the Devonian rocks. Well yields range from several gallons per minute to as much as 500 gallons per minute in some karst areas where secondary openings are well developed.

The potentiometric map indicates that ground-water movement generally conforms to the surface drainage pattern. The actual direction of movement varies from river basin to river basin.

Most water from the principal aquifer is a calcium magnesium bicarbonate type and is generally good relative to current drinking water standards. The lower St. Louis Limestone, in places, yields a calcium magnesium sulfate water that is corrosive and has a strong hydrogen sulfide odor.

The karst areas of the principal aquifer are vulnerable to contamination because of the well-developed subsurface drainage. Urban areas, industries, and agriculture are sources of contaminants that can be easily flushed into the ground-water system.

INTRODUCTION

This is the final report in a series done in cooperation with the Kentucky Geological Survey to describe the configuration of the potentiometric surface and the general ground-water quality in part of the Mississippian Plateaus region of Kentucky. It deals with the principal limestone aquifer for the entire region whereas previous reports dealt only with selected segments of the region.

This regional study was initiated in 1975. It includes not only data collected from 1975 to 1982, but also data from earlier studies. Earlier data are considered valid as ground-water levels seem to have remained relatively stable on a regional basis, except for normal seasonal variations, for at least a quarter of a century.

Little surface water is available in much of the Plateaus region, except along major streams and from man-made lakes and reservoirs. Except for the larger municipal areas and areas served by water districts, most people depend on ground water as a source of supply. Because pollutants can enter the principal limestone aquifer easily and move rapidly down gradient for long distances, data on the potentiometric surface, the direction of water movement, and basic water quality are essential for the proper utilization and protection of the ground-water system.

Purpose and Scope

The primary purpose of this report is to provide a potentiometric map of the principal aquifer which represents the level of the static head in the aquifer as defined by the height to which water will rise in tightly cased wells. This map can be used to determine the general direction of ground-water movement, to aid in determining possible paths of pollutant movement, and to help in selecting drilling sites. The altitude of the potentiometric surface also can be used, in conjunction with land-surface altitudes, to determine minimum drilling depths to water.

The secondary purpose of the report is to describe the general water quality in the principal aquifer. This information will aid in determining the suitability of the water for various uses and will provide baseline data for monitoring changes in chemical quality that may result from man's activities.

Location and Description of Area

The Mississippian Plateaus region comprises one of the five physiographic regions of Kentucky (fig. 1). It is the outcrop area of rocks of Mississippian age and extends as a broad arcuate band bordering the Western Coal Field. The Plateaus occur as a pair of cuestas with their long slopes facing toward the Western Coal Field. The inner cuesta is carved on the Cypress Sandstone of Late Mississippian age and is bounded by the south or outward-facing Drippings Springs escarpment. The outer cuesta, known as the Pennyroyal or, more commonly, Pennyrile plain (McFarlan, 1943, p. 184), is developed largely on the St. Louis Limestone of Late Mississippian age, forms the outer part of the Plateaus, and dips toward the Western Coal Field. In its typical development the Pennyrile plain is a rolling upland karst plain of low relief characterized by numerous sinkholes, subsurface drainage, and a low density of surface streams. Near the updip fringes, stream dissection has produced a rough topography. In parts of Caldwell, Livingston, and Crittenden Counties (fig. 1), a maze of normal faults has resulted in a topography of little uniformity. For a more detailed discussion of the physiography of the Plateaus the reader is referred to McFarlan (1943, p. 184-193).

The Mississippian Plateaus region lies within the Ohio River drainage basin. Much of the area is drained by the Green River and its tributaries, and the Rough, Nolin, and Barren Rivers and their tributaries. From Simpson County westward, drainage is primarily to the Cumberland River in Tennessee via the Red River and its tributaries and to Lake Barkley (impounded Cumberland) in Kentucky via the Little River and its tributaries. Those areas adjacent to the Ohio River drain directly into the Ohio.

GENERAL GEOLOGIC FRAMEWORK OF THE PRINCIPAL AQUIFER

The rocks exposed in the Mississippian Plateaus are of Early to Late Mississippian age and comprise, from older to younger, the Osagean, Meramecian, and Chesterian Series. They dip toward the Western Coal Field at about 30 to 90 feet per mile. Their stratigraphic relations are shown in figure 2. Older rocks may be exposed in valley walls and stream beds in the updip fringes of the area.

The principal aquifer, as used in this report, refers to the thick, relatively unbroken sequence of limestones underlying the Pennyrile plain. The geologic units in ascending order are the Fort Payne Formation, Warsaw (Harrodsburg) Limestones, Salem Limestone, St. Louis Limestone, and Ste. Genevieve Limestone. The aquifer may include, in places, the lowermost limestones of the overlying Chesterian Series, the Renault Limestone, the Beaver Bend and Paoli Limestones, or the Girkin Limestone, depending on location in the plain. The principal aquifer is underlain by the Devonian age Chattanooga or New Albany Shale, except where the Borden Formation replaces the Fort Payne, and is overlain by a residual mantle derived mostly from limestone. The formations are discussed in detail in the hydrogeology section.

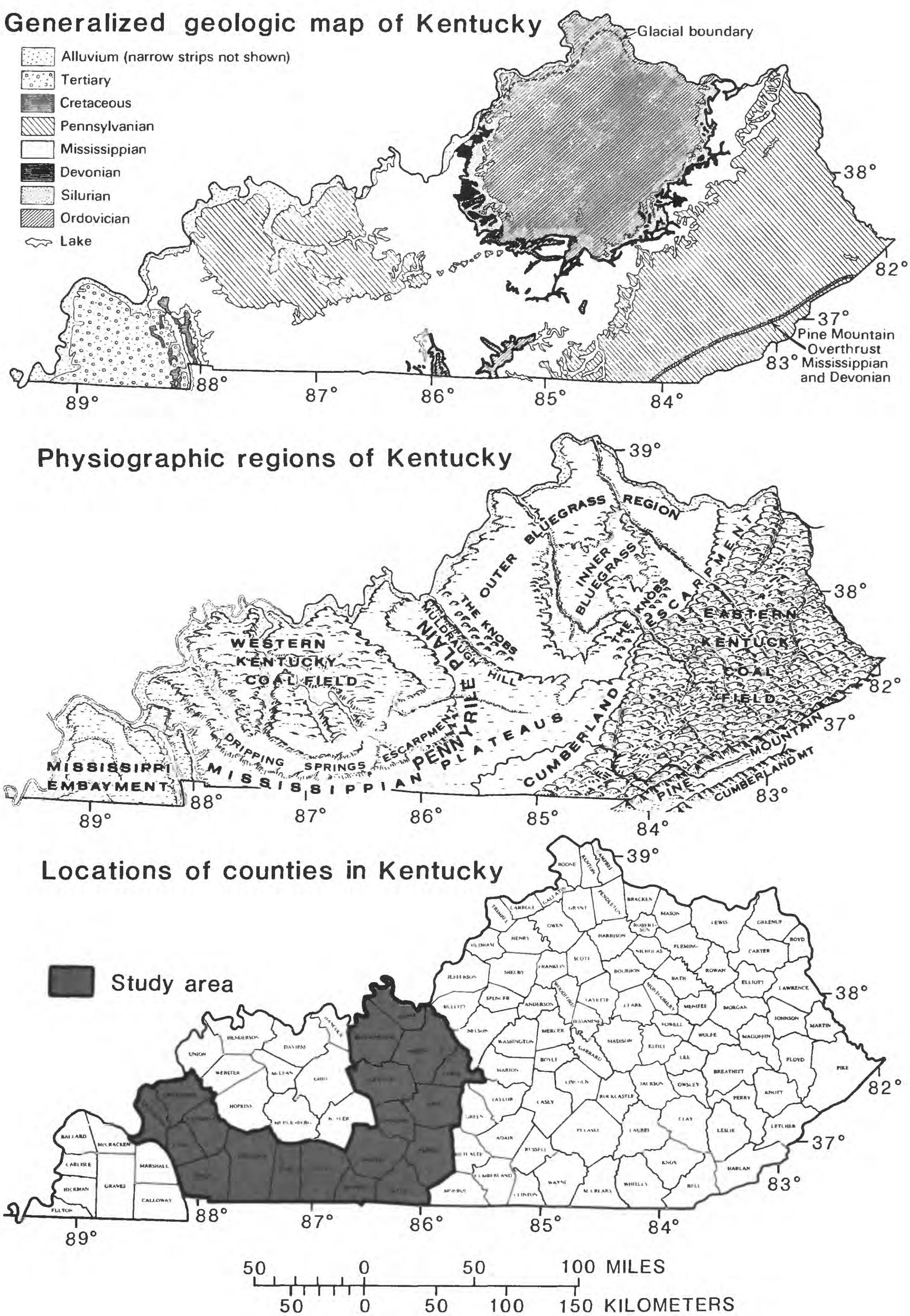

Figure 1.-- Generalized geology, physiographic regions, and counties in Kentucky.

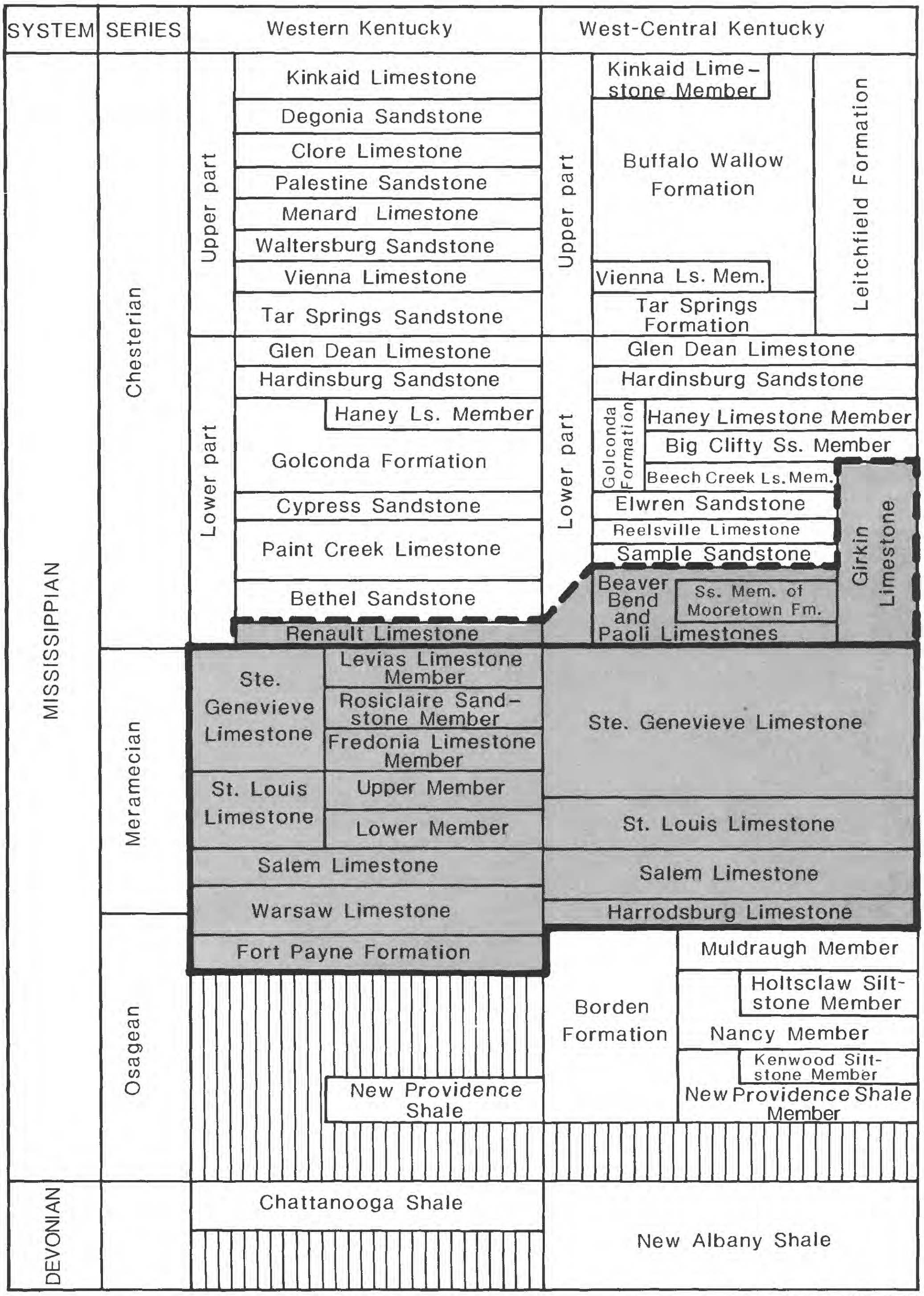

Figure 2.-- Stratigraphic column and formations of the principal aquifer in the Mississippian Plateaus region.

EXPLANATION

Principal aquifer

May be included in principal aquifer in outcrop areas of units if the potentiometric surface occurs in the units.

Although the entire limestone sequence is referred to as the "principal aquifer," the St. Louis Limestone is the most widely used formation for water-supply purposes, and the Ste. Genevieve Limestone is second. As the St. Louis thins to the point where the potentiometric surface lies below the formation, the Salem-Warsaw (Harrodsburg) sequence supplies most of the water and, as that sequence thins, the Fort Payne is used.

Because of the relative widespread importance of the combined Ste. Genevieve-St. Louis Limestones, the generalized geologic map (plate 1) differentiates their outcrop area from the underlying and overlying units. The units underlying the St. Louis [Salem-Warsaw (Harrodsburg)] are exposed in the highly-dissected updip fringe areas. The outcrop pattern of the individual units is too complex to be usably shown at the map scale used. For details of local geology in such areas, as well as of other areas of interest, the reader is referred to the pertinent 7 1/2-minute Geologic Quadrangle maps as shown on the index map (fig. 3).

As an aid to the reader, two geologic cross sections are shown in figure 4. Cross section A-A' is just south of Elizabethtown in Hardin County and cross section B-B' is just east of Hopkinsville in Christian County (plate 1). These cross sections illustrate the geologic and topographic relations of the various formations.

WATER IN THE PRINCIPAL AQUIFER

Occurrence

Water in the principal aquifer occurs in secondary openings such as joints, fractures, and openings along bedding planes. In many instances these openings have been enlarged by dissolution of the more calcareous parts of the limestone. The presence of karst topography is an indication of large-scale dissolution. Karst areas are dotted with sinkholes and caves, many of which open into extensive waterways in the limestones. Some of these channels open to the surface as springs.

Openings in limestones vary from paper-thin cracks to large pipe-like conduits. They tend to diminish in size and number with depth, and the largest openings probably occur within a few tens of feet of the land surface, depending on the position of the potentiometric surface, land-surface altitude, and geologic history of the region. Although many of the passages and conduits at shallow levels may be filled with water during and after prolonged periods of precipitation, they may be essentially water-free during dry weather except, perhaps, for small streams trickling across their floors. This means that consistently reliable quantities of water will be limited to the somewhat deeper openings.

