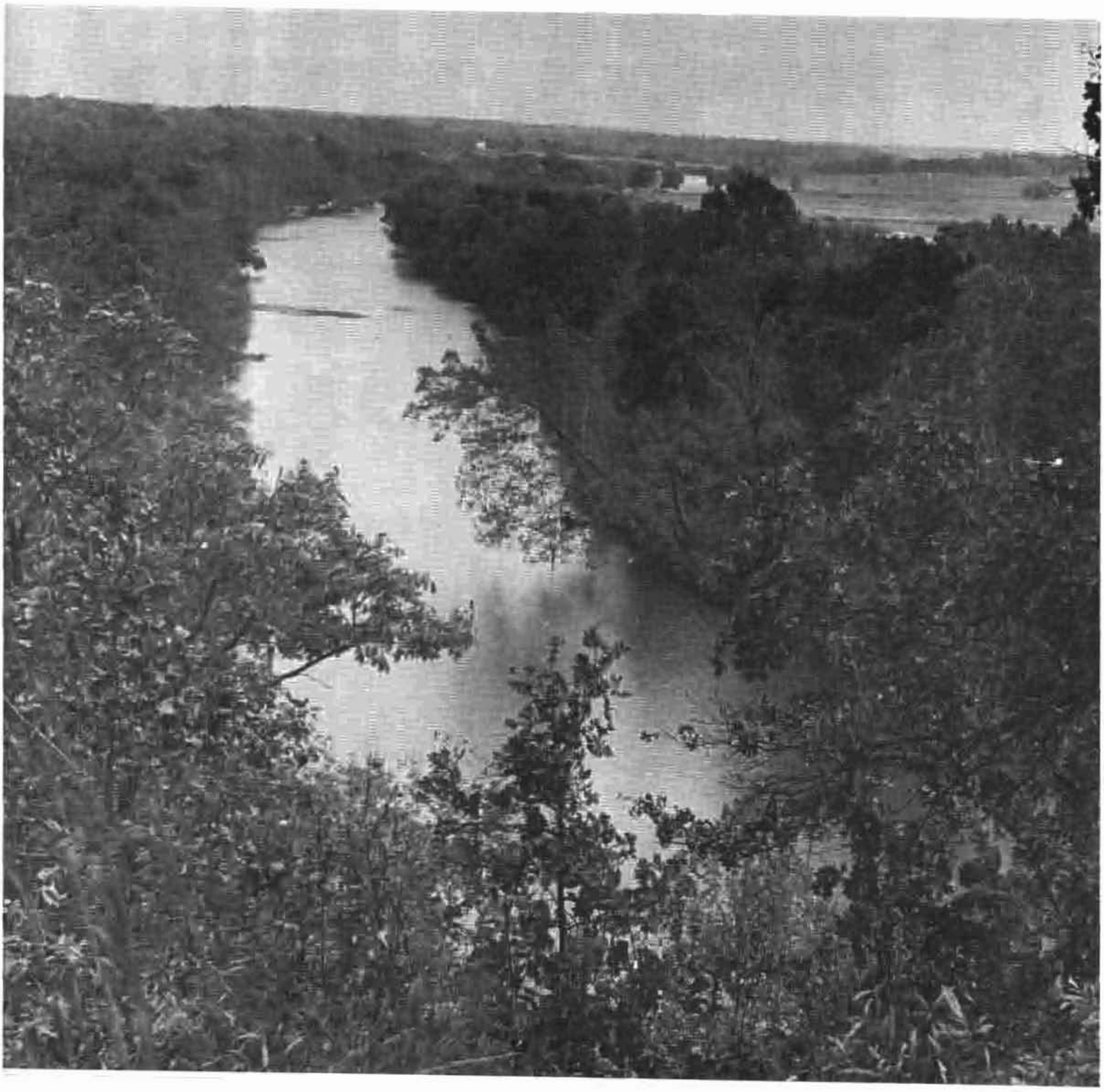
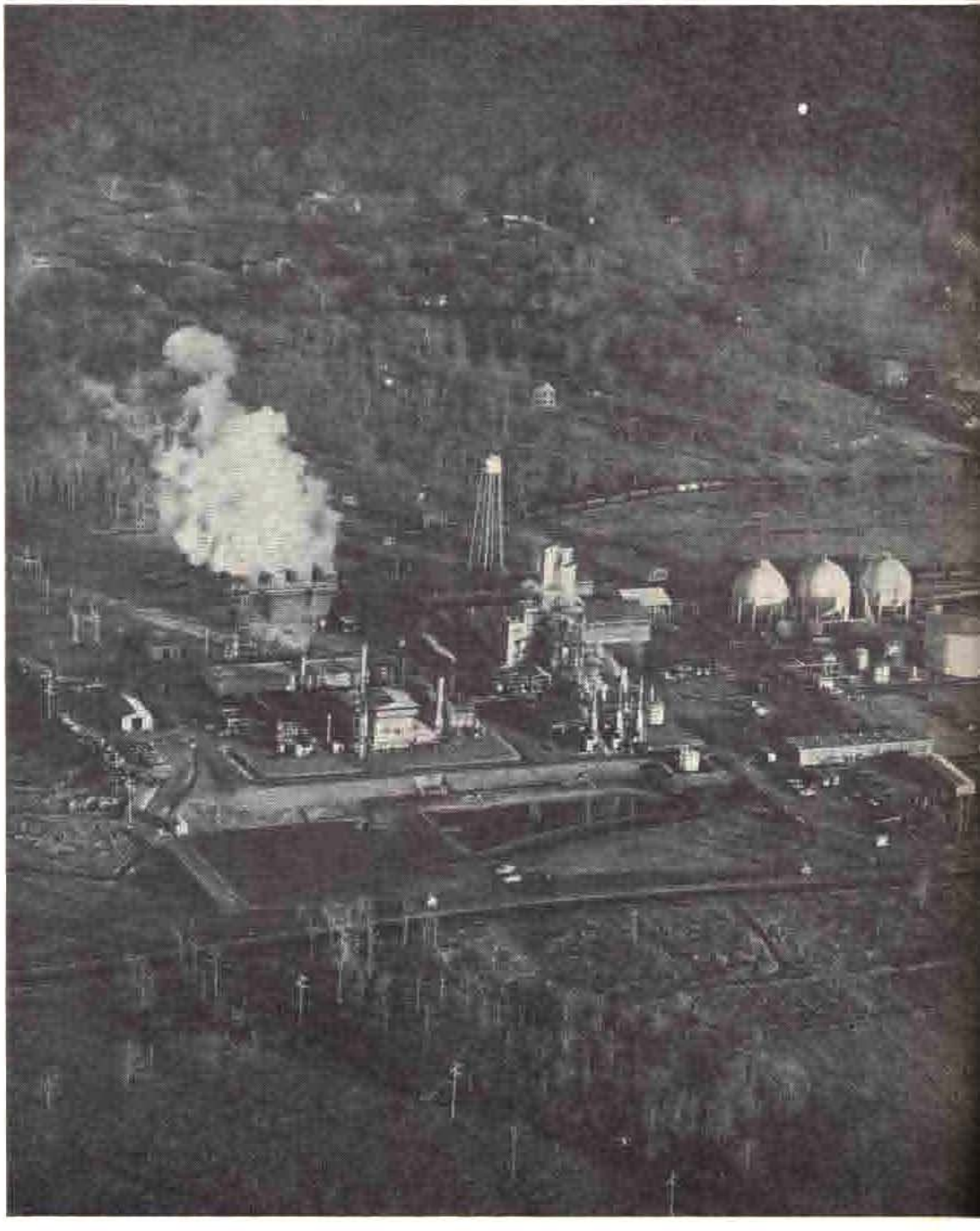
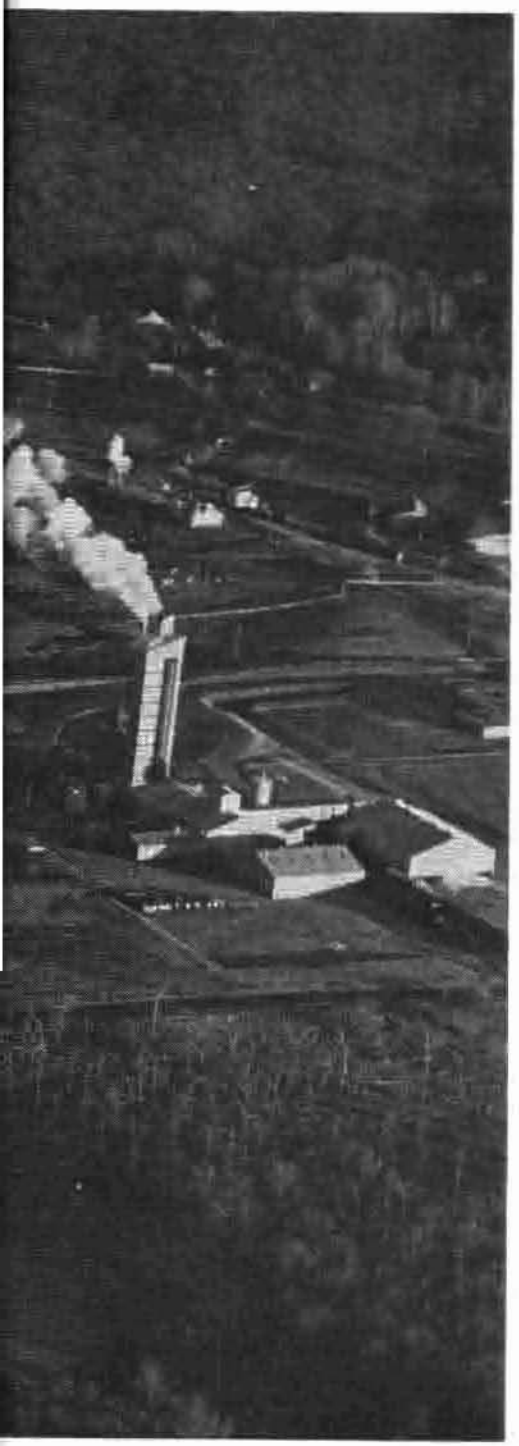
WATER RESOURCES of the JOPLIN AREA, MO.



TOURIST POTENTIAL of the Joplin area is well illustrated by this view from "Inspiration Point" on Shoal Creek just above Grand Falls.



AN INDUSTRIAL COMPLEX, east of Joplin, Mo., utilizes water from wells and springs in the area.



WATER RESOURCES of the JOPLIN AREA, MISSOURI

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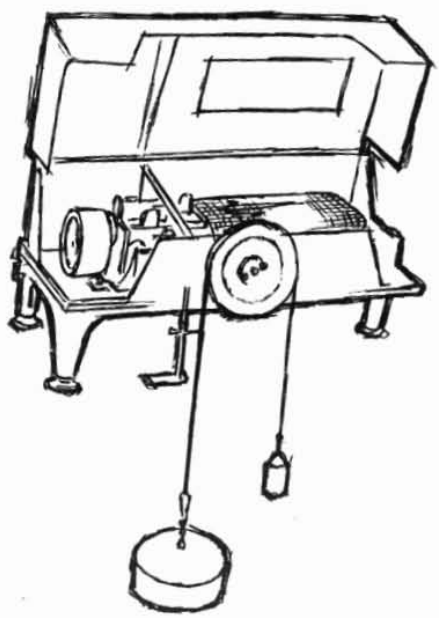

WATER RESOURCES OF THE JOPLIN AREA, MISSOURI

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ABSTRACT

Water supplies in the Joplin area are available from streams, the shallow aquifer (limestone of Mississippian age), and the deep aquifer (dolomite and sandstone of Ordovician and Cambrian ages). The shallow aquifer supplies the baseflow of the area's streams, and also provides some recharge to the deep aquifer. Although recharge to the shallow aquifer occurs within the area, most of the recharge to the deep aquifer occurs outside the area.

Streams are the largest source of water in the area and offer the greatest potential for further development. The average discharge of the area's streams is about 1 billion gallons per day (gpd), and the flow exceeds 150 million gpd 90 percent of the time. Flooding is not a serious problem at present, but increased urbanization may create problems. The Spring River basin yields the highest average flow and Shoal Creek basin yields the highest baseflow. Stream water is generally of good quality and is a calcium bicarbonate type. However, Turkey Creek and lower Center Creek are polluted by industrial and municipal wastes, and by natural drainage from mining areas.

Most wells in the deep aquifer yield 100 to 300 gallons per minute (gpm). The water is of good quality, and is a calcium magnesium bicarbonate type with a range in dissolved solids of 140 to 290 milligrams per liter (mg/l) with a median value of 227 mg/l.

Water supplies from the shallow aquifer can be obtained from wells, mine workings, and springs. Yields of wells in the shallow aquifer range from less than 10 gpm to more than 300 gpm. A well drilled to the Elsey or Reeds Spring Formation will generally yield from 10 to 50 gpm. Wells drilled in brecciated areas may produce 50 to 300 gpm. The dissolved-solids content of well water ranges from 162 to 981 mg/l, with a median value of 288 mg/l. The water is generally a calcium bicarbonate type, but locally sulfide minerals have changed it to a calcium sulfate type. Wells in the shallow aquifer are subject to contamination from the surface. A few wells contain more than 200 mg/l nitrate.

Large abandoned zinc mines in the area contain billions of gallons of water in storage and can yield from 50 to 1,000 gpm continuously. Pumping from a mine affects surrounding mines so that coordination of pumping rates by adjacent users is necessary. Most mine waters are a calcium sulfate type with a pH below 7. The dissolved-solids content ranges from 329 to 2,200 mg/l, with a median value of 1,080 mg/l. Some mine waters contain large amounts of zinc, iron, and magnesium. Due to the poor quality of mine water most uses will be restricted to industry. Disposal of mine water may present a problem to users.

There are numerous springs in the area, with many yielding 100 to 500 gpm. The water is generally of good quality, and is a calcium bicarbonate type. The dissolved-solids content ranges from 123 to 520 mg/l, with a median value of 186 mg/l.

At present about 20 mgd (million gallons per day) of water is being used in the area, of which about 8 mgd is pumped from streams. The water resources of the area have much potential for further development but proper management is essential for efficient development.

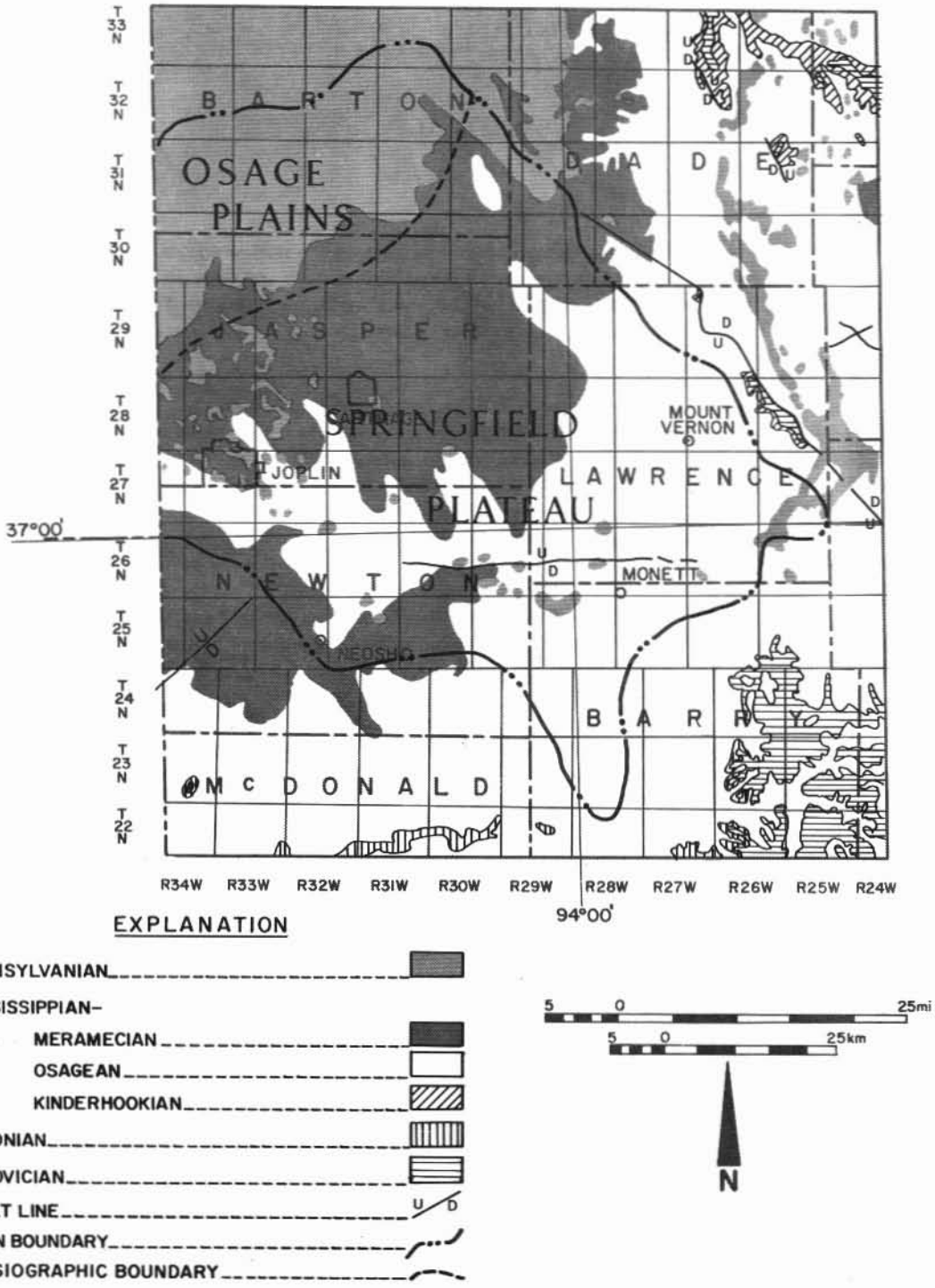


Figure 1. Geologic map of the Joplin area, Missouri, showing Spring River basin. Geology from State Geologic Map of Missouri (McCracken, 1961).

INTRODUCTION

PURPOSE AND SCOPE

Joplin, one of the famous zinc mining camps of the early 1900's, is today experiencing a considerable growth in population and industry. Continued population and industrial growth requires water, and a knowledge of its availability and quality is necessary for the continued economic expansion of the area.

Many aspects of the area's hydrologic system are unique. The area has adequate water for future development, but the interaction between waters in the various environs of the system makes proper management essential to prevent pollution and assure adequate supplies. During past periods of mining, large quantities of mine-water were discharged directly to the streams, and in dry periods the quantity of mine-water often exceeded the natural flow of those streams. With the cessation of mining activities and the advent of industrial use of mine-water, questions arose concerning its quality, availability, and its effects upon streamflow and stream quality, especially since the affected streams are, or contribute to, interstate streams.

For these reasons a study of the water resources of the Joplin area was undertaken to appraise all sources of water in the area, with respect to their potential for development, and the effects and possible consequences of man's activities on the system.

LOCATION AND EXTENT OF STUDY AREA

The Joplin area is in southwest Missouri and (for this report) includes all of the Spring River basin in Missouri (fig. 1). It is approximately bounded by latitude 36°40'N and 37°40'N, and longitude 93°40' and 94°40'. The area includes all of Jasper County, and parts of Newton, Lawrence, Barry, Dade and Barton Counties, an area of about 2,000 square miles. Particular emphasis is given to the mining area in the Missouri part of the Tri-State zinc-lead district (fig.2).

COOPERATION AND ACKNOWLEDGMENTS

This study was made in cooperation with the Missouri Geological Survey and Water Resources (Dr. William C. Hayes, State Geologist and Director). Logs of wells drilled into the Ordovician and Cambrian aquifers, structure maps, and water analyses for the deep aquifers were obtained from the files of the Missouri Geological Survey and Water Resources.

Chemical analyses of surface water were obtained in cooperation with the Missouri Water Pollution Board, Jack K. Smith, executive secretary. A survey of the biological and chemical characteristics of Spring River and Center Creek was made by the Missouri Water Pollution Board, in cooperation with Missouri Conservation Commission, and the State and Federal Surveys as part of a statewide program to determine basic surface water quality. The results of this study will be published by the Missouri Water Pollution Board.

The extensive files of George M. Fowler, Joplin, Mo., consulting mining geologist, were entrusted to Missouri Geological Survey and Water Resources for geologic studies and were made available to the writers for the study. The authors wish to thank the many homeowners, industrial and mining personnel, and city officials who furnished information and help in collecting the supporting data.

The work was performed under the direction of Anthony Homyk, District Chief, Water Resources Division, Missouri district.

WELL NUMBERING SYSTEM

The location of the wells used in the report are given in accordance with the General Land Office Surveys and according to the following formula: township, range, section, quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). The subdivisions of a section are designed a, b, c, and d in counterclockwise direction beginning in the northeast quarter. If several wells are in a 10-acre tract, they are numbered serially after the above letters, and in the order in which they were inventoried (fig. 3).

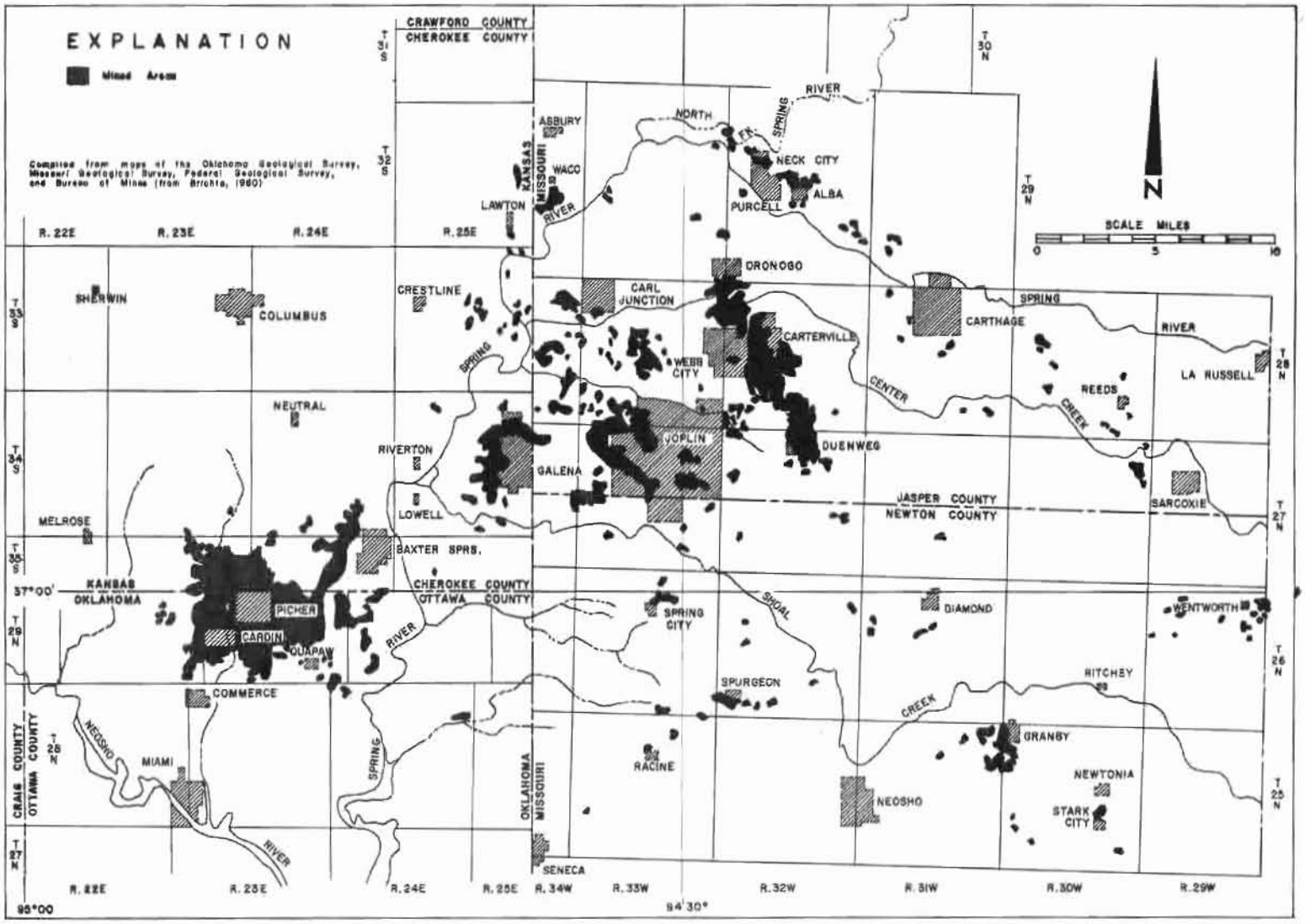


Figure 2. Principal part of the Tri-State zinc-lead district showing mined areas.

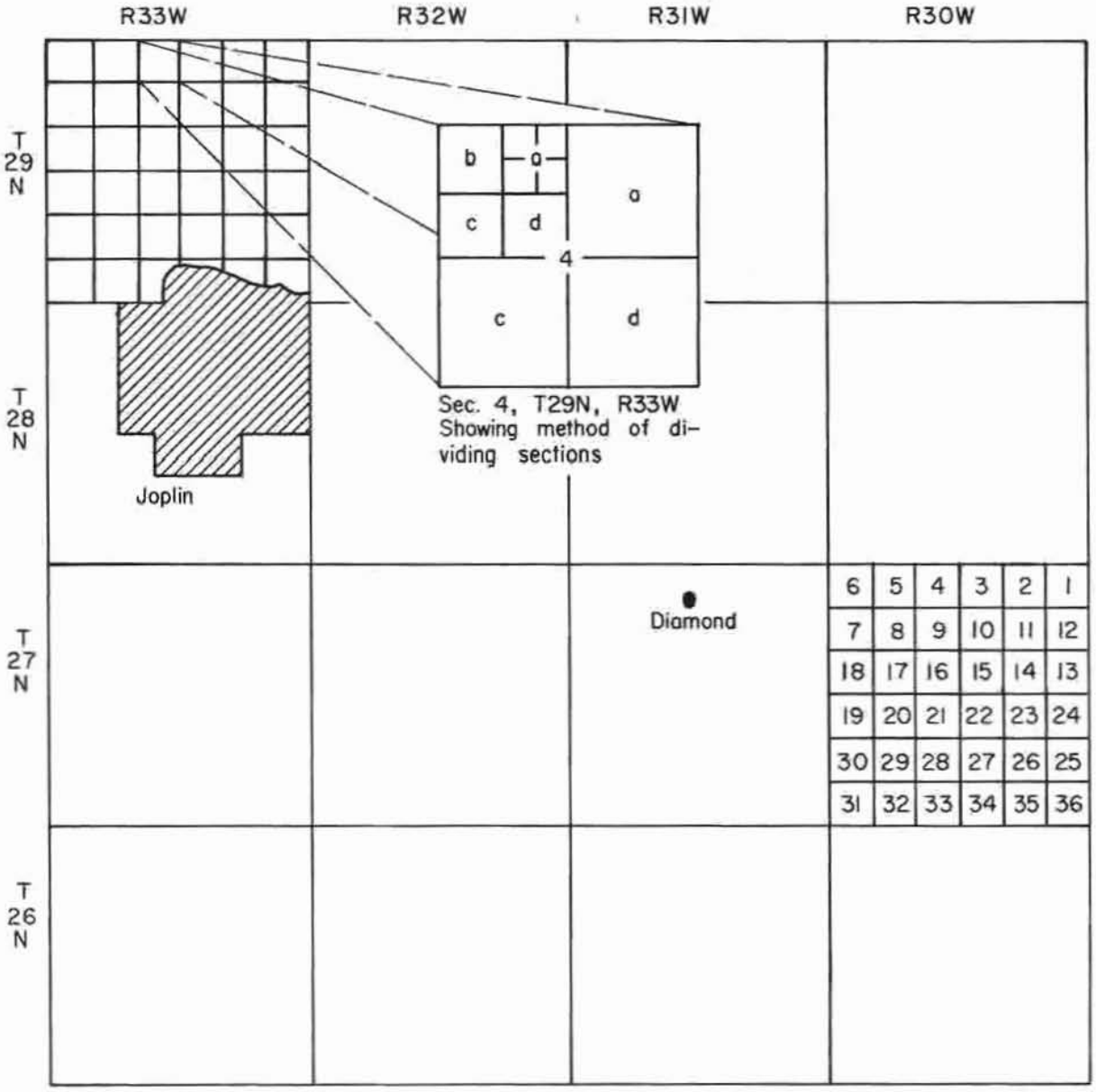


Figure 3. Diagram of part of the Joplin area illustrating the General Land Office Survey System and method of subdividing sections.

THE HYDROLOGIC ENVIRONMENT

The average annual precipitation on the area, if distributed uniformly, would amount to over 3.5 billion gallons per day. About 75 percent of this total is lost by evapotranspiration, leaving almost one billion gallons per day available to streamflow and groundwater recharge. Of this quantity an average of about 800 mgd quickly flows out of the area as surface runoff, and about 200 mgd recharges the shallow aquifer. The ground water then becomes available to wells, and as seepage to springs and streams. However, due to non-uniform distribution of precipitation, the supply available at any given time is quite variable. During periods of heavy rainfall over 20 billion gallons per day may flow out of the area as floodflow, while less than 0.1 billion gallons per day flows out during dry periods.

The water in the deep artesian aquifers is derived from infiltration outside the area and by downward seepage from the shallow aquifer.

In order to determine the occurrence, movement, quantity, and quality of water in an area, one must first understand what controls these factors. In the Joplin area, as in all areas, the controls are: climate, topography, drainage, surface features, the geologic framework, and man-made developments.

CLIMATE

The climate of the study area is continental. The average annual precipitation during the period 1931-60, based on records from six long-time stations, was 40 inches and the average annual temperature during the same period was 14.4 degrees Celsius (centigrade).

DROUGHTS

During 1952-53, rainfall averaged 14 inches below normal making it the driest period since 1887, the beginning of continuous climatological record. The cumulative effect of these 2 severely dry years, followed by below normal precipitation in 1954, resulted in the lowest streamflows of record in 1954.

Minimum streamflows in the area usually occur in September or October. At long-time continuous record stations, 44 percent of the yearly minimum discharges have occurred in September and 17 percent have occurred in October.

FLOOD FLOWS

The maximum annual rainfall of 61 inches occurred in the area in 1945. However, maximum flood peaks on the streams were recorded in May 1943.

Most peak flows occur during the spring and early summer as a result of the intense thunderstorms which occasionally sweep the area. At gaging stations with long-term records, 55 percent of the peak flows have occurred in April, May, and June.

PATTERNS OF TOPOGRAPHY AND DRAINAGE

The southern part of the basin is the maturely dissected surface of the Springfield Plateau which is underlain by Mississippian limestone. The northern part of the basin is the relatively flat Osage Plains formed predominantly by Pennsylvanian shales and sandstones. The physiographic divisions in the Joplin area are shown in figure 1. Altitudes of land surface range between 800 and 1,300 feet. Perennial streams flow to the west across the Springfield Plateau in valleys as deep as 150 feet. Streams which drain the Osage Plains flow to the south, are generally intermittent, and are not so deeply incised.