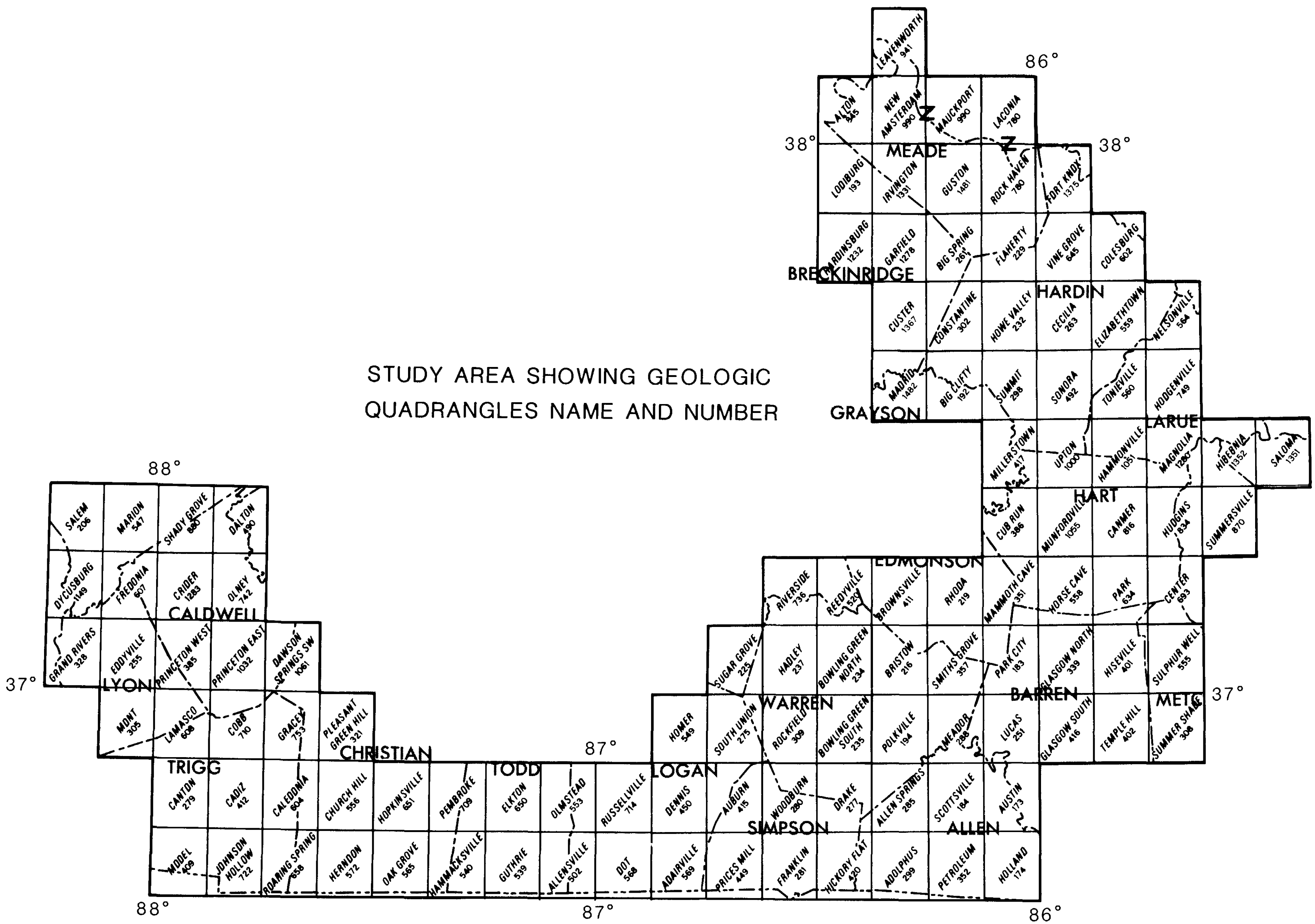

Figure 3.-- Geologic quadrangles in the Mississippian Plateaus region.

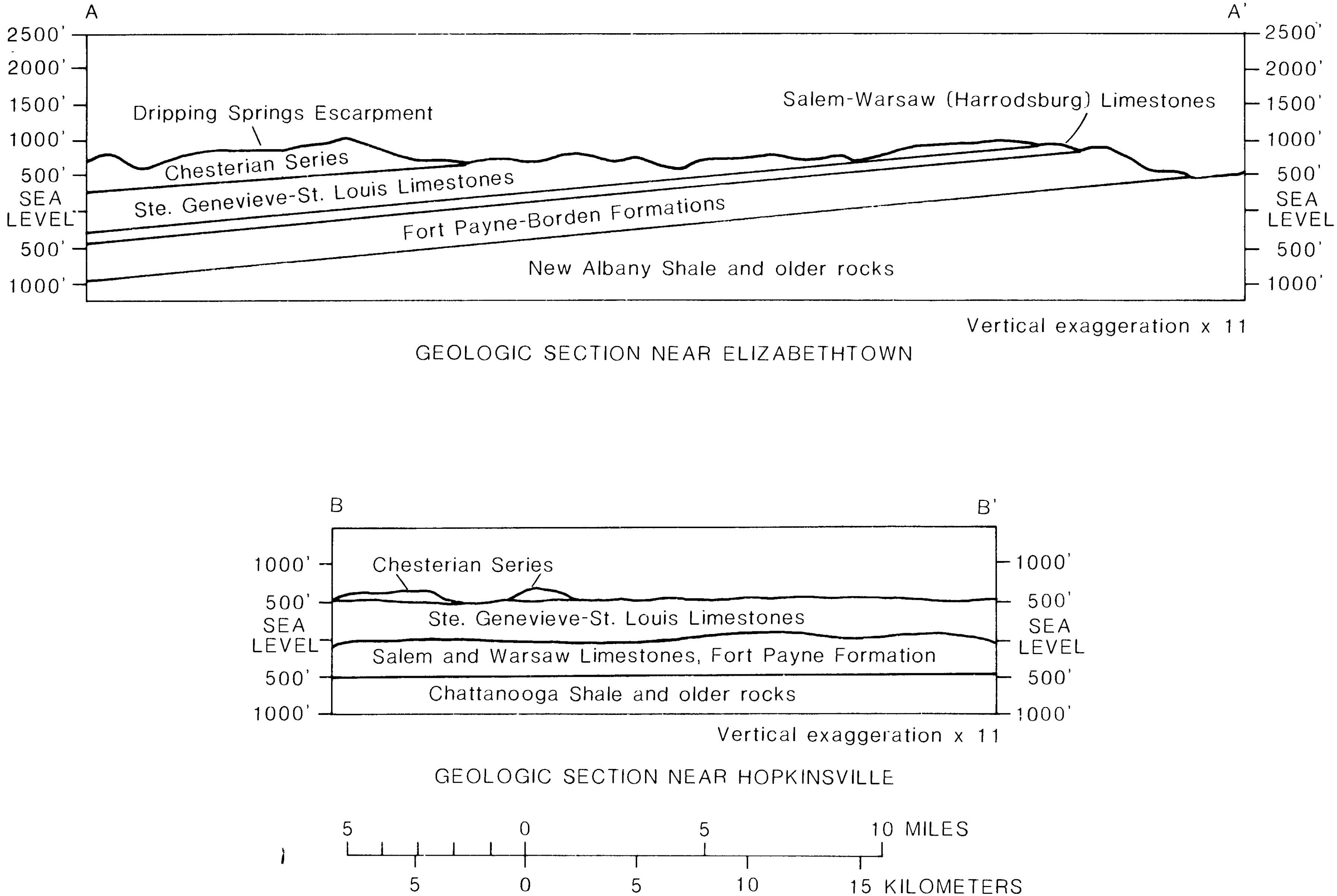

Figure 4.-- Generalized geologic sections in the Mississippian Plateaus region.
(See plate 1 for trace of sections)

Hydrogeology

Although it is standard procedure to describe geologic formations in order from oldest to youngest, in drilling for water it is more logical to describe them in the order in which the geologic formations would be penetrated during drilling-from youngest to oldest. In the following section, the various geologic formations comprising the principal aquifer, together with their water-yielding characteristics, are described from youngest to oldest, assuming that the full sequence of formations comprising the principal aquifer is present. The full sequence generally occurs at the Dripping Springs escarpment, where the lowermost Chesterian limestones directly underlie the residual mantle. Moving outward from the escarpment, progressively older units occur directly below the mantle and the aquifer, as a single entity, becomes progressively thinner.

Residual Mantle or Residuum

A residual mantle derived from limestone overlies much of the Pennyrile plain. It commonly consists of reddish clay containing bone-like fragments of chert. The mantle can attain thicknesses of as much as 60 feet, but it generally ranges from about 35 to 40 feet in thickness. The residuum yields small amounts of water to shallow wells, but supplies may be inadequate during prolonged dry periods. In the northeastern part of the plain, perhaps one-third of the wells are developed in the residuum and (or) upper few feet of the limestone bedrock.

Lower Chesterian Limestones

The lowermost Chesterian limestones, which include the Renault Limestone, the Beaver Bend and Paoli Limestones, and the Girkin Limestone, are exposed along the edge of the Dripping Springs escarpment. From Logan County westward the Renault overlies the Ste. Genevieve Limestone. From Logan County to Hart County, in the southeastern part of the plain, interbedded sandstones in the Chesterian Series disappear and the undifferentiated limestones merge to form the Girkin Limestone. From Hart County northward the limestones are differentiated into the Beaver Bend and Paoli Limestones.

The Renault Formation is mainly a thick-bedded limestone. It ranges in thickness from 70 to 125 feet in the subsurface, but is usually much thinner where exposed.

The Girkin Limestone is a crystalline, oolitic to sandy limestone. Its thickness ranges from 0 to 180 feet in the subsurface, but it may be rather thin where exposed.

The Paoli Limestone is a dark-gray to white compact to crystalline and oolitic fossiliferous limestone. It may be separated from the overlying Beaver Bend Limestone by 8 to 25 feet of gnarly sandstone. The Beaver Bend Limestone is a siliceous, ferruginous, coarsely crystalline limestone. The two limestones have a combined thickness ranging from 0 to 100 feet.

The lowermost Chesterian limestones probably are connected hydraulically, in some places, to the principal aquifer where they are exposed along the edge of the Dripping Springs escarpment. The limestones can yield sufficient water for domestic or stock use to very shallow wells. Well drillers, however, commonly drill through these limestones into the underlying Ste. Genevieve Limestone to avoid the shallow water which could be subject to local contamination.

Ste. Genevieve Limestone

The Ste. Genevieve Limestone crops out in that part of the Pennyrile plain adjacent to the Dripping Springs escarpment. In some areas it is not differentiated from the underlying St. Louis Limestone on geologic maps. The formation ranges in thickness from 190 to 320 feet in the west and 0 to 190 feet in west-central Kentucky. It consists of light-gray to almost white, partly oolitic, massive to thin-bedded or slightly cross-bedded limestone interbedded with medium-gray dolomitic limestone. Locally, it contains greenish-gray fine-grained sandstone and siltstone beds up to 10 feet thick in the upper part of the unit. The formation weathers to a deep red or maroon clay containing abundant residual chert which weathers to chalky bone-like fragments.

The Ste. Genevieve Limestone yields water from joints, fractures, and well-developed solution channels throughout the outcrop area. Yields normally are sufficient for domestic and stock use and some are adequate for small industrial and municipal supplies. Well yields of as much as 150 gal/min have been reported and higher yields may be possible. Some springs have been pumped at the rate of 600 gal/min with little lowering of water levels. The Ste. Genevieve is most important as an aquifer where both its maximum thickness is present and the potentiometric surface stands high in the formation.

St. Louis Limestone

The St. Louis Limestone underlies the Ste. Genevieve Limestone and crops out in a band adjacent to and paralleling the Ste. Genevieve Limestone outcrop. The two formations are not differentiated on some geologic maps because of their similarity. West of Christian County, the St. Louis Limestone is divided into upper and lower members. The upper member, which attains a thickness of about 250 feet in the subsurface, consists of medium- to light-gray limestone and minor amounts of light-gray lithographic limestone and light-yellowish-gray dolomitic limestone. The lithology is extremely variable with beds grading laterally into other types in short distances. Medium- to light-gray vitreous chert is common throughout the unit. In some discontinuous zones as much as 30 feet thick irregular layers and nodules of chert comprise 10 to 30 percent of the rock. The lowest part of the member may contain gypsum in thin seams and vug fillings.

The lower member attains a thickness of about 280 feet in the subsurface. The upper part of this member consists of light-gray and light-medium-gray limestone containing chert nodules. The lower part consists of medium-gray and medium-dark-gray limestone and commonly contains gypsum seams.

The St. Louis thins to the east and thicknesses decrease to about 175 to 310 feet in west-central Kentucky and to about 70 to 160 feet in south-central Kentucky. The formation is not differentiated into members east of Christian County.

The St. Louis Limestone is the unit most consistently used as a source of water throughout the Pennyrile plain. Water is obtained from secondary openings such as joints and fractures in non-karst areas and also from solution channels, cavities, springs, and other openings in karst areas. Larger yields are obtained in the karst areas. Well yields may range from several gallons per minute to as much as 500 gal/min, but extremely large yields are the exception rather than the rule. At randomly selected sites, the chances of obtaining large amounts are exceedingly poor - probably only about 1 out of 20, or 5 percent.

The lower St. Louis Limestone may contain gypsum which adversely affects water quality. The unit may yield a highly mineralized calcium magnesium sulfate water that has a strong hydrogen sulfide (H_2S) odor. It can be esthetically unpleasant as well as highly laxative in effect and corrosive to brass plumbing fixtures. Drillers in some areas equate a change from light to dark limestone as being indicative of the gypsum-bearing zone.

Salem Limestone

The Salem Limestone is exposed in the lower slopes of valley walls adjacent to the St. Louis Limestone outcrop at the fringes of the Pennyrile plain. In places it is not differentiated from the overlying St. Louis Limestone, particularly west of Christian County. East of Christian County it may not be differentiated from the underlying Warsaw (Harrodsburg) Limestone. The Salem Limestone attains a thickness of 110 to 160 feet in the west and 80 to 140 feet in the west-central part of the State. It is a medium- to dark-gray, medium- to coarse-grained, clastic and oolitic limestone interbedded with fine-grained argillaceous limestone. Chert occurs as nodules and fossil-fragmental blocks.

Warsaw (Harrodsburg) Limestones

The Warsaw Limestone is exposed in valley walls along the fringes of the Mississippian limestone outcrop in Trigg, Lyon, and Livingston Counties and along the updip edge of the southeastern and eastern Pennyrile plain where it is known as the Harrodsburg Limestone. The formation ranges in thickness from 150 to 300 feet in the west and thins to 20 to 70 feet in the west-central part of the State. The limestone is variable but is typically massive and cross-bedded, and in places is crinoidal and cherty.

In most areas the Salem, Warsaw, and Harrodsburg Limestones are too deeply buried to be economically used as a source of water and potential yields are unknown. The Salem and Warsaw Limestones can yield sufficient water for domestic and stock uses in their outcrop areas in the western Pennyrile plain, mainly from joints and fractures. Near Lake Barkley yields may be sufficient for small commercial enterprises. In places the limestones are exposed only in fault blocks, which may limit the water availability. Small yields are also obtainable from the Salem-Harrodsburg sequence where it crops out in the eastern part of the Pennyrile plain.

Fort Payne Formation

The Fort Payne Formation is exposed along the southwestern and southeastern fringes of the Mississippian limestone outcrop. The formation ranges in thickness from 430 to 660 feet in the west to 150 to 300 feet in the south-central part of the State. It consists of fine-grained cherty limestone interbedded with drab calcareous shale. Limestone is more prevalent in the upper part of the formation. In the northeastern part of the Pennyrile plain the Fort Payne is replaced by the Borden Formation which overlies the New Albany Shale.

Where it is at or near the surface the Fort Payne Formation is part of the principal aquifer. Where it is deeply buried, yields are unknown as it generally is not economically feasible to drill deep water wells. In its outcrop area the Fort Payne usually can yield sufficient water for domestic and stock uses. Yields of 70 gal/min are possible near Kentucky Lake, although the water from some wells has a milky appearance. These yields are probably from a rubble zone at the top of the formation. Yields of as much as 40 gal/min have been reported near Scottsville in Allen County. In this area, relatively insoluble layers in the formation tend to perch water and cause small springs and seeps to form on the hillsides well above the main zone of saturation. The formation is also exposed in a fault block about 1.2 miles wide by 3.5 miles long about a mile southeast of Eddyville in Lyon County. At this location the unit is very tight and yields little or no water to wells.

Recharge

Recharge to the principal aquifer is mainly from precipitation, usually in the form of rain, but sometimes as snow. The amount varies yearly, monthly, and daily. The mean annual precipitation over the Plateaus region varies from about 42 to more than 52 inches (fig. 5). The greater part is produced by tropical air masses associated with low-pressure systems which move over the area from the western Gulf of Mexico. Usually, January and March are the wettest months and September and October are the driest, but these extremes may vary from year to year.