SURFACE FEATURES

The intense mining activity which occurred in the past created surface features in the Joplin area which play an important part in the distribution of the water supply and its ultimate quality. In the mining fields, in the western part of the area, extensive chat piles (mine tailings) rapidly absorb rainfall and help to replenish the ground water supply.

Drainage ditches emptying into areas of mine cave-ins also serve as rapid means of ground water replenishment. A system of drainage ditches in the

System	Series	Group	Stratigraphic Unit	Thickness Feet	Physical Character	Depth to Top of Formation, Feet	Water-bearing Character	
QUATERNARY	Recent		Alluvium	0-30	Unconsolidated silt, sand, and gravel	Outcrop	Yields small supplies for domestic and stock use	
PENNSYLVANIAN	Desmoinesian	Cherokee		0-100+	Shales and sandstones with beds of coal	Outcrop	Yields little water to shallow dug wells	
MISSISSIPPIAN	Chesterian		Cartersville Formation	0-100	Limestones, shales, and siltstones, generally found filling depressions in underlying rocks	Outcrop to 50	Does not yield water to wells	
	Meramecian		Warsaw Formation	80-150	Dense limestone with some chert	Outcrop to 150	Yields little water except in isolated solution channels	
	Osagean		Burlington and Keokuk Limestones	50-150	Dense cherty limestone, sometimes mineralized with zinc and lead	Outcrop to 300	Shallow Aquifers	Yields little water where massive, but can yield over 100 gpm in brecciated areas. Solution channels may yield large supplies
			Elsey Formation	50±	Fine-grained, very cherty limestone, sometimes all chert and mineralized with zinc and lead	Outcrop to 450		Generally yields adequate supply for domestic and stock use, rarely over 10 gpm. Supplies many springs
			Reeds Spring Formation	5-200	Dark, very cherty, argillaceous limestone; sometimes mineralized with zinc and lead	Outcrop to 500		Generally yields adequate domestic or stock supply. Supplies many springs
			Fernvale Formation	10-30	Cherty dolomitic limestone in upper portion; silty dolomite in lower portion	100-600	Yields very small quantities of water	
	Kinderhookian		Northview Formation	0-15	Shale or shaly limestone; absent in portions of area	125-625	Aquiclude	
			Compton Formation	0-10	Shaly limestone	125-625	Generally does not yield water	
			Sedalia Formation	0-0.5	Sandstone	125-625	Does not yield water to wells	
DEVONIAN			Chattanooga Shale	0-10	Fissile, black, carbonaceous shale; absent throughout most of area	150-500	Aquiclude	
ORDOVICIAN	Lower		Cotter Dolomite	200±	Cherty dolomite; some sandstone beds	450-650	Deep Aquifers	Yields small quantities of water
			Jefferson City Dolomite	200±	Cherty dolomite	750-850		Yields small quantities of water
			Roubidoux Formation	175±	Cherty dolomite and several sandstone beds	550-1,000		Generally yields good supply of water; most supplies between 50-100 gpm
			Gasconade Dolomite	300±	Cherty limestone and dolomite; sandstone bed at bottom of formation	700-1,150		Yields small supplies of water
CAMBRIAN	Upper		Eminence and Potosi Dolomites	200±	Dolomite with drusy chert in lower 40 feet	1,000-1,450		Generally yields good supply of water, especially from lower portion, between 30-400 gpm
			Derby-Doerun, Davis and Bonneterre Formations undifferentiated	150±	Silty dolomites; some siltstones and shales	1,200-1,650		Yields small quantities of water
			Lamotte Sandstone	0-150	Quartzose sandstone	1,350-1,750		Yields very considerably. Formation may be absent over Precambrian highs
PRECAMBRIAN					Granites and rhyolites	1,350-1,850	Generally does not yield water	

Table 1. Generalized section of geologic formations in the Joplin area, Mo.

Oronogo-Duenweg mining belt was constructed during the 1930's by the Works Progress Administration to alleviate some of the mine flooding during periods of heavy rainfall. Many of these drainage ditches still function and carry large quantities of zinc-bearing waters to Center Creek during heavy rainfall.

Most of the basin outside the mining area is covered by woodlands and farmlands which help impede rapid runoff.

Although many of the features of karst topography, such as caves and springs are present, sinkholes are few. However, the cherty residual soils that have developed on the limestone are receptive to the infiltration of rain water and this is shown by the well-sustained flow of the streams during dry periods.

GEOLOGIC SETTING

The Spring River basin is principally an area of carbonate rocks which dip gently to the northwest and pass beneath the Pennsylvanian shales. In the vicinity of Joplin and Webb City mineralization of the rocks and subsequent mining have altered the water regimen by changing the recharge, distribution, and flow pattern of the ground water. Elsewhere in the basin the regimen is probably little changed.

STRATIGRAPHY

Important aquifers in the area occur in rocks of Cambrian, Ordovician, and Mississippian age. The surface geology of the basin is shown in figure 1. Limestone of Mississippian age is exposed in much of the area. Rocks of Pennsylvanian age crop out in the northwestern part of the area, and occur in many sinks and as outliers throughout the area. The Pennsylvanian rocks in contrast to those of Mississippian age have low yields of poor quality water.

A generalized section showing the order of the geologic formations and their hydrologic properties is given in table 1. The nomenclature used in this report is that of the Missouri Geological Survey and Water Resources and not necessarily that of the U.S. Geological Survey.

One of the important water-bearing units in the Mississippian section is the Elsey Formation. In this report the name "Elsey Formation" is used in preference to the name "Grand Falls Formation". As stated by Robertson (1966, p. 7), "The name 'Grand Falls chert' is restricted to a distinctive body of massive chert which crops out at and in the immediate vicinity of Grand Falls on Shoal Creek south of Joplin, Missouri. . . . .It is recommended that usage of the name 'Grand Falls' be discontinued except for this limited chert unit, and that the widespread, mappable, sedimentary unit which immediately overlies the Reeds Spring Formation and which has previously been referred to as the 'Grand Falls Formation' in southwestern Missouri be given the name 'Elsey Formation'."

The comparison of an unaltered geologic section of Mississippian rocks with one affected by solution and mineralization (fig. 4) shows the increase in porosity resulting from these processes. Because of hydrologic considerations, the aquifers have been grouped into two principal units: the Mississippian aquifer will be referred to as the shallow aquifer, and the Cambrian and Ordovician aquifers will be referred to collectively as deep aquifers. Deep and shallow aquifers are separated by the relatively impermeable Kinderhookian silty limestones and shale, which form a poor hydrologic connection between the aquifers, and by the Devonian-Chattanooga Shale, which is present only in the southern part of the area.

STRUCTURE

The Joplin area lies on the western edge of the Ozark uplift. The rock strata dip gently to the west and northwest at a somewhat steeper angle than the land surface. A structure contour map of the top of the Ordovician System showing the major structural features of the area is given in figure 5. The overlying Mississippian and Pennsylvanian formations generally reflect these structures on the surface. In the southern part of the area the streams generally flow in the direction of regional dip, but are locally controlled by fracture systems in the rock.

Rock fracturing not only affects the direction of flow of streams, but is of major importance in the movement of ground water. The courses which ground water first follows are determined by bedding-plane openings, lithologic variations, and tectonic features such as fractures, faults, and minor folds. In the mining area at Joplin, much of the rock fracturing and brecciation is a result of solution and collapse of limestone and chert beds; the effect on the availability and movement of water is considerable.

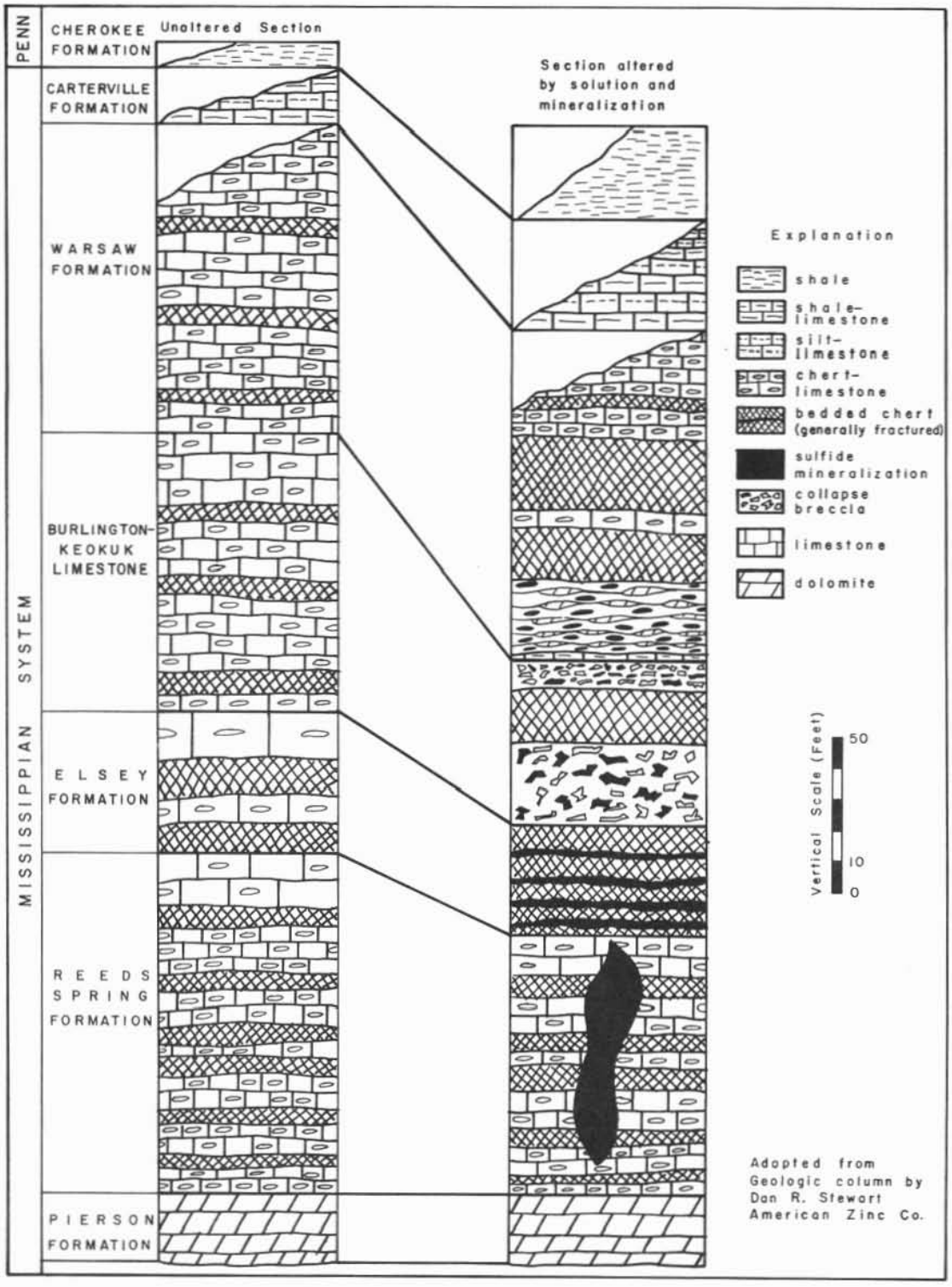


Figure 4. Comparison of an unaltered geologic section of Mississippian rocks with one affected by solution and mineralization, showing the difference in porosity.

Soon after the deposition of the cherty Mississippian limestone beds, the area was raised above sea level and solution of the limestone commenced. Except for a few periods of further deposition, solution has continued to the present. The removal of limestone by solution often left large underground openings with inadequate ceiling support. The overlying beds eventually collapsed giving rise to porous brecciated areas locally called broken ground or confused ground. Due to the relative insolubility of chert, it was left behind as the limestone was dissolved. The resulting breccia section is thinner than an undisturbed section, and contains a higher percentage of chert. (See fig. 4). According to D. R. Stewart (written communication, 1967) "Subsurface zones of solution breccia vary from very tight healed breccias to the extremely loose facies, known locally as 'hogchaw'. The tight breccias are those that are either cemented or healed with gangue minerals such as jasperoid and dolomite, plus those healed by the ore minerals themselves." Many of the breccia areas contain Pennsylvanian sediments which either settled out in these cavernous areas, or slumped in at a later date. Most of the Pennsylvanian outliers shown on geologic maps of the area occur in breccia areas.

Enlargement of openings by solution along bedding planes and fractures gave rise to caves, solution channels, lost rivers, sinkholes, and springs - the features characteristic of limestone terrane. However, sinkholes characteristic of typical karst topography are not prominent in the Joplin area or in the basin as a whole.

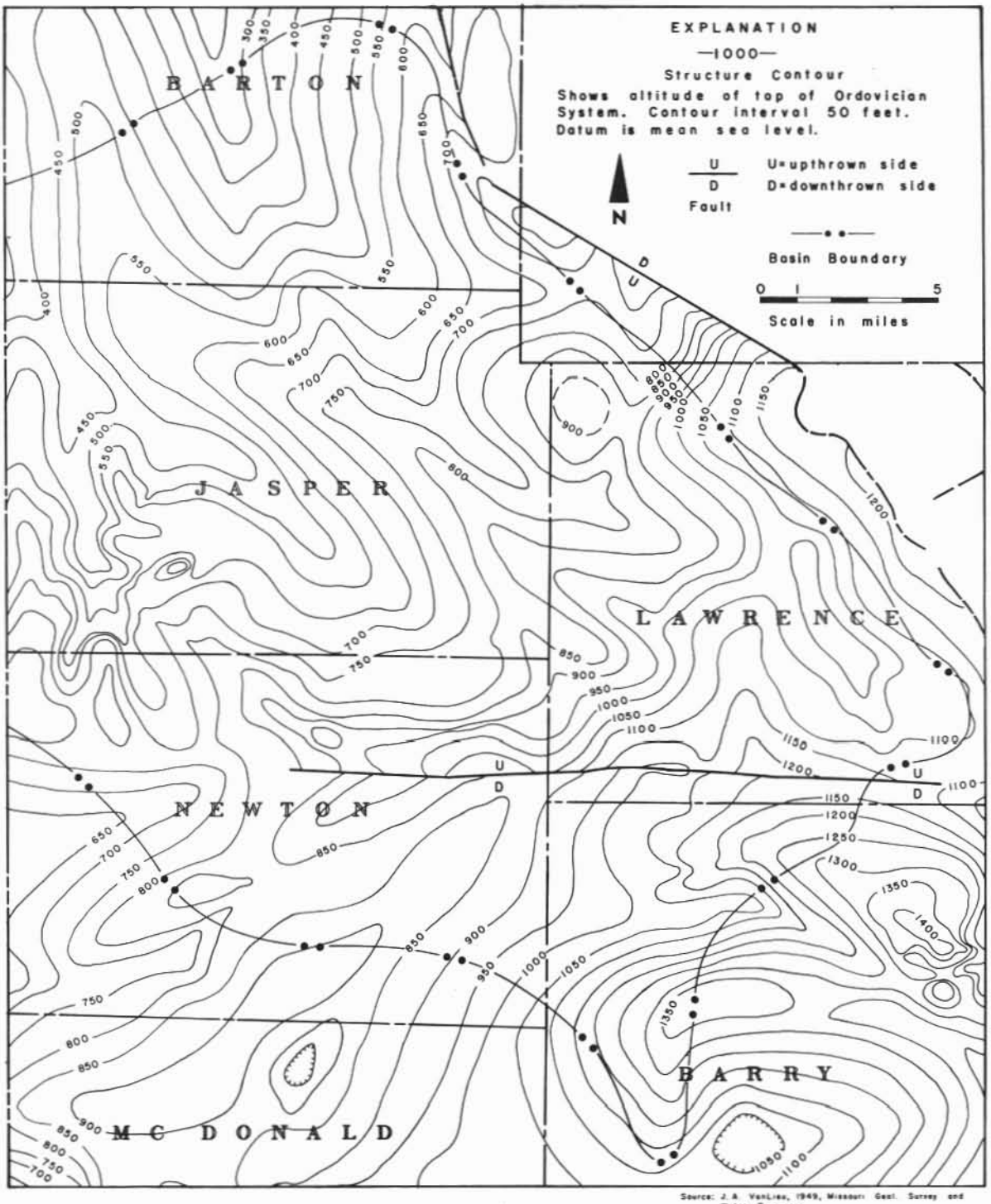
MINERALIZATION

Solutions deposited large quantities of minerals in the Mississippian limestones. Small amounts of mineralization may be encountered throughout the area, but only where lead and zinc minerals were sufficiently concentrated to justify exploitation were extensive mine workings developed. Sphalerite, galena, pyrite, marcasite, dolomite, calcite, chert, and jasperoid are the most common minerals found.