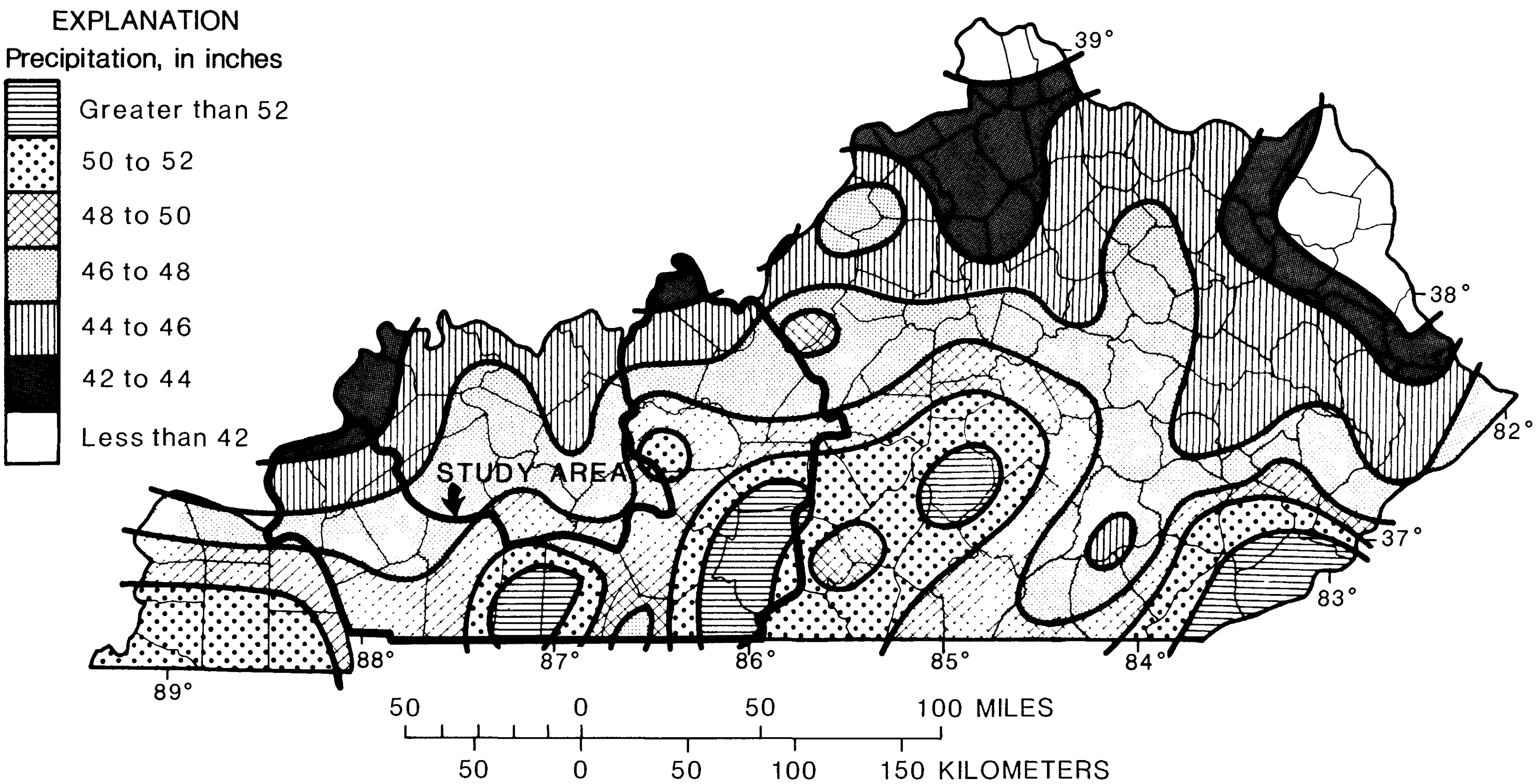

Figure 5.-- Mean annual precipitation, in inches, in Kentucky. (From Kentucky Climate Center, Western Kentucky University, climatological data based on period 1948-77)

The fastest recharge to the ground-water reservoir is overland flow into sinkholes, swallow holes, and fractures in the limestone. Karst is uniquely suited for this type of recharge because sinkholes are closed basins which trap the runoff. Recharge from overland flow is especially effective where the residual mantle is thin or missing.

Sinking streams also contribute to ground-water recharge. Streamflow enters the aquifer directly through fractures or other openings beneath the streambed. In some instances the entire flow of the stream is diverted underground in a very short distance.

Intermittent recharge can occur during periods of high stream stage. Usually, the base flows of perennial streams traversing the Pennyrile plain are maintained by ground-water flow from the aquifer to the streams. During high stream stages, however, gradients may be reversed causing water to move from the streams to the aquifer.

A slower form of recharge occurs by the downward percolation of water through the surficial deposits or the clayey and cherty mantle. If the underlying limestone lacks fractures or is shaly, water may be perched on top of the bedrock. Enlarged joints near the bedrock surface that are filled with residual material, act as funnels and reservoirs for water movement and storage.

Potentiometric Surface, Movement, and Depth to Water

The major controls on the position of the potentiometric surface in the Pennyrile plain are the regional structure, the composition of the underlying rocks, and the subsurface and surface drainage patterns. The drainage patterns and rock composition are the more significant controls and tend to mask the influence of the regional structure.

The potentiometric map has several practical uses. In the event of a toxic chemical spill the map may be used to determine the general direction of ground-water movement and areas that might be affected. This information may not be obvious from a cursory on-site inspection. The map also may be useful in determining the contaminant source area or source direction of a contaminated water supply. It can be helpful in the locating of landfills and other waste disposal sites to minimize adverse environmental effects. It will be of use in any instance where there is a potential hazard to the aquifer and to the people who use it.

The potentiometric map, together with a topographic map, or known land-surface altitude, will give an approximate minimum depth to which one would have to drill at any given site to obtain water. For example, if the land surface at a given point is 600 feet above sea level and the contour map shows the potentiometric surface at that point is 500 feet above sea level, one could expect to drill a minimum of 100 feet to obtain water. One may have to drill farther to penetrate a water-bearing opening, but the water should rise in the well to an altitude of about 500 feet if and when an opening is penetrated. The possibility of drilling a dry hole always exists, however, if no openings are penetrated. The map should be used with caution to estimate drilling depths where because of there is considerable potential for interpretive error in rugged topographic areas. This method of estimating drilling depths is more accurate where the contours are widely spaced and the potentiometric surface has a low gradient.

The potentiometric map (plate 1) shows, by means of contours, the average summer configuration of the potentiometric surface in the principal aquifer, based on water-level measurements in individual wells. The contours in the Mammoth Cave area are adapted from Quinlan and Ray (1981). The direction of ground-water flow in the principal aquifer at a specific site may be somewhat circuitous as the water must follow available openings whose orientation is dependent on joint and fracture patterns, dip of the rocks, structure, and solubility of the rocks. The net direction of flow, however, is perpendicular to the contours and from higher to lower contours. The potentiometric surface tends to conform generally, in a subdued form, to the topography which means that ground-water movement generally coincides with the surface drainage.

The potentiometric map shows that ground-water movement in western part of the study area including the western third of Simpson County is in a south to southwesterly direction toward the Cumberland River and Lake Barkley, conforming somewhat to the surface drainage pattern. From Simpson County to northern Hardin County, ground water moves northward and then westward conforming generally to the surface drainage patterns of the Barren River and upper Green River drainage areas. In extreme northern Hardin County, the northern half of Breckinridge County, and Meade County, ground water moves toward the Ohio River.

Discharge

Ground-water discharge occurs by evapotranspiration, springflow, seepage to streams, and pumping from wells. Considerable water can be lost to evapotranspiration from the residual mantle before the water percolating through the mantle reaches the limestone aquifer, especially during the growing season. Water also can be lost from the bedrock by evapotranspiration in low-lying swampy areas and in valley flats when the potentiometric surface is at or near the surface.

Springflow also can account for a large part of ground-water discharge. A single large spring can discharge more than 10,000 times the yield of an average domestic well in a given period of time, especially when springflow is at its maximum.

Springs in cavernous limestone respond rapidly to precipitation. Flows increase rapidly during heavy rains, and reach their peaks shortly thereafter. Discharge then declines rapidly until normal flows are reestablished. This suggests that a significant part of the local recharge in karst areas is discharged through springs within a relatively short period of time after the recharge water enters the aquifer.

The majority of water wells in the limestone aquifer are small-yield domestic and stock wells which are pumped intermittently. The total amount of water pumped from wells is very small in comparison to the amounts discharged by natural processes.

Long-term hydrographs of water levels in observation wells in the limestone aquifer, such as that shown for the Western State Hospital well near Hopkinsville in Christian County (fig. 6), indicate that there have been no significant long-range changes in ground-water levels in the region. Basically, recharge and discharge seem to be in equilibrium. Events, such as droughts, can temporarily decrease the amount of water in storage and lower water levels, but with the return of normal precipitation, storage increases and water levels rise to their normal range. It seems that under present climatic conditions and stage of geomorphic development the amount of water stored in the aquifer is at or near the optimum capacity.

Water Quality

The acceptability of any water has a direct relation to the use for which the water is intended. Nearly all water is acceptable for some purpose. Five major categories of use are:

1. Public water.
2. Fish, wildlife, and other aquatic life.
3. Recreation.
4. Agriculture.
5. Commerce and industry.

Certain measurable characteristics are used to evaluate water quality. These characteristics can be classified into three major groups: chemical, physical, and biological. Chemical characteristics include such constituents as dissolved solids, iron content, and hardness. Physical characteristics include such things as color, taste, odor, turbidity, and temperature. Biological characteristics include both bacteria and virus content.

Methods

Water samples for chemical analysis were collected from wells and springs mostly in the Ste. Genevieve, St. Louis, and Salem and Warsaw Limestones. In addition, analyses obtained during previous investigations dating back to 1950 were used, for statistical purposes.

Analyses for 171 wells were selected from the U.S. Geological Survey's computerized water quality data base for statistical analysis. Chemical analyses and locations are shown in Faust and others (1980) for samples collected through 1979 and in U.S. Geological Survey (1980, 1981, 1982, and 1983) for samples collected after 1979. Analyses with 10 percent or more error in the cation-anion balance were not used. Analyses were also not

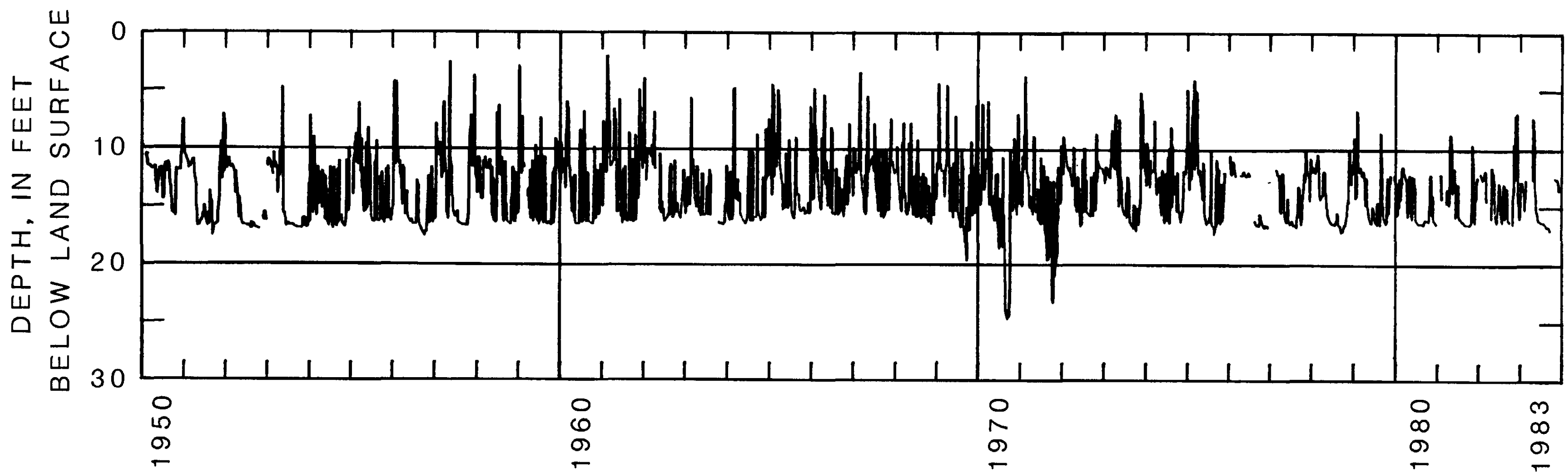

Figure 6.-- Hydrograph of Western State Hospital well near Hopkinsville, Christian County.

used if the specific conductance of the water was greater than 1,500 umhos/cm or about 1,000 milligrams per liter (mg/L) dissolved solids concentration. The analyses with high conductance values could indicate contamination of shallow water by brines from deeper aquifers, but more likely they are analyses of brines that are not representative of water in the shallow aquifers.

Piper (1944) trilinear diagrams were prepared to show the distribution of the chemical constituents in the water. Frequency analysis, analysis of variance, and t-test statistics were used in an effort to characterize the distribution of selected chemical constituents and to delineate aquifers on the basis of water chemistry.

Water Chemistry In The Principal Aquifer

A statistical summary of the water chemistry and physical characteristics data is presented in table 1. The chemistry of water in the four formations comprising the principal aquifer is similar. All four units have near neutral pH (7.2 to 7.5 units), are well buffered as indicated by pH and high bicarbonate (HCO_3) values, and have similar mean concentrations of calcium in samples from both springs and wells. Concentrations of magnesium, sodium, and chloride are higher in samples from wells than in samples from springs. The lower concentration of these dissolved constituents in springs indicates less residence time in the rock or dilution by recharge from precipitation. The mean concentrations of sulfate, sodium, and chloride are higher in ground water from the stratigraphically lower Salem and Warsaw Limestones and Fort Payne Formation indicating the possibility of longer residence time than in the overlying units.

Chemical analyses of water from the Ste. Genevieve, St. Louis, and Salem and Warsaw Limestones, and the Fort Payne Formation are plotted on Piper diagrams (figs. 7-10). In general, water from these units is classified as a calcium-magnesium-bicarbonate or sulfate type water (Field A, figs. 7-9). A few samples from the Ste. Genevieve and Salem and Warsaw Limestones plot outside of this field and may reflect some migration of brines from abandoned oil and gas wells or contamination from other sources (Field B, figs. 7-9). Several wells were reported to be contaminated with oil, apparently from natural sources. The lower St. Louis Limestone may contain gypsum as nodules or vug fillings, the dissolution of which can lead to high calcium and sulfate concentrations (Field B, fig. 8). The data for the Fort Payne Formation are too sparse to classify the water in a particular category (fig. 10).

In general, the chemical quality of the water samples from the principal aquifer is good for domestic purposes. The hardness ranges from moderately hard to very hard according to the following classification by Durfor and Becker (1964, p. 27).

Table 1.--Statistical data for selected constituents and properties of water from wells and springs

[Results in milligrams per liter except for temperature in degrees Celcius, pH in units, and specific conductance in micromhos per centimeter at 25°C]

Rock unit number and type of sample	Variable	Mean or value (median for pH)	Standard deviation	Minimum value	Maximum value
Ste. Genevieve	Temperature	14.9	1.2	10.6	17
Limestone	pH	7.5		6.7	9.0
54 wells	Specific conductance	580	252	138	1,400
	Calcium	69	39	1.4	240
	Magnesium	20	14	1.3	55
	Sodium	31	57	.2	280
	Potassium	2.4	6.0	0	43
	Chloride	18	34	.8	230
	Sulfate	77	108	0	530
	Bicarbonate	257	79	61	462
	Silica	5.1	5.4	0	15
Ste. Genevieve	Temperature	14.1	.5	13.5	14.5
Limestone	pH	7.3		7.1	7.8
3 springs	Specific conductance	497	15	480	510
	Calcium	70	34	31	93
	Magnesium	14	11	7.3	27
	Sodium	11	12	3.1	25
	Potassium	2.8	1.9	1.3	5.0
	Chloride	7.6	1.4	6.2	9.0
	Sulfate	16	12	8.0	30
	Bicarbonate	276	14	268	293
	Silica	10	.7	9.5	11
St. Louis	Temperature	14.9	1.0	12.5	18.9
Limestone	pH	7.5		6.2	8.3
99 wells	Specific	579	207	147	1,335
	conductance	579	207	147	1335
	Calcium	72	29	16	212
	Magnesium	18	12	1.0	62
	Sodium	7.2	11	.8	96
	Potassium	1.3	3.0	0	29
	Chloride	11	28	.3	270
	Sulfate	50	90	0	527
	Bicarbonate	253	65	58.0	398
	Silica	3.2	51	0	17
St. Louis	Temperature	14.1	.7	13.0	15.0
Limestone	pH	7.3		6.9	7.6
6 springs	Specific conductance	442	28	410	485
	Calcium	76	8.3	66.0	87
	Magnesium	7	1.4	5.8	9.9
	Sodium	3.1	.9	2.4	5.1
	Potassium	1.3	.2	1.1	1.7
	Chloride	5	.8	4.1	6.2
	Sulfate	10	2.6	7.0	14
	Bicarbonate	246	17	220	268
	Silica	11	.5	9.9	11

Table 1.--Statistical data for selected constituents and properties of water from wells and springs--Continued

Rock unit number and type of sample	Variable	Mean or value (median for pH)	Standard deviation	Minimum value	Maximum value
Salem and Warsaw Limestones 12 wells	Temperature	15.4	1.8	13.5	18.9
	pH	7.25	-	5.7	7.9
	Specific conductance	666	348	45	1,270
	Calcium	93	48	3.5	174
	Magnesium	18	15	.6	49
	Sodium	23	29	1.8	83
	Potassium	2.8	3.4	0	10
	Chloride	25	44	3.5	158
	Sulfate	104	91	.8	220
	Bicarbonate	277	117	14	436
	Silica	7.5	5.7	0	13
Salem and Warsaw Limestones 1 spring	Temperature	14.0	-	-	-
	pH	7.5	-	-	-
	Specific conductance	525	-	-	-
	Calcium	100	-	-	-
	Magnesium	5.9	-	-	-
	Sodium	2.1	-	-	-
	Potassium	.5	-	-	-
	Chloride	3.5	-	-	-
	Sulfate	18	-	-	-
	Bicarbonate	260	-	-	-
	Silica	12	-	-	-
Fort Payne Formation 6 wells	Temperature	16.0	1.8	14.0	19.0
	pH	7.75	-	-	-
	Specific conductance	418	332	74	1,034
	Calcium	51	33	4.2	99
	Magnesium	11	7.1	2.7	21
	Sodium	20	32	3.5	86
	Potassium	1.1	1.8	0	4.8
	Chloride	24	39	5.5	104
	Sulfate	41	60	2.6	156
	Bicarbonate	168	99	6.0	274
	Silica	8.3	4.6	0	13
Fort Payne Formation 1 spring	Temperature	14.0	-	-	-
	pH	7.4	-	-	-
	Specific conductance	410	-	-	-
	Calcium	72	-	-	-
	Magnesium	7.1	-	-	-
	Sodium	1.5	-	-	-
	Potassium	-	-	-	-
	Chloride	2.5	-	-	-
	Sulfate	12	-	-	-
	Bicarbonate	210	-	-	-
	Silica	8.9	-	-	-

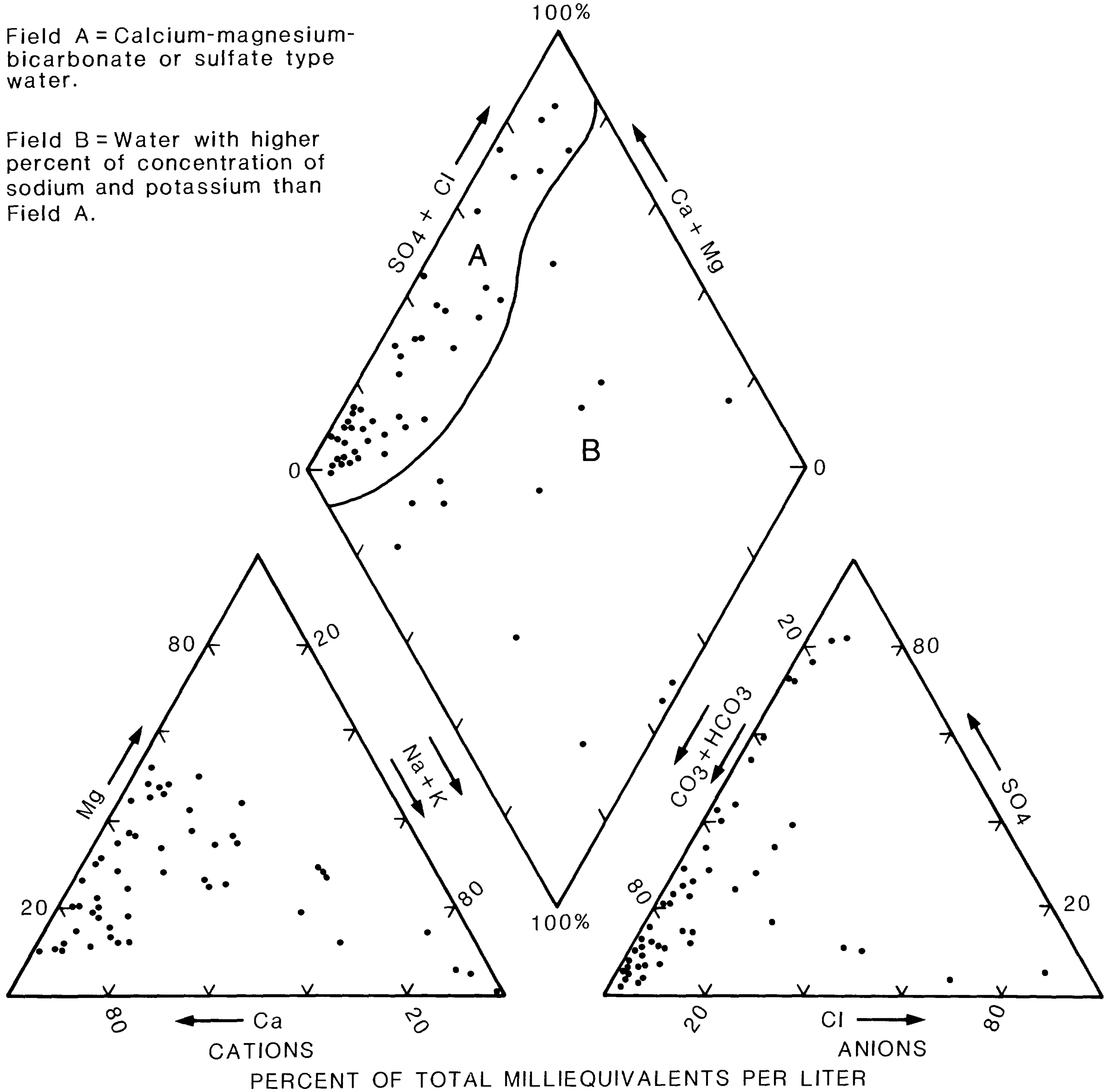

Figure 7.-- Trilinear diagram for water from the Ste. Genevieve Limestone.

Field A = Calcium-magnesium-bicarbonate or sulfate type water.

Field B = Water with higher percent of concentration of sodium and potassium than Field A.

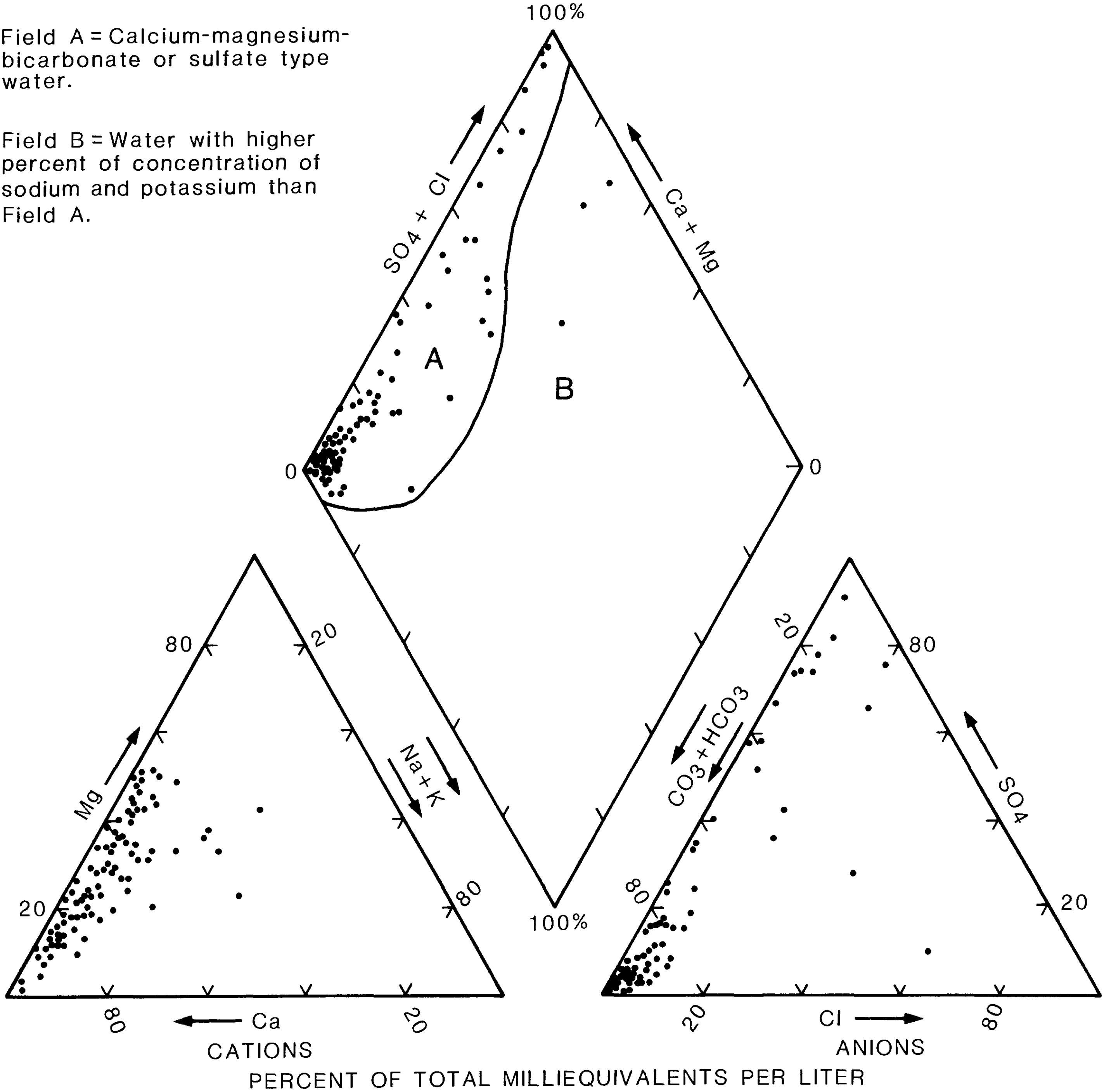

Figure 8.-- Trilinear diagram for water from the St. Louis Limestone.

Field A = Calcium-magnesium-bicarbonate or sulfate type water.

Field B = Water with higher percent of concentration of sodium and potassium than Field A.

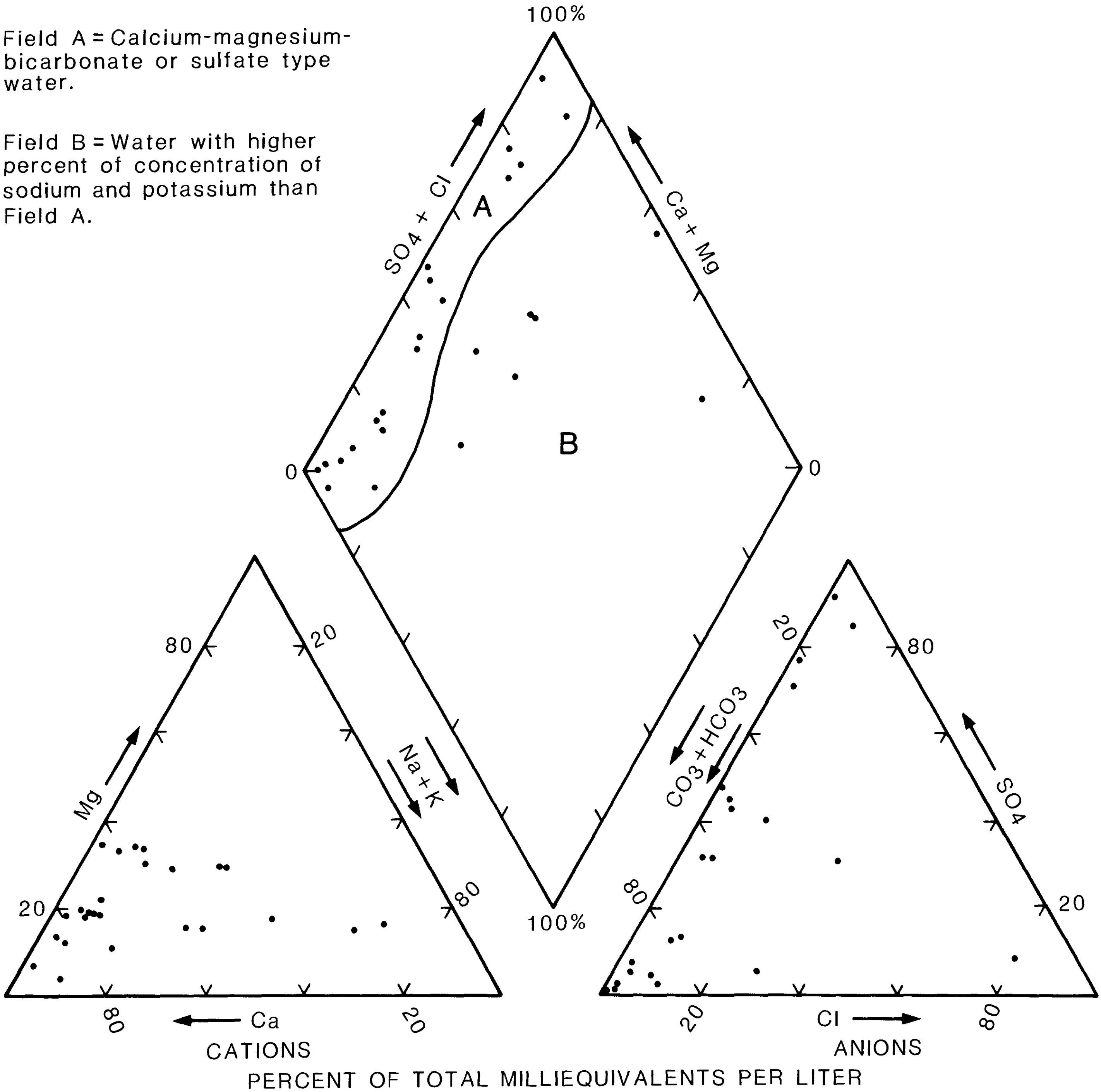

Figure 9.-- Trilinear diagram for water from the Salem and Warsaw Limestones.