Passage of water through sulfide mineralized areas causes an increase in the dissolved-solids content of the water. This increase is principally in the calcium and sulfate contents and represents the final products of a complex series of chemical reactions between the minerals, country rock, and the water and its dissolved gases. These reactions also bring zinc and iron into solution; however, the amount of these metals remaining in solution is generally small.

Mineralization in the Joplin area is usually associated with solution features. The circle deposits are the result of mineralization of breccia in sinkholes. The runs, or watercourse deposits, occur as elongated veins. These are generally large solution channels with the minerals cementing and replacing collapse breccia fragments and filling voids. The sheet ground deposits occur in areas where limestone of the cherty Elsey Formation was dissolved leaving behind the relatively insoluble chert. The chert, broken by the weight of overlying sediments, became the host for the minerals deposited by ore-bearing solutions. Mineralized areas generally contain much water, except where mineralization has completely filled the openings in the rock. After the minerals were deposited, water table changes, erosion of the overlying beds, and possible regional uplifts caused the minerals to be exposed to oxidation and solution which further increased the porosity of mineralized areas. Solution of the minerals is continuing at present, and accounts in part for the unusually high zinc content in the water of many wells and streams in the area.

Geomorphic, tectonic, and climatic events of the past have greatly altered the rates and types of solution and mineralization that occurred in the area, so that some phenomena observed at present might not have occurred in the past and vice-versa. For example, water levels in the shallow aquifer stand higher at the present time than water levels in the deep aquifers. This head relationship of the deep and shallow aquifers would not allow mineral-bearing solutions to enter the shallow aquifer from below as they did when the minerals were deposited. Since the advent of mining, man has so changed the natural conditions of this area, that it is often impossible to determine which phenomena are man-made and which are natural.



Source: J. A. VanLiew, 1949, Missouri Geol. Survey and Water Resources

Figure 5. Structure contour map of the top of the Ordovician System showing the major structural features.

SOURCES OF WATER

Water supplies can be obtained from both surface and ground water sources in the Joplin area. Quality and quantity of water vary throughout the area, and using one source often affects another. An understanding of the relationship between the sources is essential to efficient development and utilization of the water supply.

GROUND WATER

CAMBRIAN AND ORDOVICIAN FORMATIONS -- THE DEEP AQUIFERS

Water from the deep aquifers is under artesian pressure and yields of individual wells vary considerably. The water has a fairly uniform dissolved-solids content and is a calcium-magnesium bicarbonate type. Many municipalities and industries obtain their water from these formations.

Hydrologic Characteristics

In the deep aquifers water is obtained from porous and fractured dolomite and limestone, and sandstone that comprises only a small percentage of the total thickness of the section. The depth at which these aquifers are reached is about 300 feet and they extend as deep as 1,800 feet. The principal areas of recharge of the deep aquifers are outside the Spring River basin. Local variations in precipitation do not directly affect the supplies available from the deep aquifers, and the supply available is relatively constant. Only major long-term changes in the climate of the recharge areas would affect the water supply available from the deep aquifers.

A secondary source of recharge to the deep aquifers is from the overlying shallow aquifer. All water-level measurements made in the area indicate that the piezometric surfaces of the deep aquifers are below that of the shallow aquifer. This relationship favors the downward seepage of water and, in areas where faults and fracture openings connect the aquifers, direct downward leakage of water from the shallow aquifer can occur. Where the aquifers are separated by the Northview Formation, the Chattanooga Shale, or both, these shales act as aquicludes permitting little water from the shallow aquifer to pass through.

Several deep wells in the Carthage-Webb City area have abnormally high Ca:Mg ratios or heavy metals contents. This may be a result of leakage along the well bore or more widespread direct recharge from the shallow aquifer. Elsewhere in the Joplin area the shallow aquifer is generally a minor source of replenishment, but can be a source of contamination, especially in the mining area. In the Joplin-Webb City area, casings in some abandoned deep wells are not plugged and the corroded casings allow mineralized waters to move down the wells into the deep aquifers.

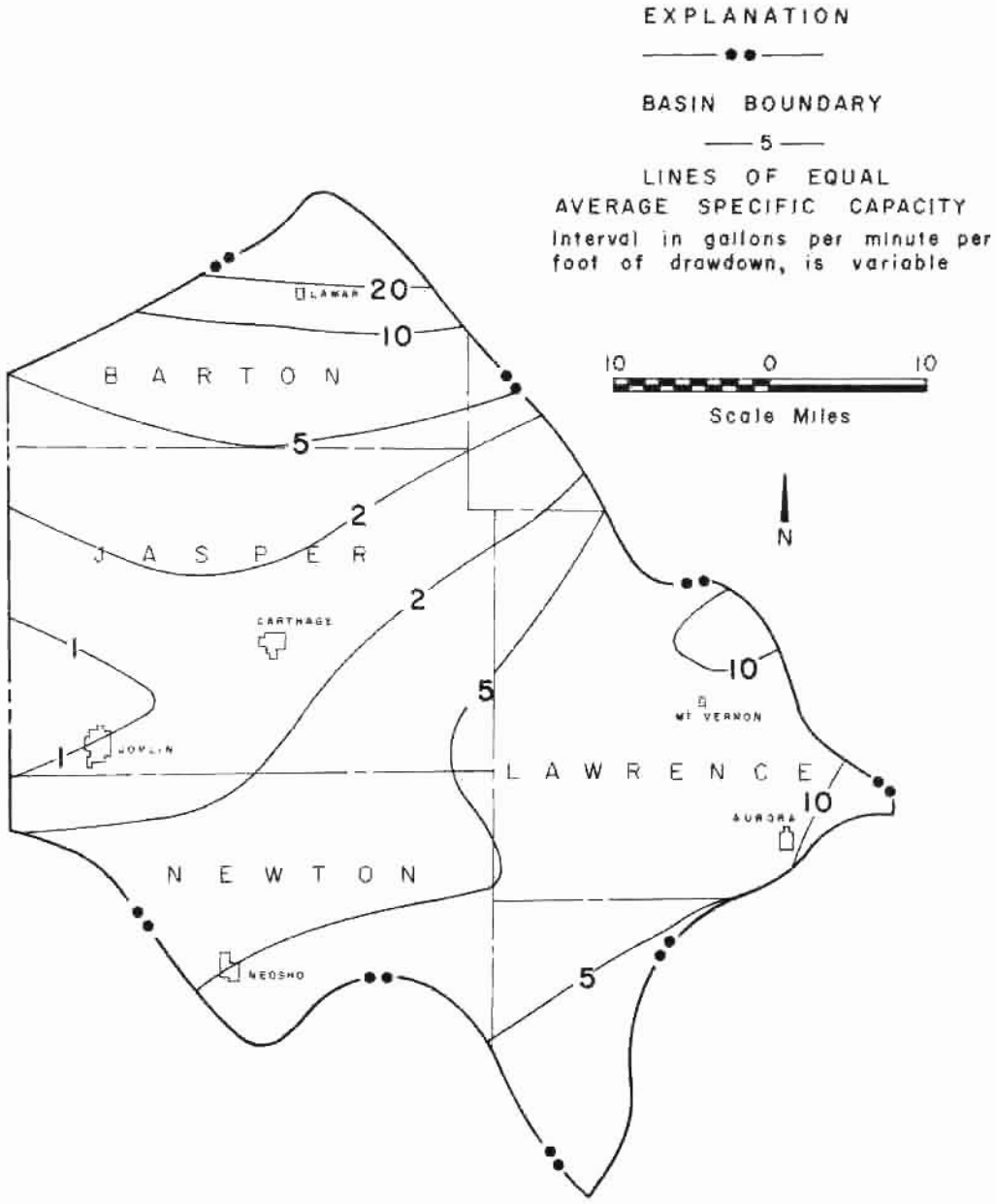
Discharge of water from the formations is by pumpage and by underflow to the west (see fig. 14).

Quantity Available

Yields of wells in the deep aquifers range from less than 50 gpm to more than 500 gpm, with most yields between 100 and 400 gpm. Specific capacities of wells in the vicinity of Joplin and Carl Junction generally range between 1 and 2 gpm per foot of drawdown. In the surrounding areas specific capacities between 5 and 15 gpm per foot of drawdown are common. Figure 6 shows the variation in specific capacity in the area. The yields obtained from selected municipal wells in the Joplin area, formations penetrated, and specific capacity are listed in Appendix I. It is generally found that acidizing a well increases production. Well yields after acidizing are also listed in Appendix I. The locations of wells listed in Appendix I are shown in plate 1.

Despite the extensive use of the deep aquifers by municipalities and industry, only a small part of the total available water supply is being used. At present much of the pumpage in the basin centers around Joplin. This is the area where differences between water levels in the shallow and deep aquifers are largest.

Water levels in the deep aquifers in the eastern part of the basin stand higher above sea level than they do in the western part. (See fig. 14). Groundwater movement is from east to west and discharge is west of the state line. In the eastern part water levels in the deep aquifers generally stand 50 to 100 feet below those of the shallow aquifer, except where water levels were measured in an existing drawdown



SOURCE: DALE FULLER, MISSOURI GEOL SURVEY AND WATER RESOURCES

Figure 6. Map showing general distribution of specific capacities of wells in the deep aquifers.

cone. Differences in the western part are as much as 180 feet.

Water level declines are moderate. At the Webb City well field a decline of about 46 feet has occurred since 1910. In other parts of the basin declines may be in the range of 50 to 100 feet in drawdown cones of well fields but much less than 50 feet elsewhere. In a well drilled to the Potosi Dolomite north of Duenweg, continuous water levels from an automatic recorder maintained by the Missouri Geological Survey and Water Resources show that there has been no decline since 1956.

A 24-hour interference test was made at the Webb City well field using four wells for observation. The pumped well (see plate 1, no. 234) and three of the observation wells were drilled to depths of 850 to 870 feet penetrating the Roubidoux Formation. The fourth observation well (drilled to 1,307 feet) reached the Eminence Dolomite. All wells were open in the Roubidoux Formation; casings were set and cemented below the Mississippian limestone. Distances from the pumped well to the observation wells ranged from 340 to 600 feet.

The specific capacity of the pumped well after 24 hours was 2 gpm per foot of drawdown. The transmissibility of the producing zone which was principally the Roubidoux Formation averaged 4,000 gallons per day per foot and the storage coefficient was 0.0002. However, plots of the water levels showed that physical conditions within the aquifer varied greatly so that the permeability of the aquifer in all directions from the pumped well is not uniform. The transmissibility and storage coefficient given above can be considered only as estimates of the magnitude of those parameters in the Webb City area.

The Webb City well field is within 1 mile of the Oronogo-Duenweg belt. Ore was mined in the Mississippian limestone above the deep aquifers and variations in physical character of the limestone are known to be great. Variations in permeability of the deep aquifers due to abrupt changes in physical characteristics such as jointing, faulting, cementation, and solution probably can be assumed. Variations in specific capacity shown in figure 6 indicate that the lowest yields can be expected in the vicinity of Joplin and better yields (on the average) elsewhere in the Spring River basin. If cementation by mineralizing solutions and tectonics are responsible for the low specific capacities of the deep aquifers in the vicinity of Joplin, these effects may not be important in the remainder of the basin

The results of the test were compared with a test made at the municipal well field at Pittsburg, Kans., about 30 miles northwest of Webb City (Stramel, 1957, p. 176). Plots of the data in that test showed more uniform conditions in the aquifer, transmissibility of 250,000 gallons per day per foot and specific capacity of 75 gpm per foot of drawdown. The ratio of transmissibility to specific capacity at Pittsburg compared with the specific capacity of the pumped well at Webb City gives a transmissibility of 6,700 gallons per day per foot. This is in the same magnitude as that estimated from the interference test.

Specific capacity is not only the measure of the performance of a well but is also a clue to the performance of the aquifer. If sufficient specific capacity measurements are available the areal variation can be portrayed as shown in figure 6. The map depicts an averaging of conditions. In limestone and dolomite aquifers large variations in specific capacity may occur in wells a few thousand feet apart. However, prediction of water level declines in multiple-well fields cannot be made on the basis of specific capacities alone, but they can help. The storage and flow characteristics of the aquifer measured by the transmissibility and storage coefficient allow the determination of interference effects in a well field. Water levels in wells too closely spaced will exhibit excessive drawdown due to the interference of other wells. This results in excessive electric power costs. Wells spaced at excessive distances require large capital expenditures for pipe line. Aquifer characteristics, electric power costs and capital expenditure must be evaluated in well field design.