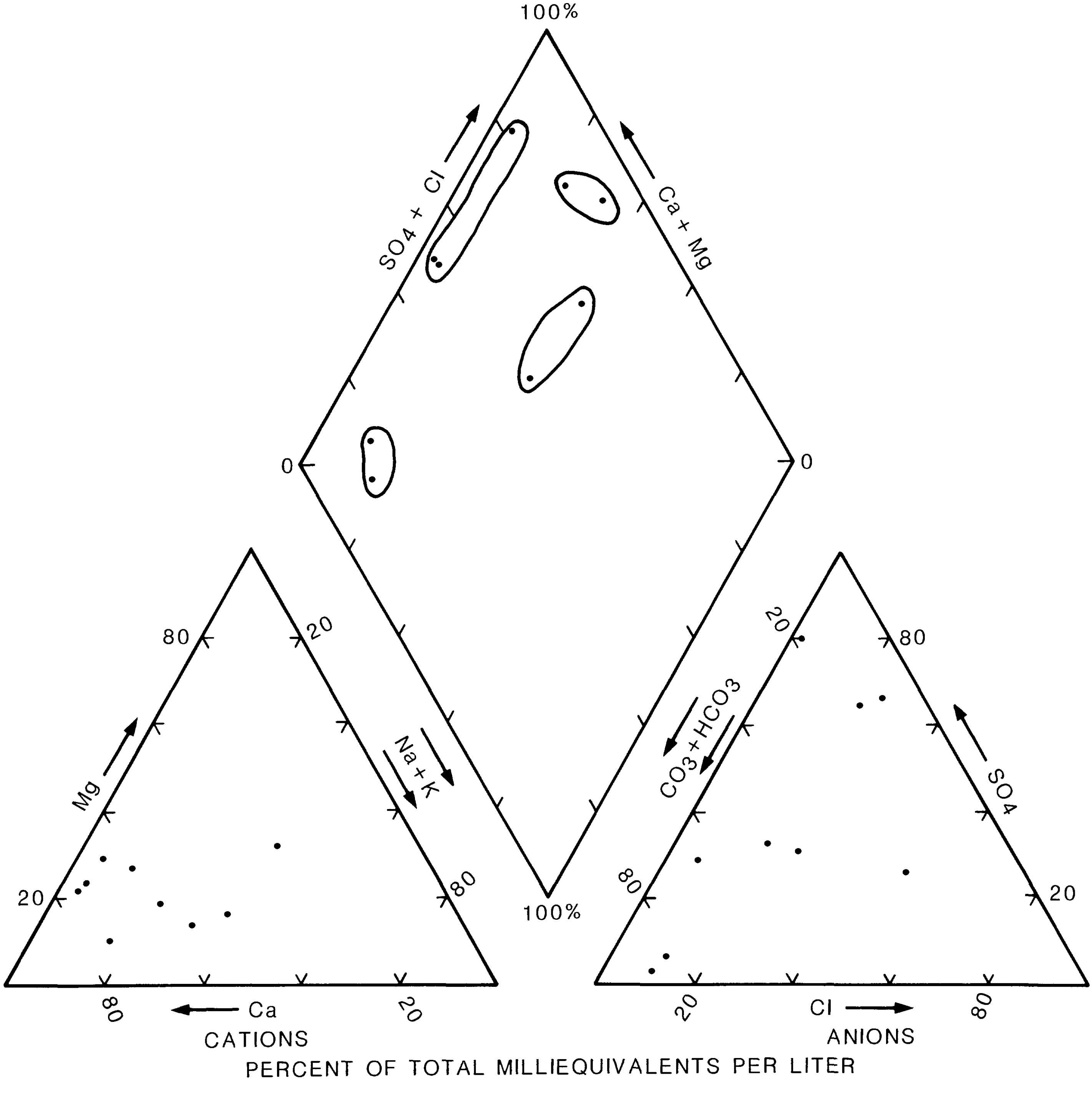

Figure 10.-- Trilinear diagram for water from the Fort Payne Formation.

HARDNESS RANGE	DESCRIPTION
(mg/L $CaCO_3$)	
0-60	Soft
61-120	Moderately Hard
121-180	Hard
More than 180	Very Hard

Except for hardness and iron most of the analyses of water from the principal aquifer fall within acceptable limits for drinking water and industrial use as defined by the U.S. Environmental Protection Agency (1977) (table 2). Iron and hardness may exceed recommended limits but these are readily corrected with proper treatment. Water having high concentrations of chlorides, sulfates, hydrogen sulfide, and dissolved solids, such as occurs in the lower St. Louis or Salem and Warsaw Limestones, may be corrosive, esthetically unpleasant (odor, taste, and stain), and difficult to treat.

Table 2.--Water-quality standards for selected properties of water and inorganic constituents dissolved in water
[Concentrations in milligrams per liter except for ph in units. Source, U.S. Environmental Protection Agency, 1977]

Constituent	Concentration	Constituent or Property	Concentration
Barium	1.0	Bicarbonate	2/250
Beryllium 1/	--	Calcium	2/100
Cadmium	.01	Chloride	250
Chromium	.05	Copper	1.0
Cobalt	.10	Iron	.3
Lead	.05	Magnesium	2/50
Molybdenum 1/	--	Manganese	.05
Nickel 1/	--	pH	6.5 - 8.5
Strontium	--	Potassium 1/	-
Vanadium 1/	--	Sodium 1/	-
Lithium 1/	--	Sulfate	250
		Zinc	5.0

1/ No limits established.
2/ Maximum acceptable level for general industrial use.

Trace Elements

Because relatively small concentrations of trace or minor elements in water can be harmful to living organisms, it is desirable to know if man's activities are contributing significant amounts of these constituents to natural waters. Trace elements occur naturally in ground water, but abnormal concentrations may be an indicator of pollution.

Samples for trace element analyses were collected at 240 selected wells and springs and results of the analyses are listed in table 3. Most trace elements are below the maximum recommended limits that have been established for selected constituents (table 2). Strontium, although without an established limit, exceeded 1 mg/L in some samples. The high concentrations of strontium are believed to be from natural causes because man-made sources of the element were not obvious in the study area.

High concentrations of trace elements have occurred near Horse Cave, Kentucky. Effluent from a wastewater treatment plant at Horse Cave is discharged in dry wells which intercept the local cave system. The effluent contains high concentrations of metals such as chromium, nickel, copper, and zinc (Quinlan and Rowe, 1977). Concentrations of these metals exceed current standards in Hidden River Cave beneath the city of Horse Cave. Concentrations are below current standards where the effluent-bearing water is discharged by springs near Green River about 5 miles north of Horse Cave (discharge reach determined by dye tracing). However, concentrations of the metals in the discharge springs are as much as 30 times higher than those in springs upstream and downstream of the discharge reach.

Statistical Analysis of Data

Several statistical tests were performed to determine if water quality could be used to distinguish the limestones and to determine if any of the limestones are more favorable as a source of ground water. Frequency plots indicated that the variables approached a normal distribution, in large samples sizes. For small sample sizes where a particular variable was not normally distributed, it was assumed for the purposes of the statistical tests that the variable would be normally distributed, if a larger sample size were available. All statistics were performed using the SAS statistical computer package (Ray, 1982).

Because raw data indicate a wide range of sulfate and specific conductivity values among the geologic units, a frequency analysis was used to determine if a visually unique distribution characterizes each unit. The frequency distribution of conductivity (fig. 11) is similar for the Ste. Genevieve and St. Louis Limestones, and for the Salem and Warsaw Limestones and Fort Payne Formation. Although the patterns are different between the two sets of units, the range of values is too similar to distinguish the limestones. The frequency distribution for sulfate (fig. 12) is similar for all the units.

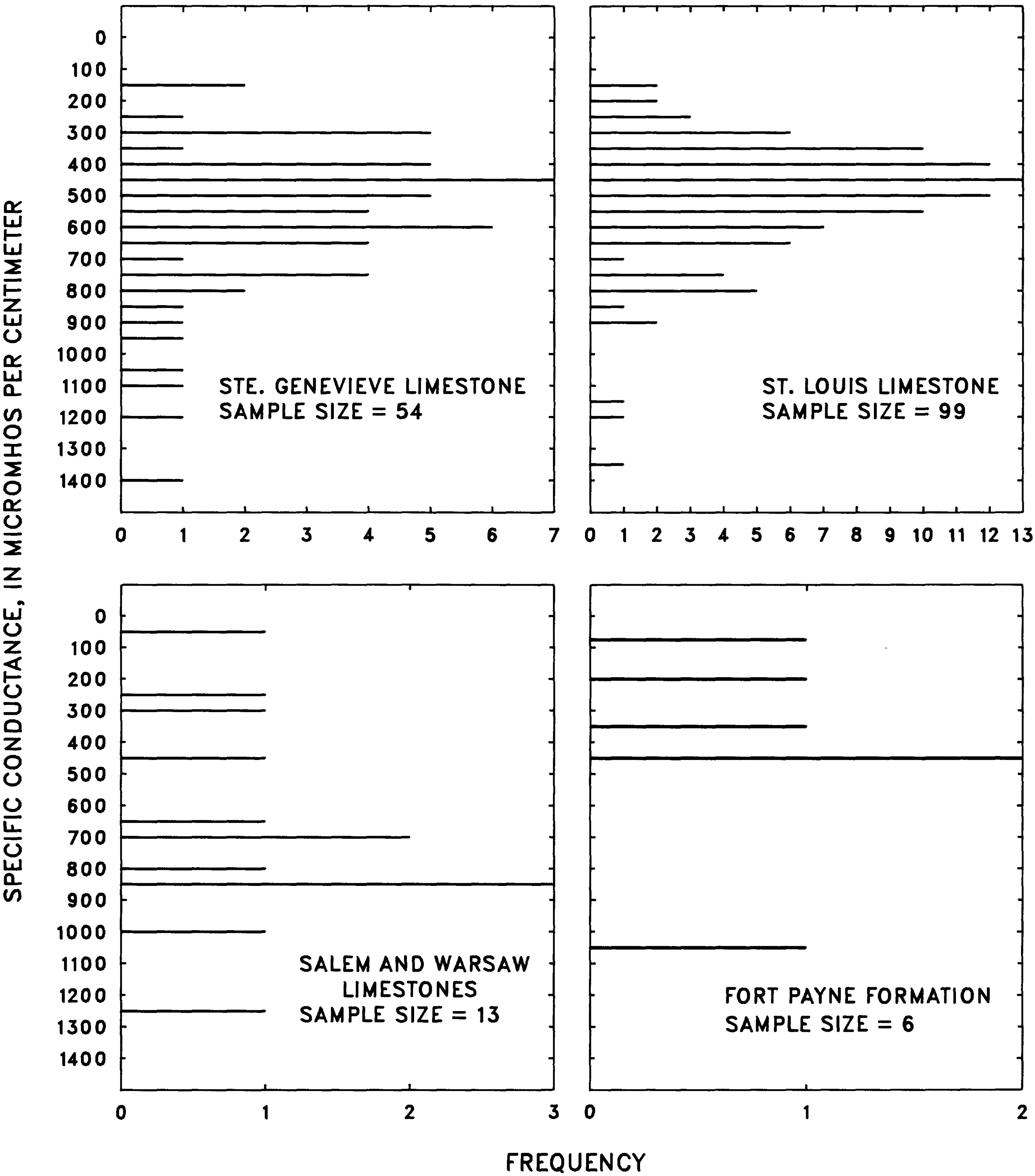

Figure 11.--Frequency analysis of conductivity values. Bars plotted at midpoint of variable range of values.

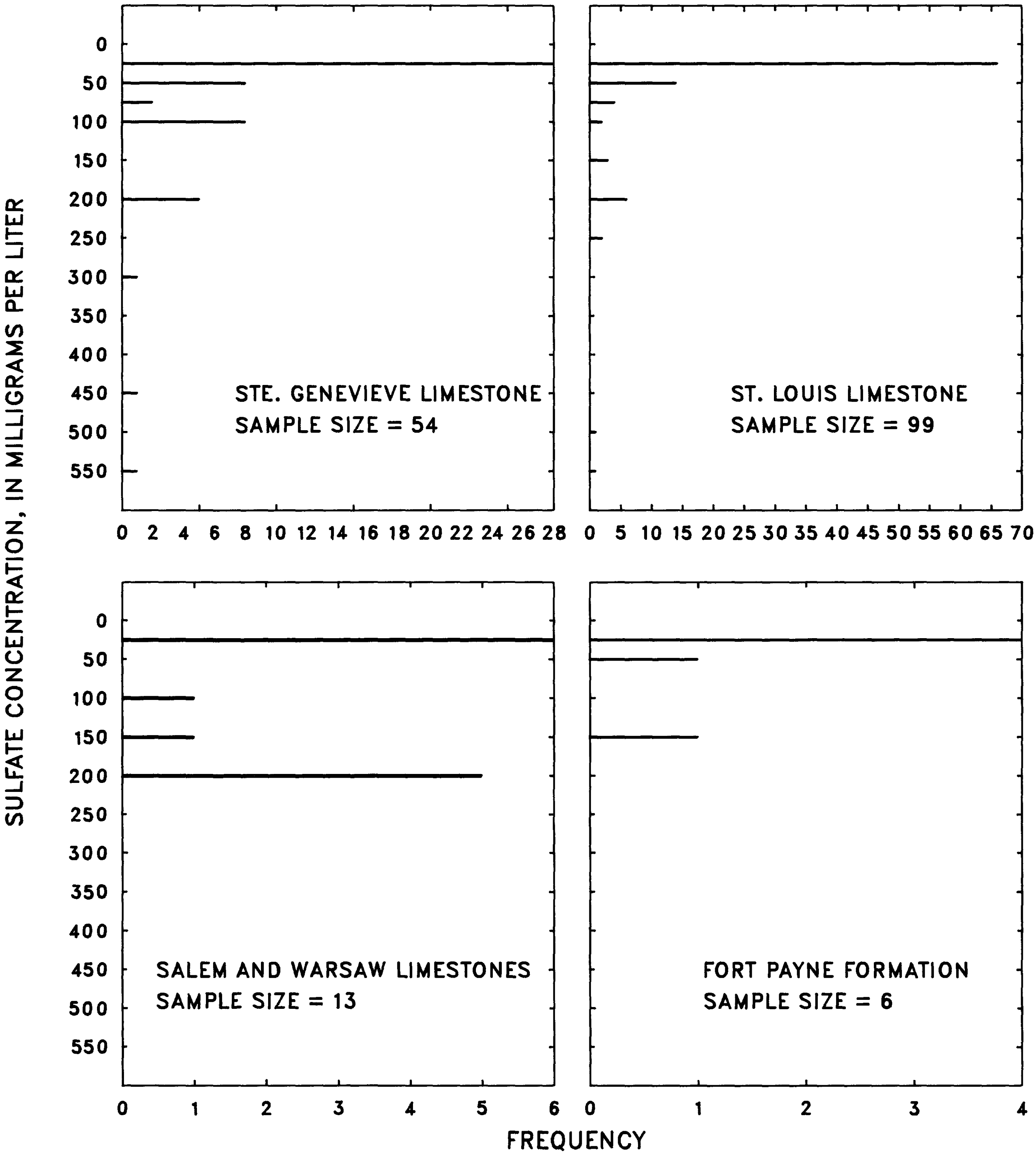

Figure 12.--Frequency analysis of sulfate values. Bars plotted at midpoint of variable range of values.

An analysis of variance statistical test was used to evaluate the variation in water chemistry among the four rock units. The test is based on the comparison of the mean value of a variable within one rock unit with the mean of the same variable among all four rock units. The results are presented in table 4 and discussions of the test are in Croxton and Cowden (1939) and Hoel (1976).

The variation of a variable within rock units is the deviation of each variable measurement from the mean of that variable. These deviations are squared and summed (sum of squares). The variation of a variable between rock units is the deviation of each rock unit mean of a variable from the grand mean (the mean of all the data). These deviations are squared, multiplied by the number of items in the group, and summed (sum of squares).

Degrees of freedom are defined as the sample size of a given variable (sulfate, calcium, and so forth) minus the number of constants to which the variable magnitudes are compared. In analysis of variance the constant used is the mean. For the "between rock units" sample, the rock unit mean of a variable in each of the four rock units is compared to a grand mean (the mean of all the data) for that variable. Therefore, the degrees of freedom are 4 minus 1 equals 3. For the "within rock units" sample, the value of a variable is compared to the mean of that variable in each of four rock units, thus there are four mean comparisons for a given variable (a mean for each of four rock units). Therefore, the degrees of freedom equals the total sample size minus the four means or 171 minus 4 equals 167.

The mean square is an estimate of the true variance of the sample about the mean. It is calculated by dividing the sum of squares by the corresponding degrees of freedom.

The F test is used to determine the acceptability of the null (H_0) hypothesis that there is no variation in water chemistry between the four rock units. The F ratio is calculated by dividing the mean square of the "between rock units" value by the mean square of the "within rock units" value. The F ratio is compared to a table of critical F values (Snedecor and Cochran, 1980, p. 480), based on varying degrees of freedom. If the calculated F ratio is less than or equal to the critical F value the null hypothesis is accepted. Otherwise it is rejected. Sodium, bicarbonate, and pH showed significant variation (at the 95 percent confidence interval) between units (table 4). All other variables showed no significant variation.

The student's t-test was also used to determine the acceptability of the null (H_0) hypothesis that there was no variation in water chemistry between pairs of rock units. The test was used because of the small sample size of the Salem and Warsaw Limestones and the Fort Payne Formation. It tests the significance of the difference of two sample means. The results of the test indicate that the variations in concentrations were not attributable to one rock unit nor were the variations consistent for any variable between all four rock units (table 5). The calculated t values were compared with a standard t-test table (Snedecor and Cochran, 1980, p. 469) and evaluated at the 95 percent confidence interval for a two-tailed t-test.

Table 4.--Summary of results for analysis of variance

Dependent variable	Source of variation	Degrees of freedom	Sum of squares	Mean square	F ratio*	H_0 acceptable at 95 percent confidence level**
Temp	between rock units	3	10.65	3.55		Accept
	within rock units	167	240.90	1.44	2.46	
pH	between rock units	3	1.21	.40		
	within rock units	167	23.80	.14	2.85	Reject
Conductance	between rock units	3	402369.39	134123.13		
	within rock units	167	9408688.26	56339.45	2.38	Accept
Ca	between rock units	3	8248.25	2749.42		
	within rock units	167	194627.44	1165.43	2.36	Accept
Mg	between rock units	3	392.86	130.95		
	within rock units	167	27083.04	162.17	.81	Accept
Na	between rock units	3	20895.81	6965.27		
	within rock units	167	195797.42	1172.43	5.94	Reject
K	between rock units	3	60.54	20.18		
	within rock units	165	2962.23	17.95	1.12	Accept
Cl	between rock units	3	4003.88	1334.62		
	within rock units	167	165886.49	993.33	1.34	Accept
SO_4	between rock units	3	50926.50	16975.50		
	within rock units	167	1501837.65	8993.03	1.89	Accept
HCO_3	between rock units	3	51266.42	17088.80		
	within rock units	167	960129.67	5749.27	2.97	Reject
SiO_2	between rock units	3	375.76	125.25		
	within rock units	166	4630.61	27.89	4.49	Reject

*Critical F value is 2.66

**H_0 hypothesis: No variation in water chemistry between the four rock units.

Table 5.--Summary of results for Student's t-test analysis

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}}}$$

$\bar{X}$ = mean, s^2 = variance, and N = sample size

	Rock unit pairs					
Variable	St. Louis Ls. Fort Payne Fm.	Salem and Warsaw Ls. Fort Payne Fm.	Ste. Genevieve Fort Payne Fm.	Ste. Genevieve Ls. Salem and Warsaw Ls.	Ste. Genevieve Ls. St. Louis Ls.	St. Louis Ls. Salem and Warsaw Ls.
Temp	1.55*	0.70*	2.03*	0.96*	0.05*	1.01*
Conductance	.73*	1.44*	1.44*	1.00*	1.50*	1.43*
Ca	1.71*	2.15*	1.07*	1.83*	.56*	1.42*
Mg	2.28*	1.38*	1.48*	.26*	.58*	.015*
Na	.93*	.19*	.75*	.76*	3.09**	1.83*
K	.25*	1.34*	1.19*	.27*	1.29*	1.58*
Cl	.82*	.05*	.42*	.64*	1.41*	1.11*
SO_4	.32*	1.74*	1.25*	.79*	1.68*	1.98*
HCO_3	2.05*	1.94*	2.55**	.55*	.36*	.70*
SiO_2	2.36*	.32*	1.36*	1.28*	2.22*	2.63**

*H_0 hypothesis that there is no variation in water chemistry between pairs of rock units is acceptable at 95 percent confidence interval.

**H_0 hypothesis is rejected at the 95 percent confidence interval.

These tests indicate that the separation of the limestone units by water chemistry is not feasible. The variations in concentrations of selected constituents may be due to local lithologic differences or possibly to pollution.

Contamination

Vulnerability

Pollution from surface sources can quickly contaminate the ground water in limestone terrain. Such polluting materials may travel considerable distances in a relatively short time due to the rapid diversion of precipitation underground by means of sinkholes, joints, fractures, and percolation through thin soils overlying bedrock. The rate of travel through the rock has been estimated in one case to be about 25 to 30 feet per minute (Plebuch, 1976, p. 20).

One of the problems in dealing with contamination of limestone aquifers is the incomplete knowledge of the exact path the contaminant will take once it is underground. Potentiometric maps, constructed from water-level data, indicate the general direction of movement but details of the local movement generally require other methods of study. Dye tracing is one such method and is being done in the Mammoth Cave area (see Quinlan and Ray, 1981). Some work on local water movement is also being done at Bowling Green, Kentucky, but much remains to be done in this regard throughout the entire Mississippian Plateaus region.

Sources

Common sources of ground-water contamination are agriculture, urban areas and industry (Blair, 1972, p. 30-38). Agricultural contaminants consist mainly of agrichemicals such as fertilizers, herbicides, and pesticides (insecticides). The chemicals may be carried to the ground-water system either by attachment to soil particles or by dissolving in water which later enters the system. Organic matter can enter the system from feedlots, barnyards, septic tanks, and other sources and cause drastic increases in the concentrations of ammonia, nitrate-nitrite, and bacterial contamination, which in turn can cause health problems.

Urban and industrial contamination sources include oil and gasoline spills, toxic waste spills, disposal lagoons, industrial waste discharges, sewage discharges, and runoff from urban areas. Runoff can cause flooding and can carry a large volume of pollutants to the ground-water reservoir in karst areas. This is especially significant where surface water generally recharges the ground-water system.

Septic tanks can create problems in karst areas. Ponding of effluent may occur over clay soil where there is little percolation, and waste may flow directly into bedrock openings where soil is thin.

Some sewage treatment plants dispose of treated water into dry wells, which are often nothing more than man-made sinkholes which permit direct access to the ground-water reservoir. This can lead to widespread contamination if plants become overloaded and treatment becomes inadequate.

Biological

Although the biological and pathological aspects of contamination of the principal aquifer were not sampled in this study, some evidence indicates that bacterial contamination is becoming a problem in some areas. The following examples give some idea of the nature and scope of this problem.

A recent thesis study (Muendel, 1980), conducted with the assistance of Bill F. Dillard, R.S., of the Christian County Health Department, involved the bacterial analysis of well and spring water in southern Christian County. The area contained an estimated 640 private water systems (wells and springs) of which 150 were randomly selected for sampling for total coliform and fecal coliform content. Analyses were made in the laboratory of the Kentucky Department of Human Resources in Frankfort, Kentucky. A total coliform count ranging from 2 to 70,000 colonies per 100 milliliters of water was found in 51 percent (76) of the samples. Of these 76 samples, 53 percent had fecal coliform counts ranging from 4 to 4,500 per 100 milliliters of water. Two of three springs in the 150 sampling sites showed evidence of contamination. The average depth of the uncontaminated wells was 110 feet as opposed to 88 feet for the contaminated wells. The geologic formations involved were the Ste. Genevieve and St. Louis Limestones.

Early in 1983 an outbreak of hepatitis in Meade County was tenatively traced to the contamination of a spring by domestic sewage containing the hepatitis virus. The spring was used locally as a source of drinking water.

SUMMARY

The principal aquifer consists primarily of the Ste. Genevieve, St. Louis, Salem and Warsaw (Harrodsburg) Limestones, and the Fort Payne Formation in the Mississippian Plateaus region of Kentucky. The St. Louis Limestone is the most widely used formation as a source of water and the Ste. Genevieve Limestone is second. Well yields as much as 500 gal/min can be obtained in some karst areas where subsurface secondary openings are well-developed. The potentiometric map shows that the direction of ground-water movement conforms, in a general way, to the surface drainage patterns.

The quality of water is one of the major factors that determines its usability. Generally, water in the principal aquifer is of good chemical quality, but the water tends to become more mineralized with depth. The lower St. Louis Limestone can yield a highly mineralized corrosive water with a strong hydrogen sulfide odor.

The karstic parts of the principal aquifer are extremely vulnerable to contamination because of the well-developed subsurface drainage. Bacterial pollution is becoming a problem in some areas. Industrial pollution is shown by high concentrations of heavy metals in ground water at Horse Cave in Hart County.

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Table 3.--Concentrations of trace elements
Results in micrograms per liter; divide by 1,000

332HNEY-Haney Limestone member of Golconda Formation
332BGCF-Big Clifty Sandstone member of Golconda Formation
332GRKN-Girkin Limestone
332PCRK-Paint Creek Limestone
332SMPL-Sample Sandstone
332RNLT-Renault Limestone

Station number	Station name	Geo-logic unit	Date of sample	Barium, dis-solved	Beryl-lium, dis-solved	Cadmium, dis-solved	Chro-mium, dis-solved	Cobalt, dis-solved
363846087124301	Meriwether Springs near Guthrie	333SGVV	08-20-75	--	--	--	--	--
			08-10-76	--	--	--	--	--
			08-22-77	--	--	--	--	--
			07-17-78	--	--	--	--	--
			08-07-79	--	--	--	--	--
			08-22-80	--	--	--	--	--
			07-21-81	--	--	--	--	--
363901086530901	Sharp, G. R.	333STLS	10-28-82	--	--	--	--	--
363911086593401	Coats Spring	333STLS	10-28-82	--	--	--	--	--
363918087181801	Davenport, J. W.	333SGSL	08-27-80	--	--	--	--	--
363924087014801	Thompson, James	333STLS	11-10-82	--	--	--	--	--
363938086274801	Witt, Earl	333STLS	11-04-82	--	--	--	--	--
363940086505001	Dromgoole Spring	333STLS	10-27-82	68	<1	1	--	<3
363942087070801	Ward, Bernice	333SGVV	11-10-82	--	--	--	--	--
363951086250501	Groves, Robert	337FRPN	11-04-82	--	--	--	--	--
364032087013901	Gill, David	333STLS	11-03-82	41	0	<1	--	<3
364116086521201	Tyler, J. M.	333STLS	10-26-82	67	<1	<1	--	<3
364138086453801	Crystal Spring	333STLS	10-27-82	--	--	--	--	--
364149086581701	Osbornse, Paul	333STLS	10-28-82	--	--	--	--	--
364230087241101	Morris, Fred O.	333SGSL	08-28-80	--	--	--	--	--
364232086514001	Kirtley, Gordon	333STLS	10-26-82	--	--	--	--	--
364244086541901	Pleasant Grove Church Spring	333STLS	11-02-82	67	<1	<1	--	<3
364252086233801	Perry, Estus	333SMWR	11-04-82	--	--	--	--	--
364330087033301	Lawrence, Edgar	333SGVV	11-03-82	--	--	--	--	--
364333087212601	Anderson, Frank, Sr.	333SGVV	11-19-80	--	--	--	--	--
364357087211301	Anderson, Frank, Sr.	333SGSL	11-19-80	--	--	--	--	--
364404086551501	Brown, Tom	333STLS	10-27-82	51	<1	2	--	3
364416087321701	Yoakum, John	333SGSL	08-20-80	--	--	--	--	--
364419087180901	McCuiston, Jerry	333SGSL	08-21-80	--	--	--	--	--
364421086483601	Delaney, Bob J.	333STLS	10-26-82	--	--	--	--	--
364425087141501	Detweiler, Ray	333STLS	11-09-82	--	--	--	--	--
364429087290401	Bardwell Farms	333SGSL	08-28-80	--	--	--	--	--
364430087095101	Campground Spring	333SGVV	11-02-82	--	--	--	--	--
364507086512301	Hobson Spring	333STLS	10-26-82	60	<1	2	--	<3
364512087101201	Miller, Joe	333SGVV	11-17-82	120	<1	<1	--	<3
364533087330601	Spring Hill Church	333SGVV	08-20-80	--	--	--	--	--
364536086443201	Overholt, Robert	333STLS	10-20-82	--	--	--	--	--
364538087124401	Indian Spring	333SGVV	11-17-82	20	<1	<1	--	<3
364545086532501	Starks, Clarence	333SGVV	07-30-80	--	--	--	--	--
364613087065801	Davenport, Simon	333SGVV	11-16-82	--	--	--	--	--
364616086374801	Smith, Wesley	333STLS	10-20-82	47	<1	1	--	<3
364630087212101	Town of Pembroke	333SGVV	09-11-80	--	--	--	--	--
364700087124401	Powell, James	333SGVV	11-18-82	--	--	--	--	--
364717087030001	Moore, Lawrence	333SGVV	11-16-82	--	--	--	--	--
364740086442401	Neely, Robert	333SGVV	10-20-82	--	--	--	--	--
364821087074901	Hurt, Clarence	332RNLT	11-18-82	--	--	--	--	--
364850087101701	U.S. Steel	333SGVV	11-18-82	--	--	--	--	--
364851087331701	White, Joe W.	333SGSL	08-27-80	--	--	--	--	--
364854086450801	Collins, James	333SGVV	07-30-80	--	--	--	--	--
364910087061901	Gibbs, Eddie	332PCRK	11-17-82	--	--	--	--	--
365018087012701	Richardson, Andrew	332PCRK	11-16-82	29	<1	<1	--	<3
365142086423201	Town Spring	333SGVV	10-22-82	69	<1	2	--	<3
365219086414101	Hall, David	332GRKN	10-21-82	--	--	--	--	--
365247086494701	Williams, Bennie	332GRKN	07-29-80	--	--	--	--	--
365308086125701	Friendship Church	333SMWR	10-29-82	--	--	--	--	--

in water from wells and springs
to compare with standards in table 2; <1, less than 1

333SGVV-Ste. Genevieve Limestone
333STLS-St. Louis Limestone
333SLEM-Salem Limestone
333SMWR-Salem and Warsaw Limestones
333SGSL-Ste. Genevieve and St. Louis Limestones
337FRPN-Fort Payne Formation

Copper, dis-solved	Copper, total recov-erable	Iron, sus-pended recov-erable	Iron, total recov-erable	Iron dis-solved	Lead, dis-solved	Manga-nese sus-pended recov-erable	Manga-nese, dis-solved	Molyb-denum, dis-solved	Nickel, dis-solved	Stron-tium, dis-solved	Vana-dium, dis-solved	Zinc dis-solved	Lithium, dis-solved
--	--	--	--	20	--	--	<10	--	--	--	--	--	--
--	--	--	--	<10	--	--	<10	--	--	--	--	--	--
--	--	--	--	20	--	--	<10	--	--	--	--	--	--
--	--	--	--	60	--	--	<10	--	--	--	--	--	--
--	--	--	--	40	--	--	50	--	--	--	--	--	--
--	--	--	--	30	--	--	10	--	--	--	--	--	--
--	--	--	--	50	--	--	180	--	--	--	--	--	--
--	--	--	--	130	--	--	9	--	--	7,900	--	--	--
--	--	--	--	13	--	--	2	--	--	--	--	--	--
--	--	--	--	30	--	--	20	--	--	--	--	--	--
--	--	--	--	10	--	--	130	--	--	--	--	--	--
--	--	--	--	<3	--	--	4	--	--	--	--	--	--
<10	--	--	--	9	<10	--	1	<10	--	500	<6.0	9	8
--	--	--	--	<3	--	--	1	--	--	--	--	--	--
--	--	--	--	<3	--	--	3	--	--	--	--	--	--
<10	--	--	--	13	<10	--	<1	<10	--	280	<6.0	28	13
<10	--	--	--	9	<10	--	<1	<10	--	580	<6.0	33	10
--	--	--	--	7	--	--	<1	--	--	--	--	--	--
--	--	--	--	32	--	--	3	--	--	--	--	--	--
--	--	--	--	10	--	--	10	--	--	--	--	--	--
--	--	--	--	8	--	--	5	--	--	--	--	--	--
<10	--	--	--	14	<10	--	34	<10	--	560	<6.0	3	15
--	--	--	--	31	--	--	71	--	--	--	--	--	--
--	--	--	--	19	--	--	1	--	--	--	--	--	--
--	--	70	70	0	--	9	1	--	--	--	--	--	--
--	--	10	10	0	--	8	2	--	--	--	--	--	--
<10	--	--	--	13	<10	--	2	<10	--	730	<6.0	33	13
--	--	--	--	20	--	--	10	--	--	--	--	--	--
--	--	--	--	100	--	--	20	--	--	--	--	--	--
--	--	--	--	24	--	--	2	--	--	20,000	--	--	--
--	--	--	--	60	--	--	10	--	--	1,100	--	--	--
--	--	--	--	30	--	--	20	--	--	--	--	--	--
--	--	--	--	14	--	--	15	--	--	--	--	--	--
<10	--	--	--	9	<10	--	53	<10	--	350	<6.0	6	8
<10	--	--	--	<3	<10	--	11	20	--	4,300	<6.0	57	11
--	--	--	--	30	--	--	10	--	--	--	--	--	--
--	--	--	--	<3	--	--	1	--	--	--	--	--	--
<10	--	--	--	110	<10	--	11	<10	--	1,600	<6.0	17	63
--	--	--	150	--	--	--	--	--	--	--	--	--	--
--	--	--	--	<3	--	--	2	--	--	--	--	--	--
<10	--	--	--	14	<10	--	2	<10	--	1,000	<6.0	20	10
--	--	--	--	20	--	--	20	--	--	--	--	--	--
--	--	--	--	<3	--	--	130	--	--	--	--	--	--
--	--	--	--	<3	--	--	3	--	--	--	--	--	--
--	--	--	--	23	--	--	4	--	--	--	--	--	--
--	--	--	--	3	--	--	2	--	--	--	--	--	--
--	--	--	--	240	--	--	670	--	--	--	--	--	--
--	--	--	--	160	--	--	10	--	--	--	--	--	--
--	--	--	1,700	--	--	--	--	--	--	--	--	--	--
--	--	--	--	<3	--	--	88	--	--	--	--	--	--
<10	--	--	--	<3	<10	--	1	<10	--	230	<6.0	20	<4
<10	--	--	--	17	<10	--	150	<10	--	260	<6.0	11	9
--	--	--	--	17	--	--	26	--	--	--	--	--	--
--	--	--	100	--	--	--	--	--	--	--	--	--	--
--	--	--	--	40	--	--	<10	--	--	--	--	--	--