For example, a well drilled into an aquifer with a transmissibility of 4,000 gallons per day per foot and a storage coefficient of 0.0002 and pumped at an average rate of 200 gpm for a year will cause a drawdown of 52 feet at a distance of 500 feet. At a distance of 1,000 feet the drawdown would be 44 feet. However, if the transmissibility were 10,000 and the storage coefficient 0.0005, the drawdowns would be 21 feet and 18 feet respectively. It is obvious that the extra lift and attendant power costs reflected in drawdowns caused by interference are important considerations in well field design. In lieu of transmissibility

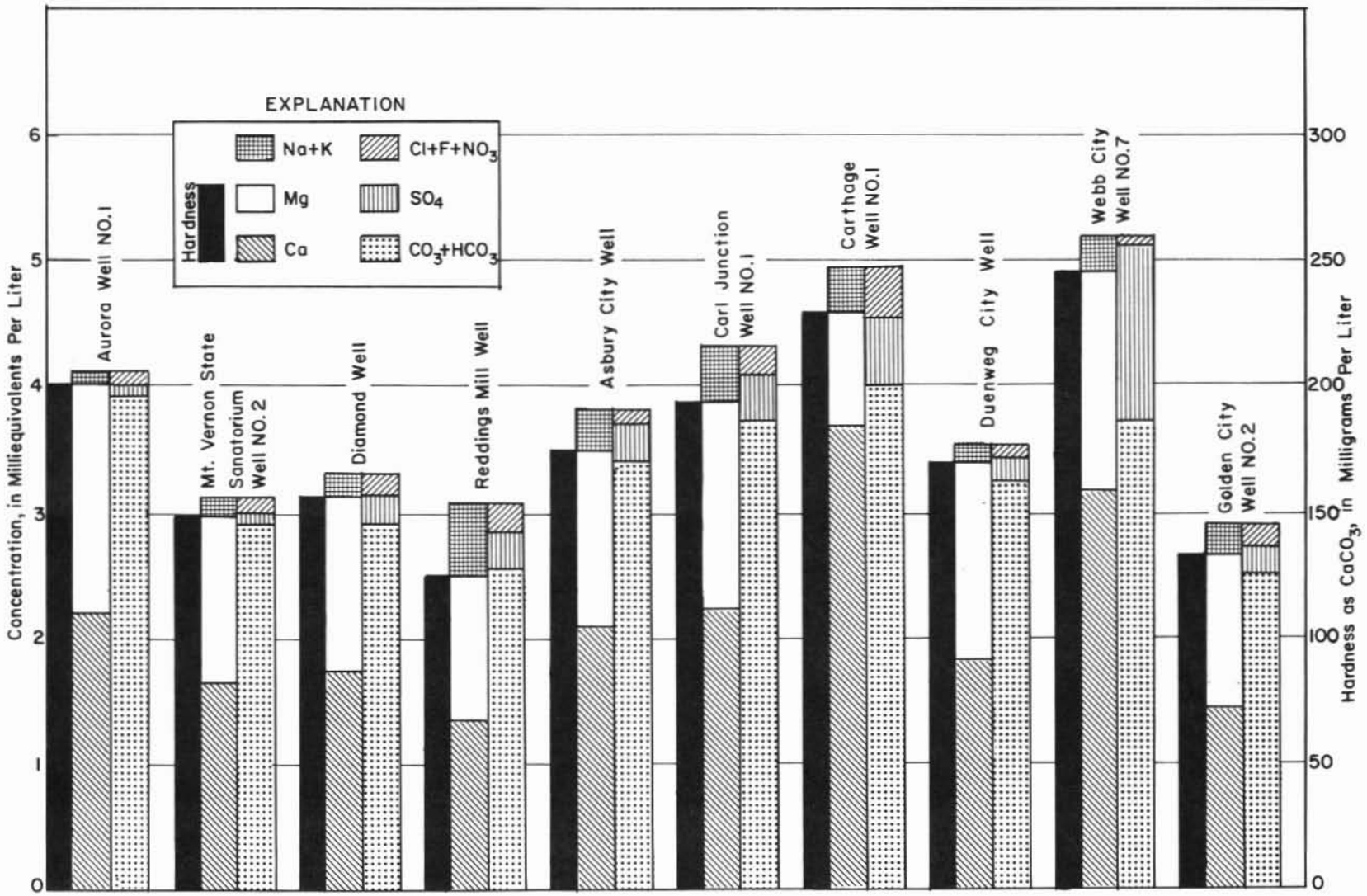


Figure 7. Bar diagrams showing variations in the chemical character of water from the deep aquifers.

values specific capacities are useful in design. Generally, where specific capacities are highest well spacing can be closer.

The general practice in the Joplin area, when drilling a deep well, is to case off the shallow formations and to leave the hole open below the casing. This allows mixing of water from all formations penetrated below the casing and makes it difficult to determine the relative yields of the formations. In general, the more formations penetrated the greater the supply of water. However, the maximum supply of water available from even the deepest wells is quite variable. A method for estimating the depth that a well must be drilled to penetrate the deep aquifer is given in Appendix II.

Further development of the deep aquifers will be most successful at locations away from present areas of heavy pumping and in areas where specific capacities are highest. Proper spacing of wells with adequate casings is essential to the most efficient development of this valuable water supply.

Quality of Water

The chemical quality of water in the deep aquifers is relatively uniform over the area. Calcium, magnesium, and bicarbonate are the predominant constituents dissolved in the water (fig. 7, table 2), reflecting the dolomitic character of these formations. Other constituents generally are present in small amounts, but in a few places sulfate is a significant part of the dissolved solids. Maximum values for sodium, chloride, and nitrate in table 2 are unusual and they are not representative of any area. Median values are typical for water in much of the area. The complete chemical analyses are listed in Appendix III and well locations are shown on plate 1.

The generalized distribution of the dissolved-solids content of water in the deep aquifers in southwestern Missouri is shown in figure 8. The area of lowest dissolved-solids content of water in the deep aquifers shown in figure 8 is anomalous because it is not in or near the outcrop and it is surrounded by water with a higher dissolved-solids content. Water in the shallow aquifer overlying the anomalous area has a higher dissolved-solids content than the water in the deep aquifers; hence, leakage through fractures or fault openings connecting the two aquifers cannot account for the lower dissolved-solids content of the water in the deep aquifers. The anomalous area generally coincides with the presence of the Northview Formation and the Chattanooga Shale which lie between the shallow and deep aquifers. It is possible that this anomalous condition is influenced in some way by the membrane properties of these shales. However, proof of this is beyond the scope of this report.

In the Spring River basin the dissolved-solids content of the water generally is lower in the southern part and increases to the northwest. Wells in deep aquifers are open below the shallow aquifer and the formations between the bottom of the casings and the bottom of the wells contribute water. The analysis for a well may represent water from one or several formations.

Water levels in the deep aquifers are lower than those in the overlying shallow aquifer and, where a direct connection between the two aquifer systems exists, the deep aquifers are recharged from the overlying shallow aquifer. The ratio of calcium to magnesium in water from Carthage Well No. 1 and Webb City Well No. 7 and the nitrate content of water from the Carthage well indicate that water from the overlying limestone is leaking into these wells. Spectrographic analyses (Appendix III) show that water from these two wells also contains more zinc than is found in water from other wells in these formations. Zinc is a common constituent of water in the Mississippian limestone.

Changes in chemical character that result from the leakage of water from the shallow aquifer are shown in figure 9. The upper diagram is for water from the shallow aquifer; the middle diagram represents the mixture of water from Carthage Well No. 1, and the bottom diagram is for water from the deep aquifer only. In the examples shown, note that the magnesium and nitrate contents are intermediate between those concentrations for water from the deep and shallow aquifers. Changes in the chemical character of water in deep aquifers where direct leakage from the shallow aquifer occurs would be similar to those shown, but the magnitude of changes would depend on the amount of leakage and the concentration of constituents in the water in the overlying aquifer.

Probably the best method for determining if direct leakage has occurred is to compare the ratio of calcium to magnesium. In deep aquifers, the ratio is

Data in milligrams per liter, except pH

Constituent	Maximum	Minimum	Median
Silica (SiO_2) --------	12	5.0	8.0
Iron (Fe) ----------	1.7	.00	.07
Calcium (Ca) ---------	74	25	40
Magnesium (Mg) -------	22	11	18
Sodium (Na + K) ------	30	1.6	5.4
Carbonate plus bicarbonate (CO_3+HCO_3)	257	120	206
Sulfate (SO_4) --------	68	3.7	13
Chloride (Cl) --------	22	1.7	5.2
Fluoride (F) ---------	.5	.1	.1
Nitrate (NO_3) --------	12	.0	.0
Dissolved Solids -----	290	140	227
Hardness as $CaCO_3$ ----	246	112	176
pH ----------	8.4	7.3	7.6

Table 2. Maximum, minimum, and median values of constituents dissolved in water from deep aquifers.

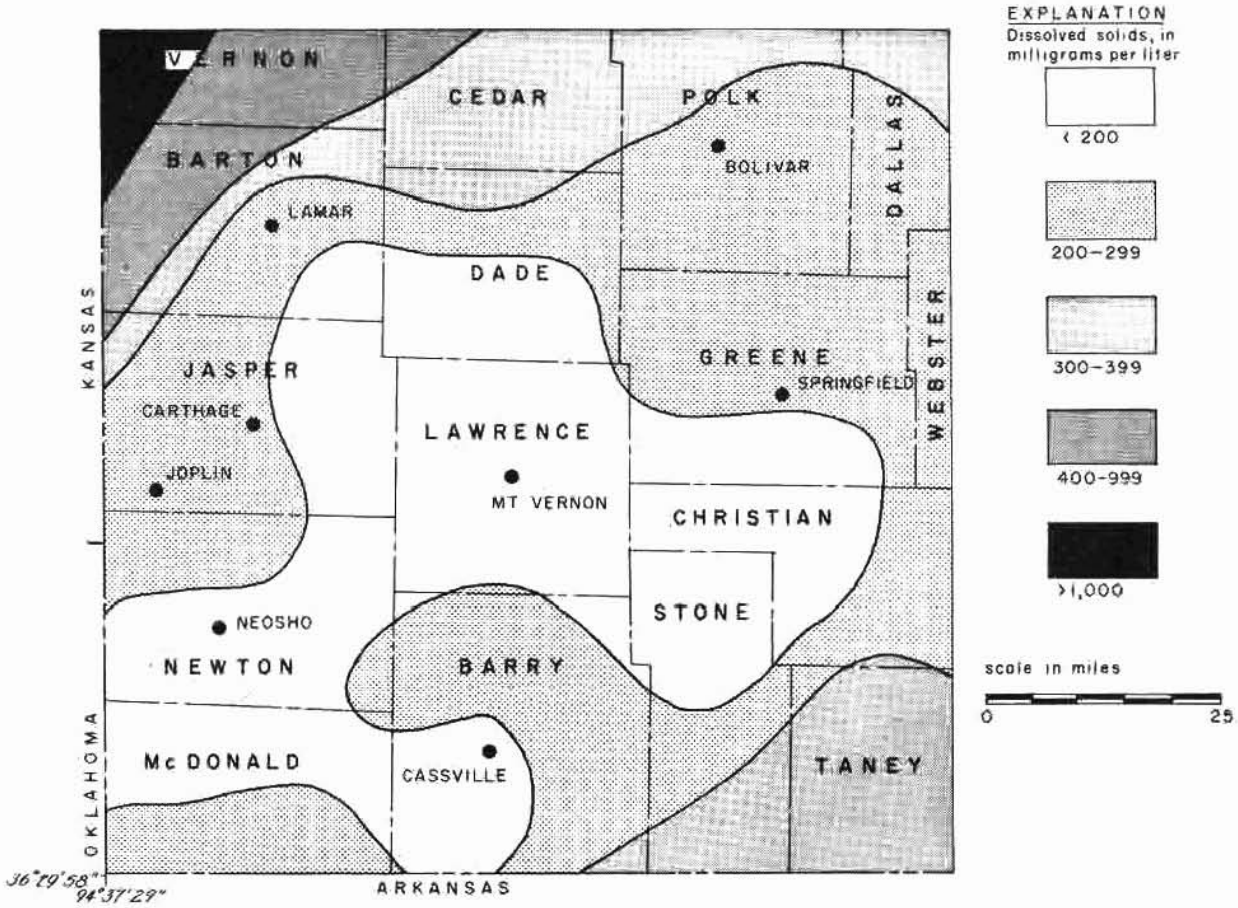


Figure 8. Map of southwest Missouri showing generalized dissolved-solids content of water in the deep aquifers.

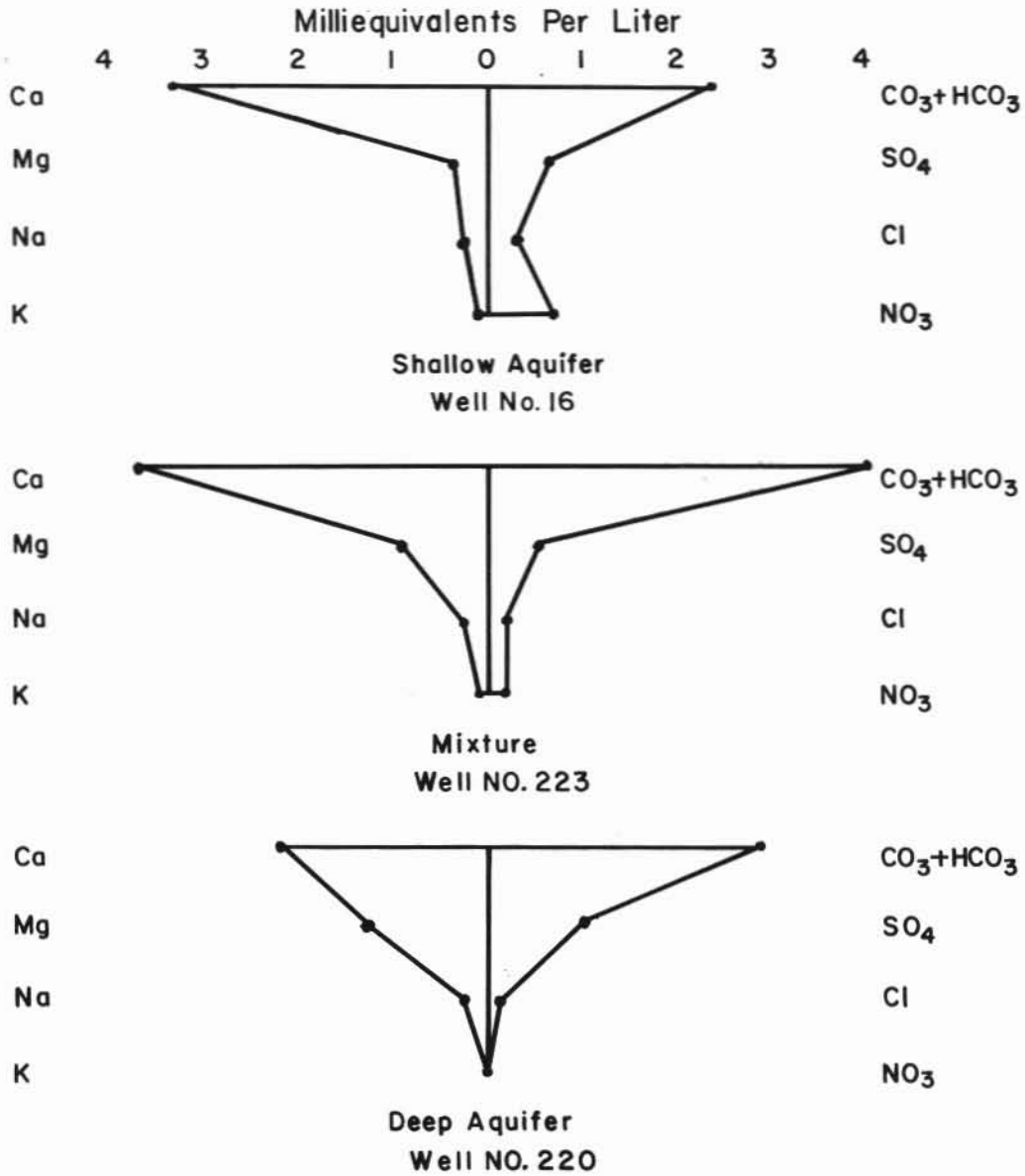


Figure 9. Diagrams showing chemical character of water from a well in the shallow aquifer, the deep aquifers, and a well containing a mixture of water from both sources.

Table 3. Source and significance of dissolved mineral constituents and properties of water

Constituent or property	Source or cause	Significance
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 mg/l. High concentrations, as much as 100 mg/l, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high-pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 mg/l of soluble iron in surface waters generally indicates acid wastes from mine drainage or other sources.	More than about 0.3 mg/l stains laundry and utensils reddish brown. Objectionalbe for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. USPHS (1962) drinking-water standards state that iron should not exceed 0.3 mg/l. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Manganese (Mn)	Dissolved from some rocks and soils. Not so common as iron. Large quantities often associated with high iron content and acid waters.	Same objectionable features as iron. Causes dark brown or black stain. USPHS (1962) drinking-water standards state that manganese should not exceed 0.05 mg/l.
Calcium (Ca) and magnesium (Mg)	Dissolved from practically all rocks and soils, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see Hardness). Waters low in calcium and magnesium desired in electroplating, tanning, and dyeing and in textile manufacturing.
Sodium (Na) and potassium (K).	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers, and a high sodium content may limit the use of water for irrigation.
Bicarbonate (HCO_3) and carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot-water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium they cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives a bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. USPHS (1962) drinking-water standards recommend that the sulfate content should not exceed 250 mg/l.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial wastes.	In large amounts in combination with sodium gives salty taste to water. In large quantities increases the corrosiveness of water. USPHS (1962) drinking-water standards recommend that the chloride content not exceed 250 mg/l.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth depending on the concentration of fluoride, the age of the child, the amount of water consumed, and the susceptibility of the individual. The maximum concentration of fluoride recommended by the USPHS (1962) varies with the annual average of maximum daily air temperatures and ranges downward from 1.7 mg/l for an average maximum daily temperature of 10.0° C to 0.8 mg/l for an average maximum daily temperature of 32.5°C. Optimum concentrations for these ranges are from 1.2 to 0.7 mg/l.