Station number	Station name	Geo-logic unit	Date of sample	Barium, dis-solved	Beryl-lium, dis-solved	Cadmium, dis-solved	Chro-mium, dis-solved	Cobalt, dis-solved
365414086383301	Pogue, Gordon	332GRKN	10-19-82	--	--	--	--	--
365420086441001	Head of Gasper	332GRKN	10-19-82	64	<1	<1	--	<3
365437086392901	Ezell, Wyatt	333SGVV	10-14-82	7	<1	1	--	<3
			10-19-82	7	<1	1	--	<3
365526086382801	Finney Spring	332GRKN	10-21-82	28	<1	1	--	<3
365614086440701	Dearmond, Lisle	332GRKN	10-21-82	--	--	--	--	--
365900085545301	Glasgow Foods, Inc.	337FRPN	10-27-81	--	--	--	--	--
365946085411401	Wilson, Charles	337FRPN	07-31-80	--	--	--	--	--
370051085424801	Wilson, Austin	333STLS	10-29-81	--	--	--	--	--
370118085350901	Acree, Albie	333SMWR	08-05-80	--	--	--	--	--
370124085335401	Wilson, James	333SMWR	08-06-81	--	--	--	--	--
370252085460301	Burris, H. S.	333STLS	10-27-81	--	--	--	--	--
370303085451101	Irwin, Junior	333STLS	10-29-81	--	--	--	--	--
370324085552101	England, Charles	333STLS	10-20-81	--	--	--	--	--
370359085565401	Pace Construction Co., J. F.	333STLS	10-02-81	--	--	--	--	--
370408085401701	Anderson, Paul	333STLS	10-28-81	--	--	--	--	--
370438085430801	Piper, Gilbert	333STLS	07-31-80	--	--	--	--	--
370519085471701	Summers Valley Farm	333STLS	10-22-81	--	--	--	--	--
370602085380201	Metcalfe County Park at	337FRPN	08-04-80	--	--	--	--	--
	Sulphur Well		08-06-81	--	--	--	--	--
370620085400301	North Metcalfe Elementary School	333STLS	10-28-81	50	1	1	<10	<1
370654085501001	Bagby, John	333STLS	10-22-81	--	--	--	--	--
370658085500501	Bagby, John (Tenant House)	333STLS	10-22-81	--	--	--	--	--
370711085540901	Steenbergen, J. D., Jr.	333STLS	10-20-81	--	--	--	--	--
370756085450101	Norris, Eugene	333STLS	10-21-81	--	--	--	--	--
370834085314101	Wright, Henry	333STLS	12-08-80	--	--	--	--	--
370844085381701	Thompson Number 1, Philip	333STLS	10-07-81	--	--	--	--	--
370848085435301	Walton, Stanly	333STLS	10-07-81	--	--	--	--	--
370857085504801	London, Ray	333STLS	10-21-81	--	--	--	--	--
370924086041301	National Park Service	333SGVV	08-21-75	--	--	--	--	--
			08-23-77	--	--	--	--	--
			07-25-78	--	--	--	--	--
371005085423001	Louisville Gas and Electric, Center Field	333STLS	10-07-81	--	--	--	--	--
371016085362301	Curry, Estill	333STLS	12-03-80	--	--	--	--	--
371050085314401	Pruitt, Mickey	333STLS	10-28-81	40	<1	<1	10	<1
371145086050001	Three Springs at Mammoth Cave	332HNEY	08-21-75	--	--	--	--	--
			09-07-77	--	--	--	--	--
			07-25-78	--	--	--	--	--
			07-02-79	--	--	--	--	--
			07-27-81	--	--	--	--	--
371223085464601	Russell, Robert	333STLS	10-06-81	--	--	--	--	--
371242085502801	Overfelt, Bruce	333STLS	10-21-81	--	--	--	--	--
371257085415301	Davis, W. E.	333STLS	10-06-81	--	--	--	--	--
371333085440701	Higdom, Robert	333STLS	10-06-81	--	--	--	--	--
371352085353501	Davis, Fred	333STLS	12-08-80	--	--	--	--	--
371400085591701	Roundtree, Roger	333STLS	12-15-80	--	--	--	--	--
371533085550401	Jaggers, Ernest	333STLS	10-27-80	--	--	--	--	--
371547085410601	Estes, Elmer Jr.	333STLS	10-02-81	--	--	--	--	--
371556085410801	O'Banion, Allen	333SMWR	10-01-81	--	--	--	--	--
371605085450301	Maxey, Winford	333STLS	10-30-80	--	--	--	--	--
371644085362001	Perkins, Frank	333SMWR	09-30-81	--	--	--	--	--
371644085502901	Sims, W. H.	333STLS	10-30-80	--	--	--	--	--
371758085505301	Johnson Spring	333STLS	10-16-80	--	--	--	--	--
371847085594601	Crain, Claud	333SGVV	10-17-80	--	--	--	--	--
371919086033801	Caddock, R. H.	332GRKN	10-30-80	--	--	--	--	--
371927085340501	Vaughn, Woodruff	333STLS	09-30-81	--	--	--	--	--
371927085405401	Jewell, Delbert	333STLS	10-31-80	--	--	--	--	--
371929085461701	Rio-Verde Spring at Rio	333STLS	08-05-81	--	--	--	--	--
372008085414201	Wildcat Hollow Springs near Hudgins	333STLS	09-22-81	--	--	--	--	--
372021086020301	Terry, James	332GRKN	08-06-80	--	--	--	--	--

in water from wells and springs--Continued

Copper, dis-solved	Copper, total recov-erable	Iron, sus-pended recov-erable	Iron, total recov-erable	Iron, dis-solved	Lead, dis-solved	Manga-nese, sus-pended recov-erable	Manga-nese, dis-solved	Molyb-denum, dis-solved	Nickel, dis-solved	Stron-tium, dis-solved	Vana-dium, dis-solved	Zinc dis-solved	Lithium, dis-solved
--	--	--	--	14	--	--	2	--	--	4,900	--	--	--
<10	--	--	--	<3	<10	--	41	<10	--	320	<6.0	12	5
<10	--	--	--	<3	<10	--	<1	<10	--	520	<6.0	<3	330
<10	--	--	--	<3	<10	--	<1	<10	--	520	<6.0	<3	330
<10	--	--	--	8	<10	--	18	<10	--	390	<6.0	13	11
--	--	--	--	14	--	--	72	--	--	--	--	--	--
--	--	--	--	14	--	--	7	--	--	--	--	--	--
--	--	150	160	10	--	10	0	--	--	--	--	--	--
--	--	--	--	6	--	--	24	--	--	--	--	--	--
--	--	--	4,300	--	--	--	--	--	--	--	--	--	--
--	--	--	660	<10	--	--	20	--	--	--	--	--	--
--	--	--	--	20	--	--	5	--	--	--	--	--	--
--	--	--	--	84	--	--	4	--	--	--	--	--	--
--	--	--	--	6	--	--	13	--	--	--	--	--	--
--	--	--	--	330	--	--	11	--	--	--	--	--	--
--	--	--	--	2,200	--	--	40	--	--	--	--	--	--
--	--	570	750	180	--	10	50	--	--	--	--	--	--
--	--	--	--	9	--	--	<1	--	--	--	--	--	--
--	--	200	280	80	--	10	20	--	--	--	--	--	--
--	--	750	790	40	--	0	20	--	--	--	--	--	--
2	--	--	--	5	2	--	1	1	<1	--	<1.0	14	11
--	--	--	--	10	--	--	2	--	--	--	--	--	--
--	--	--	--	790	--	--	40	--	--	--	--	--	--
--	--	--	--	6	--	--	4	--	--	--	--	--	--
--	--	--	--	7	--	--	5	--	--	--	--	--	--
--	--	--	140	--	--	--	--	--	--	--	--	--	--
--	--	--	--	3	--	--	2	--	--	--	--	--	--
--	--	--	--	8	--	--	190	--	--	--	--	--	--
--	--	--	--	6	--	--	13	--	--	--	--	--	--
--	--	--	--	<10	--	--	<10	--	--	--	--	--	--
--	--	--	--	<10	--	--	<10	--	--	--	--	--	--
--	--	--	--	80	--	--	30	--	--	--	--	--	--
--	--	--	--	9	--	--	2	--	--	--	--	--	--
--	--	--	--	80	--	--	8	--	--	--	--	--	--
2	--	--	--	1,700	2	--	100	<1	3	--	<1.0	42	6
--	--	--	--	<10	--	--	<10	--	--	--	--	--	--
--	--	--	--	30	--	--	<10	--	--	--	--	--	--
--	--	--	--	100	--	--	<10	--	--	--	--	--	--
--	--	--	--	<10	--	--	1	--	--	--	--	--	--
--	580	--	--	20	--	--	3	--	--	--	--	--	--
--	--	--	--	20	--	--	2	--	--	--	--	--	--
--	--	--	--	7	--	--	5	--	--	--	--	--	--
--	--	--	--	12	--	--	<1	--	--	--	--	--	--
--	--	--	--	55	--	--	5	--	--	--	--	--	--
--	--	450	450	0	--	510	3	--	--	--	--	--	--
--	--	60	60	0	--	10	100	--	--	--	--	--	--
--	--	160	180	20	--	9	1	--	--	--	--	--	--
--	--	--	--	7	--	--	<1	--	--	--	--	--	--
--	--	--	--	130	--	--	30	--	--	--	--	--	--
--	--	90	100	10	--	10	0	--	--	--	--	--	--
--	--	--	--	11	--	--	4	--	--	--	--	--	--
--	--	170	180	10	--	10	0	--	--	--	--	--	--
--	--	220	230	10	--	30	1	--	--	--	--	--	--
--	--	70	70	0	--	20	2	--	--	--	--	--	--
--	--	140	140	0	--	4	6	--	--	--	--	--	--
--	--	--	--	10	--	--	1	--	--	--	--	--	--
--	--	120	130	10	--	20	2	--	--	--	--	--	--
--	--	--	220	<10	--	10	10	--	--	--	--	--	--
--	--	--	--	13	--	--	8	--	--	--	--	--	--
--	--	320	330	10	--	20	0	--	--	--	--	--	--

Station number	Station name	Geo-logic unit	Date of sample	Barium, dis-solved	Beryl-lium, dis-solved	Cadmium, dis-solved	Chro-mium, dis-solved	Cobalt, dis-solved
372026085435401	Puckett, Marshall	333STLS	07-24-80	--	--	--	--	--
372032085462901	Shelton, George O.	333STLS	08-01-80	--	--	--	--	--
372038085371401	Brush Creek Church Spring near Allendale	333STLS	09-22-81	--	--	--	--	--
372040085335301	Shofner, Claude	333STLS	07-24-80	--	--	--	--	--
372136085584301	Gibson, Roger	333STLS	08-06-80	--	--	--	--	--
372148085490201	Hawks, James	333STLS	10-31-80	--	--	--	--	--
372152085541801	Marsh, Kenneth	333STLS	10-16-80	--	--	--	--	--
372202085313301	Paxton, Terry	333STLS	09-30-81	--	--	--	--	--
372215086001701	Sullivan, Chester	333SGVV	10-30-80	--	--	--	--	--
372228085422301	Phillips, Welsy - Upper Spring	333STLS	09-21-81	<50	<10	1	10	4
372228085422302	Phillips, Welsy - Lower Spring	333STLS	09-21-81	100	<10	1	<10	3
372232085495701	Highball, Charles	333STLS	11-12-80	--	--	--	--	--
372243085292201	Edrington, William	333STLS	07-24-80	--	--	--	--	--
372259085535701	Bonnieville, City of	333STLS	10-19-80	--	--	--	--	--
372315085585001	Burba, James	333SGVV	09-25-80	--	--	--	--	--
372321085272201	Gaddie, Herbert	337FRPN	08-22-75	--	--	--	--	--
			09-07-77	--	--	--	--	--
			07-27-78	--	--	--	--	--
			07-04-79	--	--	--	--	--
			07-24-80	--	--	--	--	--
			07-30-81	--	--	--	--	--
372343085363301	Liberty Church Spring near Mount Sherman	333STLS	10-28-80	--	--	--	--	--
372356085282601	Stillwell, Earl	333SLEM	07-24-80	--	--	--	--	--
372417085410901	Skaggs, Jim	333STLS	10-22-80	--	--	--	--	--
372431085371501	Warren, Howard	333SMWR	10-29-80	--	--	--	--	--
372439085534101	Ash, Charles	333SGVV	08-06-80	--	--	--	--	--
372458086001001	Riggs, Doris	333SGVV	10-08-81	--	--	--	--	--
372504085564301	Roundstone Spring near Vento	333SGVV	09-23-81	--	--	--	--	--
372507085565801	Lower Bluehole Spring near Vento	333SGVV	09-23-81	--	--	--	--	--
372524085512401	Fulkerson, David	333STLS	10-15-80	--	--	--	--	--
372529086025601	Sullivan, Freeman R.	333SGVV	10-29-80	--	--	--	--	--
372548085545001	Falling Spring near Upton	332BGCF	08-06-81	--	--	--	--	--
372553086001201	Fields, Wendell	333SGVV	10-29-80	--	--	--	--	--
372639085410801	Clopton, Shelby	333STLS	10-22-80	--	--	--	--	--
372650086010701	Hornback, Arnold	333STLS	10-02-81	--	--	--	--	--
372702085533801	Kentucky Stone Company	333STLS	09-25-80	--	--	--	--	--
372704086024501	Big Spring near Millerstown	333SGVV	09-09-81	--	--	--	--	--
372716085434501	Kidd, Michael	333STLS	07-24-80	--	--	--	--	--
372803085495501	Sherrard, Richard	333STLS	10-15-80	--	--	--	--	--
372807086030501	Huffman, Francis	333SGVV	08-27-80	--	--	--	--	--
372814086170601	Flowing Well at Leitchfield	332BGCF	08-04-80	--	--	--	--	--
			07-15-81	--	--	--	--	--
372824085410301	Bailey, Ted	333STLS	10-22-80	--	--	--	--	--
372840085302001	Thompson, Fred	333SLEM	10-28-80	--	--	--	--	--
372849085371801	Perkins, Clifford	333STLS	10-28-80	--	--	--	--	--
372852085460201	McDonald	333STLS	08-06-80	--	--	--	--	--
372858085514101	McCanless Cemetery Spring near Upton	333SGVV	10-23-80	--	--	--	--	--
372912086051801	Spencer, Calvin	333SGVV	10-29-80	--	--	--	--	--
373033086002801	Jaggers, Charles R.	333SGVV	08-04-80	--	--	--	--	--
373052085482401	Reynolds, W. T.	333STLS	08-26-80	--	--	--	--	--
373200085441601	Sinking Spring at Lincoln Park	333STLS	08-05-81	--	--	--	--	--
373336085434501	Skaggs Spring near Aetna Furnace	333STLS	09-18-81	--	--	--	--	--
373343086021201	White Mills Spring	333SGVV	08-27-80	--	--	--	--	--
373428085490801	Heady Spring near Eagle Mills	333STLS	09-09-81	--	--	--	--	--
373435085553301	Cardin Brothers	333STLS	08-01-80	--	--	--	--	--
373613085441301	Morrison, E. L.	333STLS	08-26-80	--	--	--	--	--
373628086045501	Akers, Dennis	333SGVV	08-27-80	--	--	--	--	--
373640086105501	Sydnor, Donald	333SGVV	08-27-80	--	--	--	--	--
373809085494401	Fultz, Jess	333STLS	11-10-82	29	<1	<1	10	<3
373818086233601	Hidden Valley Spring	332SMPL	08-17-81	--	--	--	--	--