Table 3. Source and significance of dissolved mineral constituents and properties of water--Continued

Constituent or property	Source or cause	Significance
Nitrate (NO_3)	Decaying organic matter, legume plants, sewage, nitrate fertilizers and nitrates in soils.	Concentration much greater than the local average may suggest pollution. USPHS (1962) drinking-water standards suggest a limit of 45 mg/l. Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding. Nitrate has been shown to be helpful in reducing the intercrystaline cracking of boiler steel. It encourages the growth of algae and other organisms which may cause odor problems in water supplies.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils.	USPHS (1962) drinking-water standards recommend that the dissolved solids should not exceed 500 mg/l. However, 1,000 mg/l is permitted under certain circumstances. Waters containing more than 1,000 mg/l of dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most waters, nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Waters of hardness up to 60 mg/l are considered soft; 61-120 mg/l moderately hard; 121-180 mg/l hard; more than 180 mg/l very hard.
Specific conductance (micromhos at 25°C).	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. It varies with the concentrations and degree of ionization of the constituents, and with temperature.
Hydrogen-ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 denote increasing acidity. pH is a measure of the activity of hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline water may also attack metals.
Color	Yellow-to-brown color of some water usually is caused by organic matter extracted from leaves, roots, and other organic substances. Color in water also results from industrial wastes and sewage.	Water for domestic and some industrial uses should be free from perceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes.
Temperature	Climatic conditions, use of water as a cooling agent, industrial pollution.	Affects usefulness of water for many purposes. Most users desire water of uniformly low temperature. Seasonal fluctuations in temperature of surface waters are comparatively large depending on the volume of water.
Suspended sediment	Erosion of land and stream channels. Quantity and particle-size gradation affected by many factors such as form and intensity of precipitation, rate of runoff, stream channel and flow characteristics, vegetal cover, topography, type and characteristics of soils in drainage basin, agricultural practices, and some industrial and mining activities. Largest concentrations and loads occur during periods of storm runoff.	Sediment must generally be removed by flocculation and filtration before water is used by industry or municipalities. Sediment deposits reduce the storage capacity of reservoirs and lakes and clog navigable stream channels and harbors. Particle-size distribution is a factor controlling the density of deposited sediment and is considered in the design of filtration plants. Sediment data are of value in designing river-development projects, in the study of biological conditions and fish propagation, and in programs of soil conservation and watershed management.

[1]"Public Health Service Drinking Water Standards," revised 1962, apply to drinking water and water-supply systems used by carriers and others subject to Federal quarantine regulations.

about 10 parts calcium to 6.5 or more parts magnesium and in the shallow aquifer, the ratio is about 10 parts calcium to 2.0 or less parts magnesium. The ratio in a mixture would be somewhere between these two limits. Although the mixing of water from two aquifers might not be detrimental as far as chemical quality of the water is concerned, water in areas of direct leakage is susceptible to contamination because water in the shallow aquifer is subject to rapid contamination from surface sources.

Water from the deep aquifers is of a good chemical quality and is suitable for most uses. The hardness of the water in some areas is undesirable for domestic and municipal use and softening would be beneficial. The source and significance of the major constituents and properties of water are shown in table 3.

MISSISSIPPIAN FORMATIONS — — THE SHALLOW AQUIFER

The quantity of water available in the Mississippian formations is highly variable and its quality is generally poorer than that in the deep aquifers. Most wells in the shallow aquifer were drilled for domestic water supply. Large quantities of poor quality water are available for industrial use from abandoned mines penetrating the shallow aquifer. All of the springs in the area issue from the shallow aquifer, many of which are perennial and yield supplies of good quality water. Springs are presently being used by homes, farms, industries, and fish hatcheries.

Hydrologic Characteristics

The shallow aquifer consists of about 300 feet of limestone and chert. Solution and collapse of the limestones, and mineralization have resulted in large variations in the permeability of the shallow aquifer. Highly permeable breccia areas may yield up to several hundred gallons per minute. Undisturbed areas of dense limestone, locally called limestone bars, surround the brecciated areas and generally have low yields. Mineralized breccia areas generally have high permeabilities, but the groundwater inflow to these areas is controlled by the permeability of the surrounding limestone bars. Figure 10, which is adapted from a series of maps (Mo. Geol. Survey and Water Resources, 1942) shows the distribution of breccia areas in the vicinity of Joplin.

Breccia areas which contain mines are locally called pools. The pools contain large amounts of water stored in abandoned mine workings and the surrounding breccia area. Where mine workings connect adjacent breccia areas, a single large pool is formed. During past mining periods there was often 200 feet of head difference between adjacent pools immediately after dewatering one of them, because of poor interconnections. However, the effects of dewatering a pool slowly extends to surrounding pools, especially during dry seasons. An example of the effect can be shown in the recent dewatering of the Hyde Park mine (Pool No. 6 in fig. 11). Shortly after the pumps were turned on in the summer of 1965, the mine hydrographs (fig. 12) showed the effect on the Nowata shaft (Pool No. 5) 1½ miles to the northwest; even the McGregor mine shaft (Pool No. 4) 3 miles away, is affected by the dewatering.

A well drilled in a breccia area can yield 50 to 100 gpm or more, while a few hundred feet away (outside the breccia area) well yields may be 15 gpm or less. Due to the scarcity of outcrops and the thick residuum in the area, breccia areas are difficult to locate outside mining areas. The series of maps showing mineralized areas (breccia) in the vicinity of Joplin (Mo. Geol. Survey and Water Resources, 1942) can be used to locate such areas. These maps are based on many thousands of drill-hole records, outcrop studies, and mine examinations. Undoubtedly breccia areas exist outside the area covered by the maps and figure 10. Resistivity surveys in portions of the area indicate its possible use as a tool to locate such areas. The water saturation in these areas produces anomalously low resistivity readings.

The shallow aquifer acts as both a confined and water-table aquifer as shown in the schematic cross-section in figure 13. In this report no distinction is made between the piezometric surface and the water table of the shallow aquifer; both are referred to as the water table. When drilling in breccia areas, water may be reached at the water table (Well No. 1). In other areas water may first be tapped several hundred feet below the water table and will rise in the well to a level corresponding with the water table (Well No. 2.) Where the aquifer is confined, a well which is drilled below the level of the water table and does not penetrate the confined aquifer will generally be dry (Well No. 3). In areas where the land surface is below the water table, wells and abandoned mine shafts penetrating the confined aquifer will flow

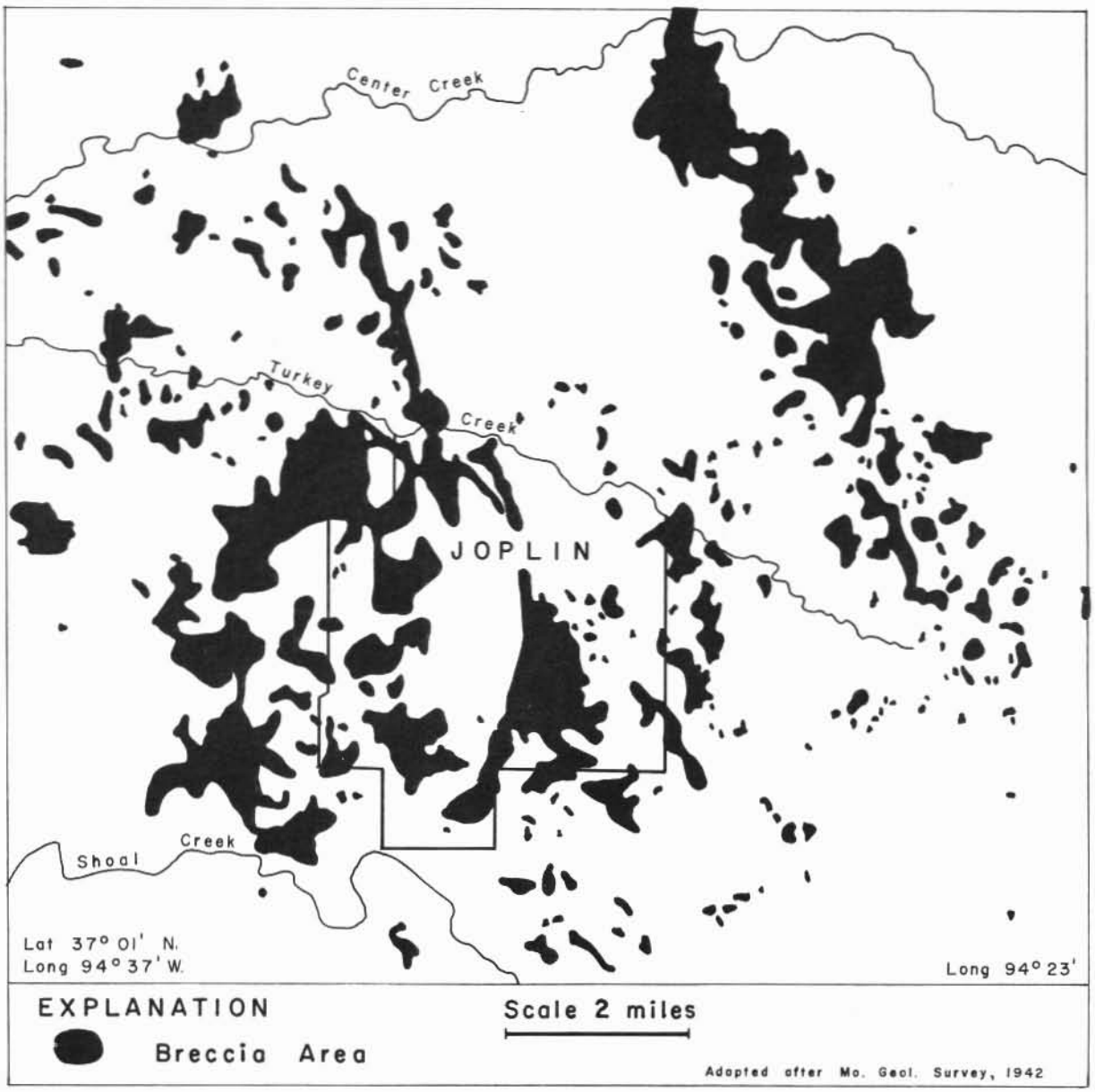


Figure 10. Map showing distribution of breccia areas in the vicinity of Joplin.

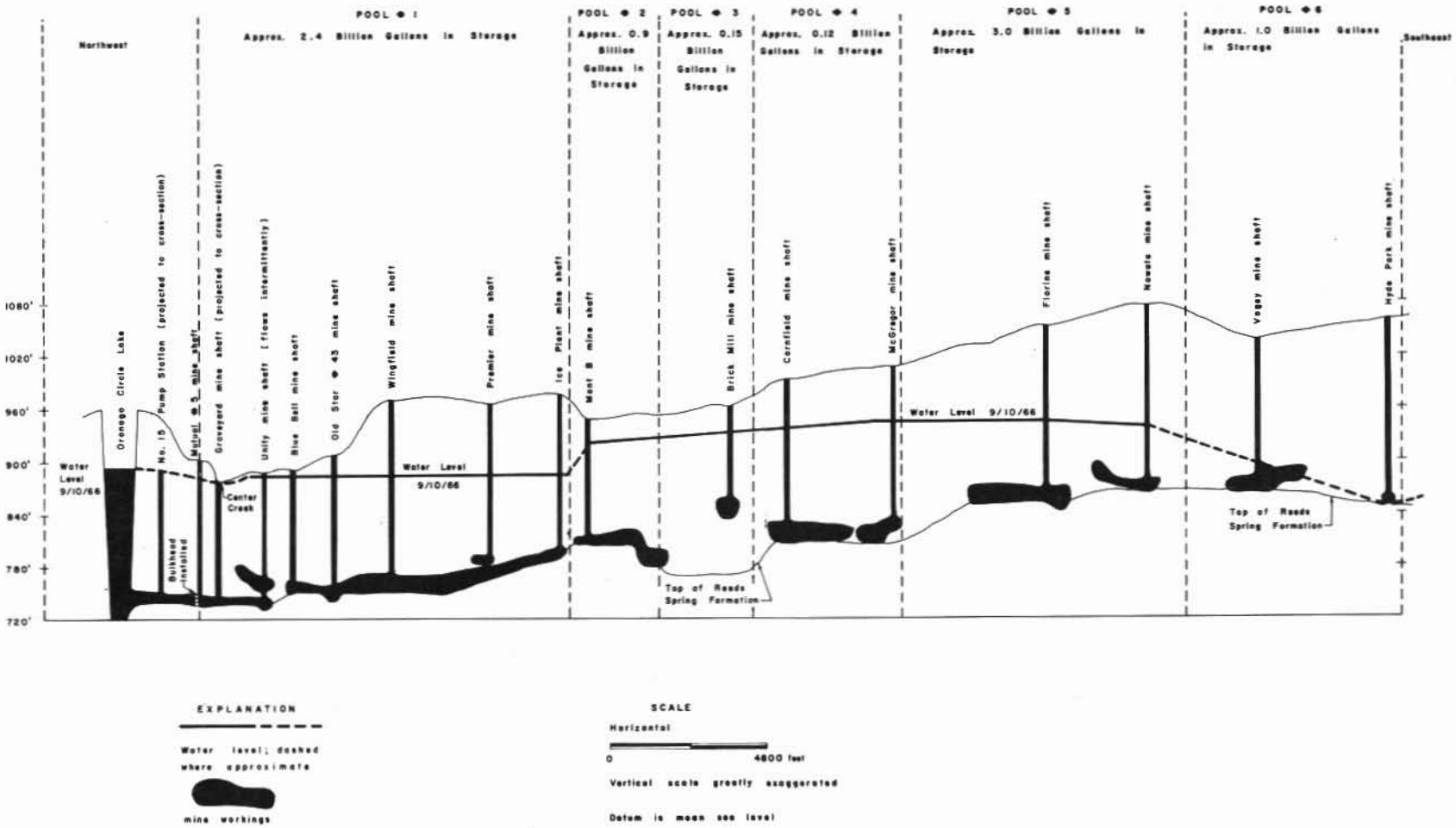


Figure 11. Diagrammatic cross-section of the Oronogo-Duenweg mining belt from the Hyde Park mine shaft to Oronogo Circle Lake showing mine-workings, Pools, and the water table of the shallow aquifer on Sept. 10, 1966.

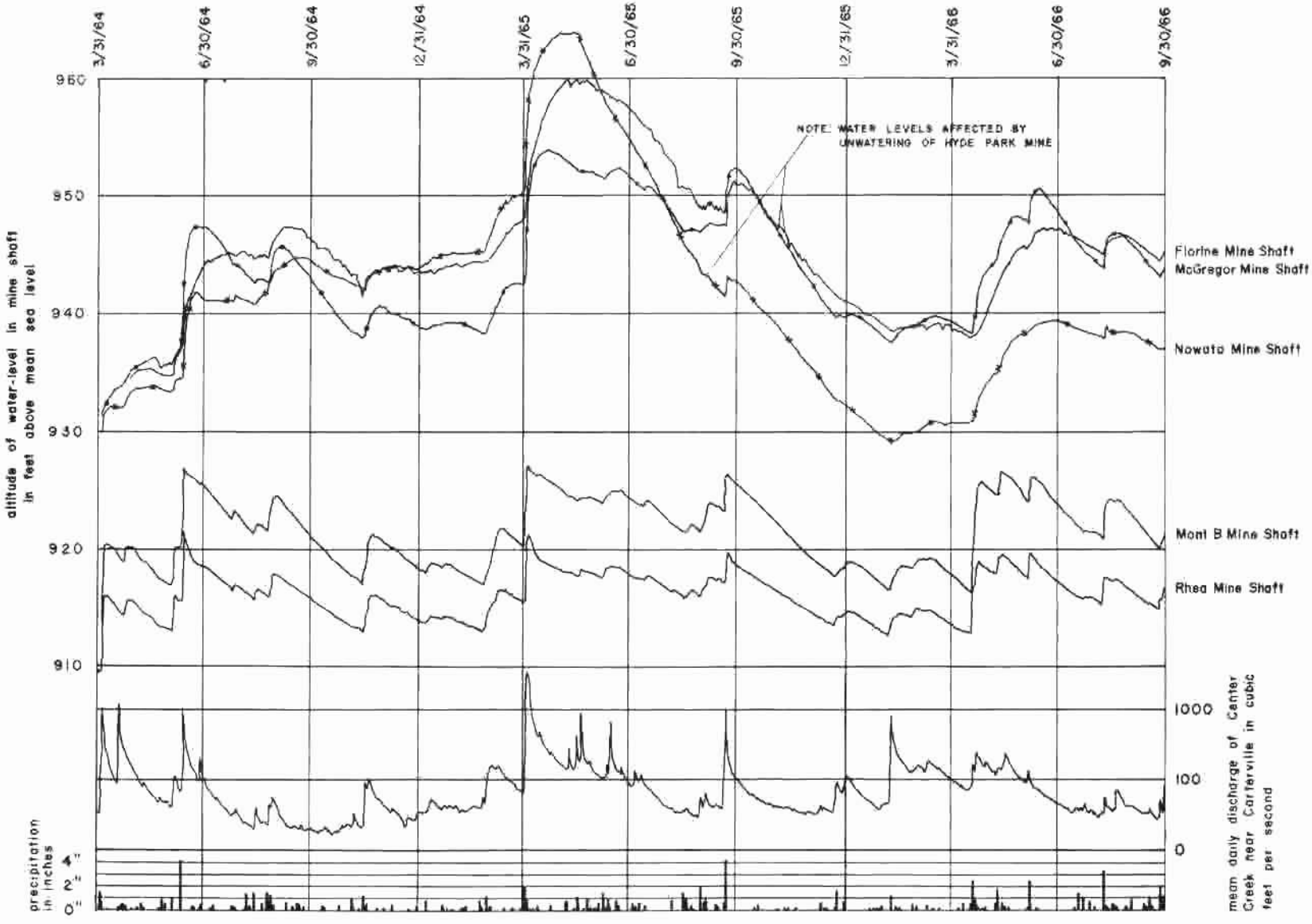


Figure 12. Hydrographs of mine water-level fluctuations, streamflow in Center Creek near Carterville, Mo., and the daily precipitation at the Joplin, Mo. airport.

(Well No. 4). Flowing mine shafts and test holes can be mistaken for springs because watercress, usually associated with springs, is often present.

Water in the shallow aquifer is recharged rapidly by local precipitation, which moves through solutionally enlarged fractures and bedding-plane openings toward stream valleys where it is discharged through seeps and springs. Springs which contribute most of the base flow to the streams are more numerous and have larger flows in the southeastern portion of the area, farthest removed from the Pennsylvanian outcrop, where solution has advanced further in the exposed older rocks.

The water table map of the area, figure 14, shows the slope of the water table in the aquifer and the direction of movement of the water toward the streams. Regionally the water table slopes to the west similar to the slope of the piezometric surface of the deep aquifers. Heavy pumping in the area north of Duenweg has formed a cone of depression and has altered the normal groundwater flow pattern, causing water to flow into the cone to replace water that has been pumped.

Hydrographs of mine water level fluctuations, streamflow in Center Creek near Carterville, Mo., and the daily precipitation at the Joplin airport (fig. 12), show how rapidly the shallow aquifer is recharged by local precipitation in the mining area and the decline of the water table during dry periods as the water discharges to Center Creek. Figure 15 shows the effects of a single storm on the water level in the Mont B mine shaft and the streamflow of Center Creek near Carterville, Mo. Figure 16 depicts the yearly departure from mean annual precipitation at Joplin from 1930 to 1966 and the variability of rainfall in the area. During wet periods, such as the period from 1941 to 1945, groundwater levels remain high and water users can safely maintain greater pumping rates in the aquifer. During dry periods, such as 1952 to 1956, groundwater levels are unusually low and the sustained yield of the aquifer is reduced. For dewatering operations, greater pumping capacity would be needed for wet periods than for dry periods.

After an extended drought a return to the normal rainfall pattern will quickly raise groundwater levels. Unless the shallow aquifer is replenished periodically by precipitation, the streams in the area will go dry. However, the Joplin area has never experienced a drought severe enough to dry up its streams, though stream-flow has been sharply reduced during a few recent drought periods. Greatly increased pumpage from the shallow aquifer would reduce natural groundwater discharge to streams.

Quantity Available

Wells and Springs. – – The shallow aquifer discharges an average of approximately 300 cfs (135,000 gpm) to the streams of the area. However, the amount of water available from a single well is generally small by comparison. Wet periods and droughts increase and decrease well yields to a slight extent, but the variation is less than the change in flow of streams. Well yields of more than 100 gpm are rare in the shallow aquifer, but many springs in the area issuing from the shallow aquifer yield 100 to 500 gpm or more. Because springs in the area yield as much as 9,000 gpm, wells drilled to intersect spring drainage systems can have larger yields than any presently developed.

The several formations (table 1) which comprise the shallow aquifer have different water yielding characteristics. Wells in the Reeds Spring Formation and the Elsey Formation yield small supplies which are adequate for farms and homes. The Elsey Formation rarely yields over 50 gpm, except where it is highly fractured. Where fractured and mineralized, the Elsey Formation is locally called sheetground and may yield up to 300 gpm of fair to poor quality water. The overlying Burlington-Keokuk Formation is generally a poor water producer, except in breccia areas where it usually yields 25 to 100 gpm, and as high as 300 gpm.

Isolated solution channels carrying large quantities of water may be penetrated outside the breccia areas. The most favorable sites for finding solution channels are near springs in areas that contribute large quantities of ground water to stream base-flow. Geophysical methods and test drilling may be used to reveal the existence of solution channels.

Most of the springs in the area issue from the Elsey and Reeds Spring Formations. These springs generally occur along outcrops in stream valleys, and flow from bedding planes and joints enlarged by solution. The magnitude of these springs varies from small intermittent springs to large springs yielding more than 20 cfs (9,000 gpm). Flows of all springs fluctuate during the year, but some springs vary less

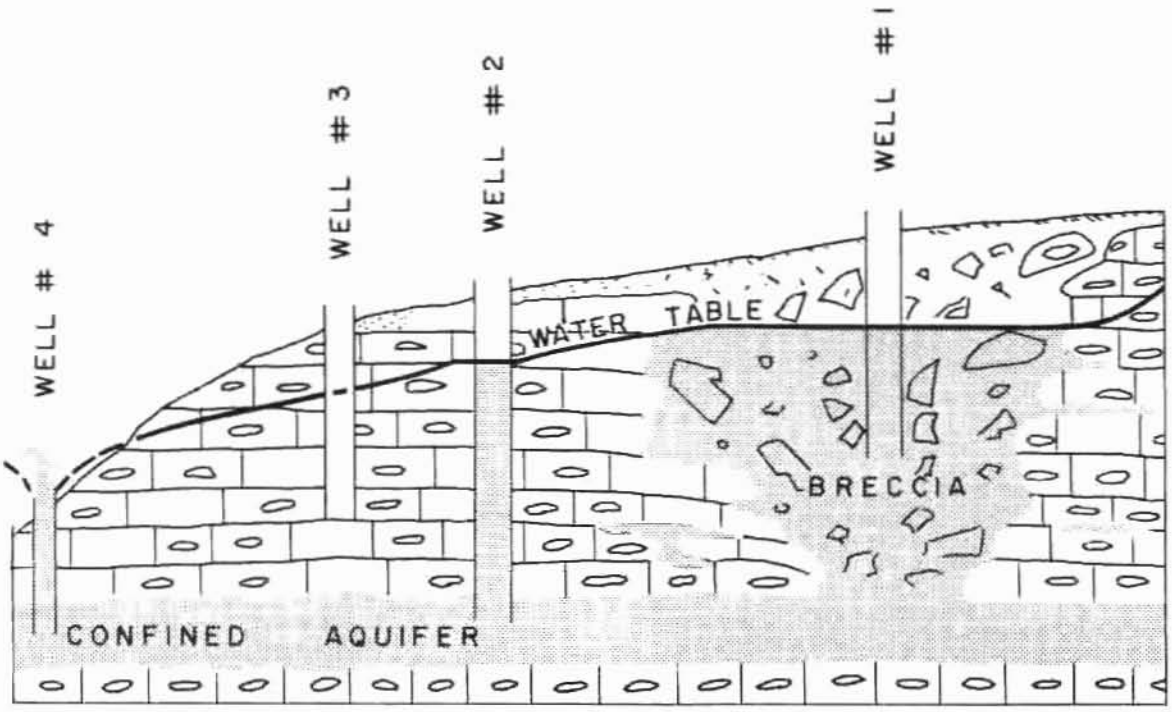


Figure 13. Schematic cross-section of a part of the shallow aquifer showing the occurrence of both artesian and water table conditions.

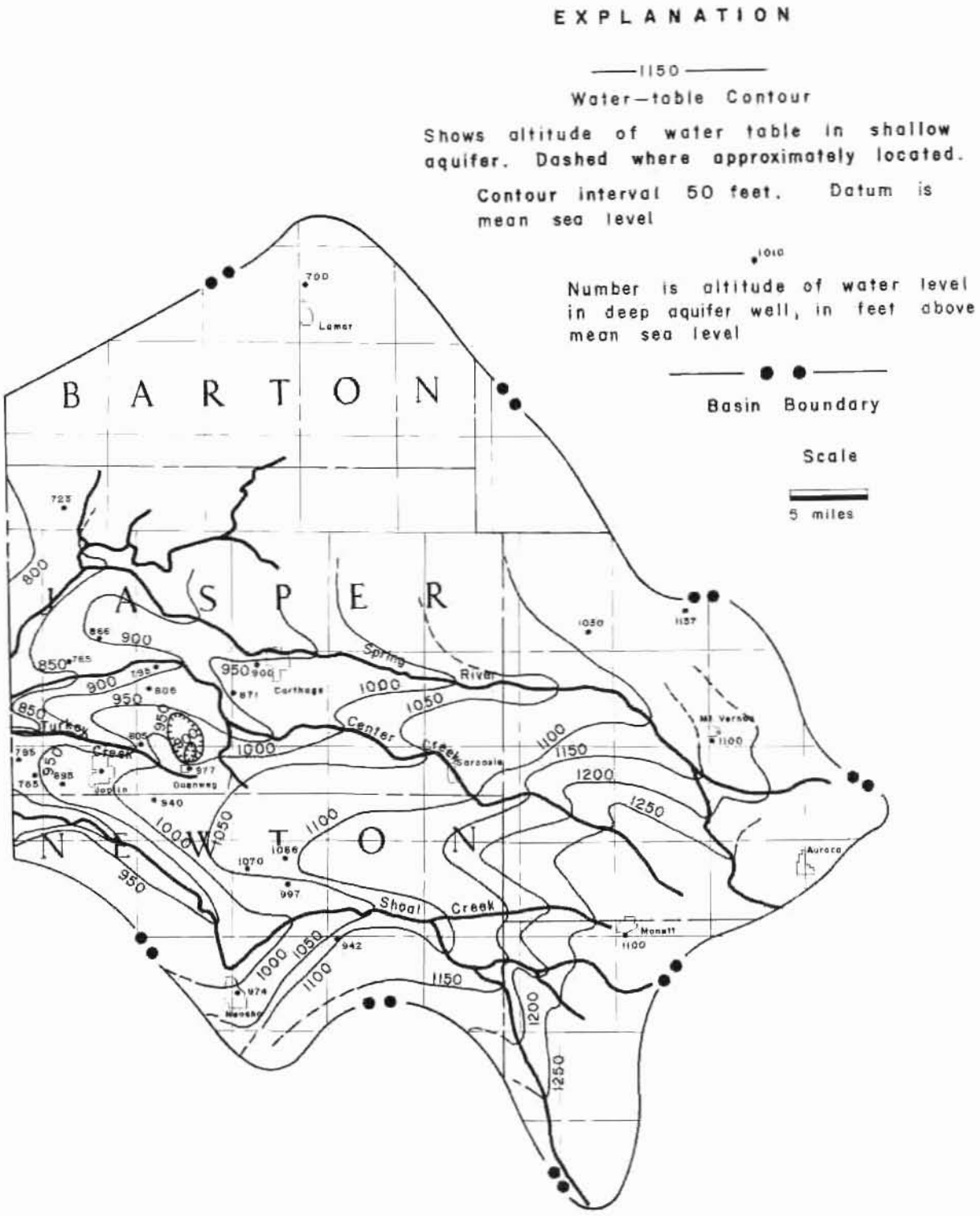


Figure 14. Water table map of the shallow aquifer for June 1966, with altitudes of water levels in selected deep wells.