in water from wells and springs--Continued

Copper, dis-solved	Copper, total recov-erable	Iron, sus-pended recov-erable	Iron, total recov-erable	Iron, dis-solved	Lead, dis-solved	Manga-nese, sus-pended recov-erable	Manga-nese, dis-solved	Molyb-denum, dis-solved	Nickel, dis-solved	Stron-tium, dis-solved	Vana-dium, dis-solved	Zinc dis-solved	Lithium, dis-solved
--	--	--	40	--	--	--	--	--	--	--	--	--	--
--	--	110	120	10	--	10	0	--	--	--	--	--	--
--	--	--	--	10	--	--	<10	--	--	--	--	--	--
--	--	--	200	--	--	--	--	--	--	--	--	--	--
--	--	290	290	0	--	10	0	--	--	--	--	--	--
--	--	2,600	2,600	50	--	80	10	--	--	--	--	--	--
--	--	290	290	0	--	20	0	--	--	--	--	--	--
--	--	--	--	8	--	--	1	--	--	--	--	--	--
--	--	50	60	10	-	40	5	--	--	--	--	--	--
1	--	--	--	<10	3	--	<10	<1	<1	--	--	20	<10
1	--	--	--	20	3	--	<10	<1	<1	--	--	10	<10
--	--	1,300	1,300	0	--	60	0	--	--	--	--	--	--
--	--	--	120	--	--	--	--	--	--	--	--	--	--
--	--	1,900	2,700	770	--	60	40	--	--	--	--	--	--
--	--	--	--	20	--	--	20	--	--	--	--	--	--
--	--	--	--	370	--	--	870	--	--	--	--	--	--
--	--	--	--	40	--	--	30	--	--	--	--	--	--
--	--	--	--	150	--	--	550	--	--	--	--	--	--
--	--	--	--	<10	--	--	<10	--	--	--	--	--	--
--	--	--	--	--	--	--	10	--	--	--	--	--	--
--	--	--	--	20	--	--	10	--	--	--	--	--	--
--	--	490	520	30	--	7	3	--	--	--	--	--	--
--	--	--	680	--	--	--	--	--	--	--	--	--	--
--	--	20	360	340	--	0	20	--	--	--	--	--	--
--	--	210	1,100	890	--	20	5	--	--	--	--	--	--
--	--	290	290	0	--	10	10	--	--	--	--	--	--
--	--	--	--	11	--	--	2	--	--	--	--	--	--
--	--	--	--	6	--	--	2	--	--	--	--	--	--
--	--	--	--	18	--	--	4	--	--	--	--	--	--
--	--	220	230	10	--	7	3	--	--	--	--	--	--
--	--	140	150	10	--	20	4	--	--	--	--	--	--
--	--	--	110	<10	--	6	4	--	--	--	--	--	--
--	--	200	210	10	--	30	0	--	--	--	--	--	--
--	--	60	60	0	--	10	0	--	--	--	--	--	--
--	--	--	--	27	--	--	3	--	--	--	--	--	--
--	--	--	--	170	--	--	30	--	--	--	--	--	--
--	--	450	470	20	--	--	<10	--	--	--	--	--	--
--	--	--	310	--	--	--	--	--	--	--	--	--	--
--	--	200	200	0	--	10	0	--	--	--	--	--	--
--	--	80	90	10	--	0	10	--	--	--	--	--	--
--	--	--	80	--	--	--	--	--	--	--	--	--	--
--	--	--	--	10	--	--	10	--	--	--	--	--	--
--	--	120	130	10	--	0	10	--	--	--	--	--	--
--	--	350	450	100	--	10	9	--	--	--	--	--	--
--	--	90	100	10	--	10	0	--	--	--	--	--	--
--	--	230	380	50	--	20	0	--	--	--	--	--	--
--	--	120	140	20	--	3	2	--	--	--	--	--	--
--	--	260	270	10	--	9	1	--	--	--	--	--	--
--	--	--	190	--	--	--	--	--	--	--	--	--	--
--	--	240	250	10	--	10	0	--	--	--	--	--	--
--	--	--	130	<10	--	--	1	--	--	--	--	--	--
--	--	--	--	30	--	--	<10	--	--	--	--	--	--
--	--	470	770	300	--	0	80	--	--	--	--	--	--
--	--	290	310	20	--	--	<10	--	--	--	--	--	--
--	--	80	90	10	--	10	0	--	--	--	--	--	--
--	--	60	70	10	--	10	0	--	--	--	--	--	--
--	--	600	4,200	3,600	--	0	350	--	--	--	--	--	--
--	--	180	190	10	--	0	10	--	--	--	--	--	--
<10	--	--	--	6	<10	--	<1	<10	--	93	<6.0	210	<4
--	--	140	150	10	--	--	1	--	--	--	--	--	--

Station number	Station name	Geo-logic unit	Date of sample	Barium, dis-solved	Beryl-lium, dis-solved	Cadmium, dis-solved	Chro-mium, dis-solved	Cobalt, dis-solved
373836085503801	McMillian, Joe	333STLS	12-01-82	41	<1	<1	10	<3
373849085425701	Nicholas, Logan	333STLS	09-16-80	--	--	--	--	--
373927085562501	William Jr., Guy	333STLS	09-25-80	--	--	--	--	--
373929085485101	Rogers, Margret	333STLS	11-10-82	130	<1	<1	10	<3
373929085540401	Dyers Spring	333STLS	11-11-82	37	1	1	10	3
373945085524001	Overall Jr., W.	333STLS	11-11-82	35	<1	<1	10	<3
373956085461901	Perry, R. C.	333STLS	09-16-80	--	--	--	--	--
373959085541601	Bush, Charles	333STLS	11-18-82	64	<1	1	10	<3
374012085531901	Meyer, Stewart	333STLS	11-18-82	30	<1	<1	10	<3
374017085472001	Vincent, R.	333STLS	12-01-82	100	<1	<1	10	<3
374017085503001	Hunt, Carol	333STLS	12-01-82	160	<1	<1	10	<3
374022085520001	McDowell, G. A.	333STLS	11-10-82	52	<1	1	20	<3
374043085523001	Elizabethtown Spring	333STLS	11-11-82	49	<1	<1	10	<3
374049085523501	Elizabethtown (PW1)	333STLS	11-16-82	94	<1	<1	20	<3
374049085551201	Metcalf, Walter	333STLS	11-18-82	37	1	1	10	3
374057085483301	Slack, Anthony	333STLS	12-01-82	64	<1	<1	10	<3
374123086160501	Johnson, Frank	333SGVV	09-18-80	--	--	--	--	--
374133085561501	Hamilton, Leonard	333STLS	11-17-82	58	1	2	20	3
374143085542901	Thomas, M. E.	333STLS	11-17-82	55	<1	<1	10	<3
374146086063101	Pirtle Spring	333SGVV	08-26-80	--	--	--	--	--
374156085531501	Preston, Keenus	333STLS	11-17-82	42	<1	<1	20	<3
374207085492301	Aubrey, George	333STLS	12-02-82	87	<1	1	10	<3
374224085545801	Blue Spring	333STLS	11-12-82	70	<1	1	10	<3
374231085511201	Drake, Presly	333STLS	12-02-82	78	<1	3	10	<3
374245086094201	Kentucky Highway Department	333SGVV	08-18-81	--	--	--	--	--
374247086103301	Collee, Russell	333SGVV	08-27-80	--	--	--	--	--
374249085564401	Dillard, William	333STLS	12-07-82	62	<1	<1	10	<3
374257085584301	Brangers, G. D.	333STLS	12-07-82	39	<1	<1	10	<3
374300085535801	Sells, Donald	333STLS	12-07-82	220	<1	<1	10	<3
374307086045401	Head of Rough	333SGVV	08-26-80	--	--	--	--	--
374331085553801	Dillard, Roy	333STLS	12-07-82	71	<1	<1	10	<3
374410085570001	Mattingly, Aubin	333STLS	12-03-82	87	<1	<1	--	<3
374411086034601	Hunt, Thomas	333STLS	09-18-80	--	--	--	--	--
374434085553401	Stallins, Samuel	333STLS	12-03-82	76	<1	<1	10	<3
374453085573201	Patterson, Horace	333STLS	12-03-82	99	<1	<1	10	<3
374514085520301	Montgomery, Danny	333STLS	12-02-82	41	1	1	10	3
374525085560501	Brangers, Lawrence	333STLS	12-03-82	42	<1	<1	10	<3
374554085521701	Bailey, Paul R.	333SLEM	09-30-80	--	--	--	--	--
374610085561001	Wise, Louise	333STLS	09-24-80	--	--	--	--	--
374755086090401	Big Spring at Big Spring	333SGVV	10-02-80	--	--	--	--	--
			08-12-81	--	--	--	--	--
374759085511701	Stovall, Dessie	333SLEM	09-30-80	--	--	--	--	--
374847086252801	Withers, James	333SGVV	09-24-80	--	--	--	--	--
374923086003701	Berry, James R.	333STLS	08-18-81	--	--	--	--	--
375051086172401	Bandy, Roy	333SGVV	09-12-80	--	--	--	--	--
375055086044701	Hardesty, Jerry	333STLS	09-12-80	--	--	--	--	--
375114085561501	Sanders Spring	333STLS	09-25-80	--	--	--	--	--
375127086201701	Stull, Roger	333SGVV	08-20-81	--	--	--	--	--
375140086120001	Thomas, James	333STLS	08-27-80	--	--	--	--	--
375257086170103	Irvington, City of	333SGVV	09-11-80	--	--	--	--	--
375307086103301	Cox, Ben	333STLS	08-27-80	--	--	--	--	--
375356086273901	Sugar Tree Run, Head of (near Sample)	333SGVV	08-20-81	--	--	--	--	--
375441086052401	Felker, Donald M.	333STLS	09-12-80	--	--	--	--	--
375835086242901	Nevitt, Denny	333SGVV	09-17-80	--	--	--	--	--
380006086092201	Buttermilk Falls at Brandenburg	333STLS	09-25-80	--	--	--	--	--
			07-22-81	--	--	--	--	--
380037086113701	Embrey, Carl	333STLS	09-17-80	--	--	--	--	--
380207086160701	Meunier, J. B.	333STLS	09-17-80	--	--	--	--	--
380358086213401	Wolf Creek, Head of (near Wolf Creek)	333SGVV	10-02-80	--	--	--	--	--
380645086194901	Devasier, Allen	333STLS	09-11-80	--	--	--	--	--
381108086215701	Herbaugh, Robert	333STLS	08-12-81	--	--	--	--	--

in water from wells and springs--Continued

Copper, dis-solved	Copper, total recov-erable	Iron, sus-pended recov-erable	Iron, total recov-erable	Iron, dis-solved	Lead, dis-solved	Manga-nese, sus-pended recov-erable	Manga-nese, dis-solved	Molyb-denum, dis-solved	Nickel, dis-solved	Stron-tium, dis-solved	Vana-dium, dis-solved	Zinc dis-solved	Lithium, dis-solved
<10	--	--	--	18	10	--	<1	<10	--	130	<6.0	41	5
--	--	190	200	10	--	10	0	--	--	--	--	--	--
--	--	60	70	10	--	10	0	--	--	--	--	--	--
<10	--	--	--	56	<10	--	320	10	--	6,800	<6.0	220	<4
10	--	--	--	24	10	--	16	10	--	120	6.0	9	4
<10	--	--	--	21	<10	--	2	<10	--	100	<6.0	28	<4
--	--	70	70	0	--	10	0	--	--	--	--	--	--
<10	--	--	--	22	<10	--	<1	20	--	310	<6.0	15	9
<10	--	--	--	<3	<10	--	<1	<10	--	82	<6.0	54	<4
<10	--	--	--	60	<10	--	10	<10	--	1,400	<6.0	370	<4
<10	--	--	--	12	<10	--	1	<10	--	2,700	<6.0	55	<4
<10	--	--	--	21	<10	--	1	<10	--	10,000	<6.0	16	9
<10	--	--	--	4	<10	--	9	<10	--	280	<6.0	12	<4
<10	--	--	--	12	<10	--	5	<10	--	4,300	<6.0	4	<4
10	--	--	--	12	10	--	2	10	--	96	6.0	110	5
<10	--	--	--	14	<10	--	2	<10	--	14,000	<6.0	170	14
--	--	70	90	20	--	0	10	--	--	--	--	--	--
10	--	--	--	14	10	--	1	20	--	150	6.0	53	4
<10	--	--	--	4	<10	--	2	10	--	66	<6.0	81	<4
--	--	470	480	10	--	20	10	--	--	--	--	--	--
<10	--	--	--	9	<10	--	4	10	--	82	<6.0	140	<4
<10	--	--	--	36	<10	--	2	<10	--	260	<6.0	180	5
<10	--	--	--	13	<10	--	54	<10	--	560	<6.0	4	<4
<10	--	--	--	21	20	--	10	<10	--	370	<6.0	2,200	5
--	--	180	190	10	--	9	1	--	--	--	--	--	--
--	--	340	790	450	--	0	30	--	--	--	--	--	--
<10	--	--	--	21	<10	--	2	<10	--	200	<6.0	100	<4
<10	--	--	--	20	<10	--	1	<10	--	140	<6.0	5	<4
<10	--	--	--	7	<10	--	<1	<10	--	430	<6.0	39	18
--	--	350	360	10	--	10	10	--	--	--	--	--	--
<10	--	--	--	71	<10	--	46	<10	--	20,000	<6.0	28	11
<10	--	--	--	12	10	--	2	<10	--	330	<6.0	14	5
--	--	90	100	10	--	10	0	--	--	--	--	--	--
<10	--	--	--	10	<10	--	2	30	--	25,000	<6.0	110	6
<10	--	--	--	55	20	--	19	<10	--	1,400	<6.0	1,300	<4
10	--	--	--	62	10	--	5	10	--	58	6.0	170	4
<10	--	--	--	4	<10	--	<1	<10	--	81	<6.0	78	<4
--	--	100	110	10	--	10	0	--	--	--	--	--	--
--	--	70	80	10	--	0	30	--	--	--	--	--	--
--	--	180	200	20	--	10	10	--	--	--	--	--	--
--	--	2,000	--	--	--	0	--	--	--	--	--	--	--
--	--	220	270	50	--	10	0	--	--	--	--	--	--
--	--	530	730	200	--	10	30	--	--	--	--	--	--
--	--	240	250	10	--	7	3	--	--	--	--	--	--
--	--	40	40	0	--	10	0	--	--	--	--	--	--
--	--	120	250	130	--	10	0	--	--	--	--	--	--
--	--	1,100	1,100	40	--	70	20	--	--	--	--	--	--
--	--	1,200	1,200	10	--	40	5	--	--	--	--	--	--
--	--	240	250	10	--	10	0	--	--	--	--	--	--
--	--	290	300	10	--	--	--	--	--	--	--	--	--
--	--	160	410	250	--	10	20	--	--	--	--	--	--
--	--	440	510	70	--	10	10	--	--	--	--	--	--
--	--	80	90	10	--	0	100	--	--	--	--	--	--
--	--	1,400	1,800	360	--	10	20	--	--	--	--	--	--
--	--	160	180	20	--	10	0	--	--	--	--	--	--
--	--	--	--	<10	--	--	5	--	--	--	--	--	--
--	--	240	360	120	--	10	10	--	--	--	--	--	--
--	--	70	110	40	--	210	10	--	--	--	--	--	--
--	--	2,700	2,700	20	--	140	0	--	--	--	--	--	--
--	--	280	310	30	--	10	0	--	--	--	--	--	--
--	--	1,900	1,900	30	--	30	8	--	--	--	--	--	--