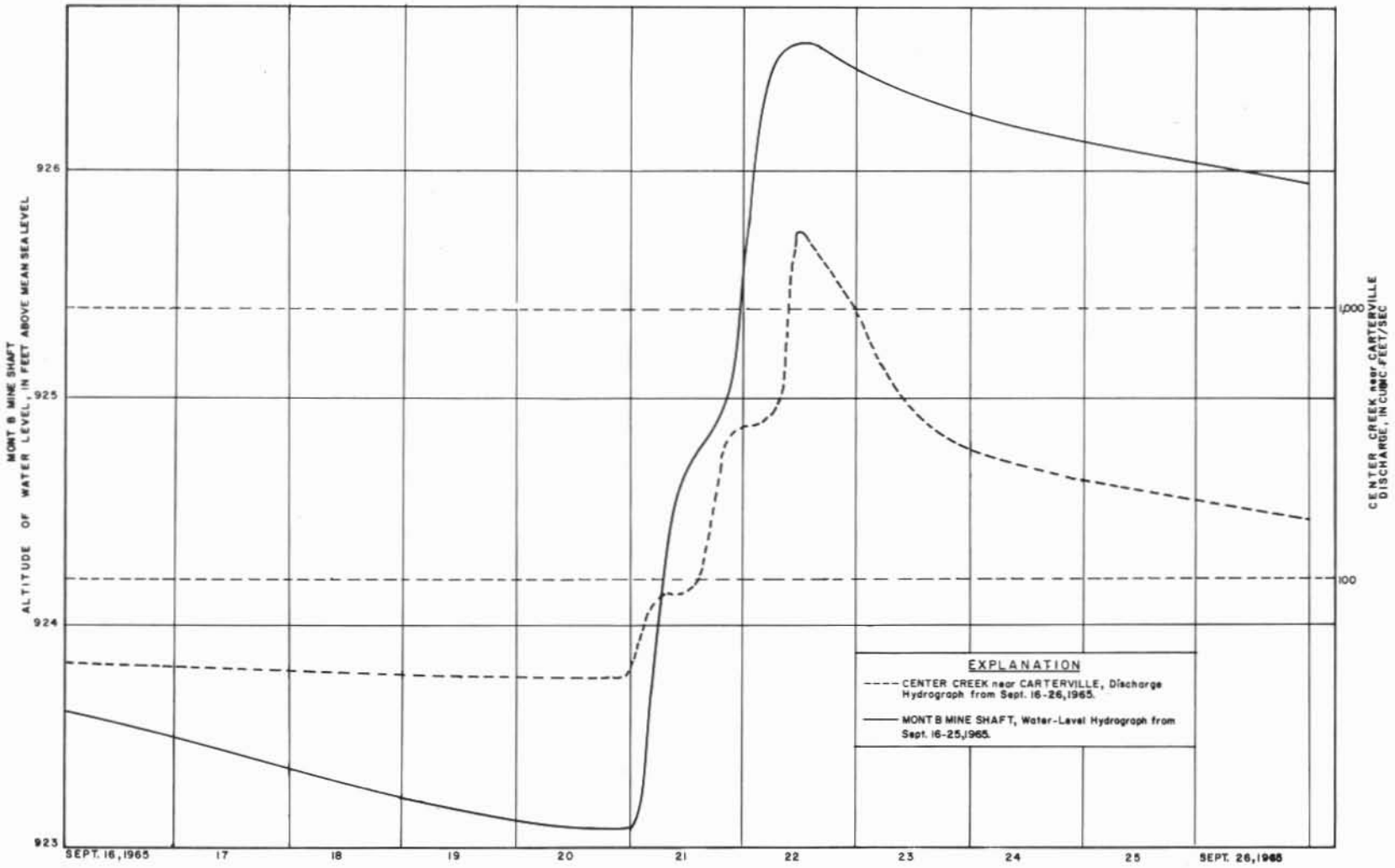


Figure 15. Hydrographs showing detailed effects of a single storm event on the water level in the Mont B mine shaft and the flow of Center Creek near Carterville, Mo.

than others. Springs with direct connections to surface drainage and little storage capacity show a sharp rise and fall in discharge following a heavy rain. The measured discharges given with the chemical analyses of water from springs in Appendix III indicate that where several measurements are available for a single spring the flow varies seasonally.

Mines.— — Large quantities of water are available from abandoned mines in the area. As much as 1,000 gpm have been pumped from individual mines over extended periods, and as little as 40 gpm from others. Pumpage and use of mine water in and around Joplin are shown in table 4. Supplies available from any one mine or group of mines are quite variable; factors controlling availability are:

1) Extent of mine workings
2) Permeability and location of surrounding limestone bars
3) Permeability of the ground overlying the mine
4) Extent of tailings piles in the vicinity of the mine
5) Surface drainage around the mine
6) Amount of local precipitation
7) Proximity to other pumping

Because of these factors an extensive mine may have a large amount of water in storage, but its inflow or sustained yield may be lower than a much smaller mine. A seepage run made on Center Creek during the low-flow season indicates that the Oronogo-Duenweg mining belt contributes a minimum of about 1,500 gpm to the stream by natural discharge. This is in addition to approximately 2,000 gpm being pumped from the mines. During past mining periods an average of about 13,000 gpm was pumped from the field to keep it unwatered. This is probably the most water that could be pumped from the field continuously, and may include a large quantity of recirculated water. Wet and dry periods would alter this figure temporarily. When determining the potential yield of a mine, consideration should be given to the departure from normal precipitation preceding and during the pump test or unwatering period.

To determine the seasonal variability in yield of a mine with continuous flow, a weir was placed on the outflow channel of the Anderson and Crackerjack mines (T. 28, R. 33, sec. 33). A staff gage was installed on a lake, with very little surface drainage area, formed by a mine cave-in about 1,000 feet south of the shaft. The water level in the lake coincided with the water table. Periodic readings were taken of the gage and the weir over a period of 6 months. The flow from the shaft ranged from 150 to 450 gpm, with lake levels directly related to flow. During heavy rainfall the water level in the lake rose and the flow from the shaft increased rapidly; soon after the rain, however, both receded at a gradually diminishing rate. The results of this study and a similar study of fluctuations of mine shaft water levels and seepage to Center Creek in the Oronogo-Duenweg mining field indicate that in developing a water supply from a mine an optimum pumping rate would be one that provided for a compromise between maximum water storage for dry periods and maximum available storage for wet periods to minimize outflow.

Quality of Water

Water from limestone of Mississippian age generally has moderate dissolved-solids content and is a calcium bicarbonate type, but the chemical character and dissolved-solids content of the water vary with the source. Water is available from three sources: springs, wells, and mines. Chemical analyses, tabulated by sources, are presented in Appendix III, and they are summarized in table 5. The data in table 5 show that, for many of the constituents, there is considerable overlap between the maximum values for one source and the minimum values for another source. Spring water generally contains less dissolved solids and is more uniform in chemical character than well or mine water because of freer circulation. Well water is intermediate between spring and mine water, while mine water is more variable in both chemical character and dissolved-solids content than that from either springs or wells.

The principal factors that cause departures from the natural calcium bicarbonate type of water are contact of the water with sulfide mineral deposits, and contamination of the water from surface sources. The influence of these factors can be recognized by a high sulfate or nitrate content. A comparison of the maximum and minimum values in table 5 shows that increases in dissolved solids result principally from increases in calcium, sulfate, and nitrate. Maximum values for sodium and chloride in water from wells are unusual and sources of these constituents are not

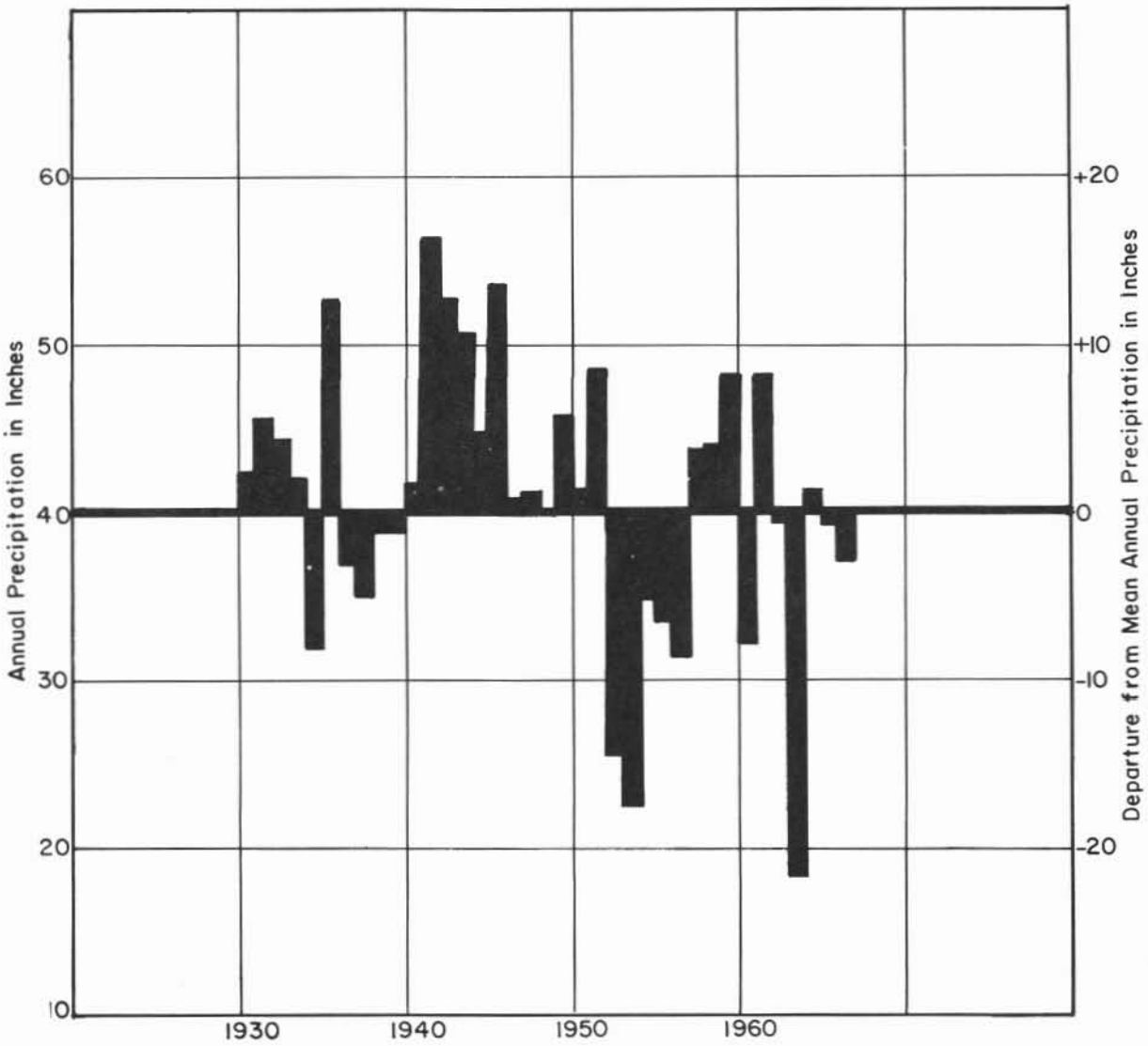


Figure 16. Graph showing yearly departure from mean annual precipitation at Joplin, Mo. from 1930-66.

Map No.	Name of Mine	Owner	Pumping Rate, gpm	Use	Remarks
114	Vogey ----------	Independent Gravel Co.	900	Gravel washing	Measured 7/19/65. Intermittent pumping.
113	Hyde Park ----------	P. Childress	750	Mine unwatering	Measured 7/19/65. Rate varies during wet and dry periods
102-103	King William - St. Regis	Davison Chemical Co.	500[r]	Cooling	Intermittent pumping
118	Anderson and Crackerjack	L. McDonald	500[r]	Gravel washing	Flows 150-450 gpm when not pumping Intermittent pumping
106	Ice Plant ----------	Independent Gravel Co.	800[r]	Gravel washing	Intermittent pumping
100	Athletic ----------	Atlas Chemical Co.	800[r]	Cooling	Intermittent pumping
105	Kramer ----------	Farmers Chemical Co.	100[r]	Cooling	Intermittent pumping
111	George H ----------	Dr. B. F. Graves	1,500[r]	Hydraulic mining	Intermittent pumping
34		A. Collard	200[r]	Irrigation	Seasonal pumping

[r] Reported

Table 4. Pumpage and use of mine water in the Joplin area, Mo.

Data in milligrams per liter, except conductance, pH, color

Constituent	Springs			Wells			Mines		
	Max.	Min.	Median	Max.	Min.	Median	Max.	Min.	Median
Silica (SiO_2)	27	5.0	9.8	22	7.2	9.0	26	2.5	10
Iron (Fe)	.77	.00	.02	2.4	.00	.24	33	.00	.18
Manganese (Mn)	.1	.00	.00	.2	.00	.00	5.4	.00	.3
Zinc (Zn)	--	--	--	6.7	.05	.9	35	.2	7.7
Calcium (Ca)	147	31	55	221	33	80	557	94	266
Magnesium (Mg)	7.3	.4	2.4	36	.5	6.8	31	3.3	11
Sodium (Na)	10	1.1	4.3	106	3.0	7.6	81	4.4	10
Potassium (K)	1.8	.2	.9	43	.4	1.4	12	.7	2.0
Carbonate plus bicarbonate (CO_3+HCO_3)	253	90	158	339	72	225	277	12	181
Sulfate (SO_4)	192	1.2	6.6	446	1.6	43	1,350	104	592
Chloride (Cl)	13	2.9	6.2	130	.2	4.1	13	2.0	6.2
Fluoride (F)	.2	.0	.0	.8	.0	.2	3.9	.0	.6
Nitrate (NO_3)	18	1.1	9.3	277	.0	4.2	11	.0	.4
Dissolved Solids	520	123	186	981	162	288	2,200	329	1,080
Hardness as $CaCO_3$	397	92	148	597	138	231	1,440	248	749
Specific conductance (micromhos at 25° C)	741	201	301	1,390	285	470	2,200	514	1,260
pH	8.3	7.0	7.5	8.3	6.1	7.9	8.0	5.6	7.3
Color	5	0	1	10	0	1	5	0	2

Table 5. Maximum, minimum, and median values of constituents dissolved in water from rocks in the shallow aquifer.

known. The higher chloride content in water from some wells is associated with higher nitrate content. Higher magnesium contents reflect dolomitization which occurred during mineralization of the rocks. A comparison of minimum and median values indicates that near maximum values for many of the constituents are unusual. Median values are representative of the average chemical quality of water in much of the area.

Mine water contains more iron, manganese, and zinc than well or spring water. The concentrations of iron and zinc shown in the table of analyses for well water probably have been influenced by the solution of these two constituents from well casings, piping, and pressure tanks. Analyses of a few comparative samples collected directly from wells and faucets after the pressure tanks indicate that 35 to 100 percent of the zinc content of well waters is from the galvanized plumbing.

Variations in the concentration and chemical character of water from rocks of Mississippian age are shown in figures 17, 18 and 19.

The diagrams in figures 17 and 18 show that water from wells and springs generally is a calcium bicarbonate type. Diagrams for the lower concentrations are illustrative of the chemical quality of water in areas where rocks are relatively pure cherty limestone and where sulfide mineralization of the rocks is not widespread. Variations in the dissolved-solids content of water in these areas are essentially due to changes in the concentration of calcium and bicarbonate.

The diagrams for mine water (fig. 19) and those wells and springs with the higher concentrations and higher percentages of sulfate are illustrative of water in areas of sulfide mineralization. Principal areas of sulfide mineralization are in the Joplin-Webb City vicinity (see fig. 2), but many well records in southwestern Missouri show sulfide minerals in drill cuttings indicating that isolated patches of sulfide mineralization occur throughout the area. The diagrams show that sulfate is an appreciable part of the anion concentration in water from areas of sulfide mineralization, and that most of the increase in total concentration is caused by increases in calcium and sulfate. This tendency toward a calcium sulfate type of water as the total concentrations increase is caused by the oxidation of insoluble sulfide minerals to a soluble sulfate form and the subsequent solution and hydrolysis of the soluble sulfates. Sulfuric acid is produced during hydrolysis, and the neutralization of this acid by the calcium carbonate wall rock leaves calcium and sulfate in solution. An exception to this is well No. 39 (plate 1). This well is in the northern part of the basin and all or most of the sulfate content of water from this well is a result of leakage of more concentrated water in the overlying Pennsylvanian rocks into the underlying Mississippian rocks.

The relatively high nitrate content shown by many of the diagrams for well and spring water indicates a widespread distribution of nitrate throughout the area. As there are no extensive geologic sources for the nitrate, it is likely that it comes from surface sources such as nitrate fertilizers, barnyards, or cesspools. The range in concentration of nitrate is much greater in water from wells than in water from springs, but the median values (table 5) indicate that the nitrate content of spring water generally is higher. Spring discharge is a composite of water from many small areas of both high and low nitrate content, whereas water from a well generally receives its nitrate from a small area around the well. Although the nitrate content of most samples was less than the 45 mg/l recommended limit for potable water supplies, consideration should be given to a bacteriological examination of the water if it is to be used as a domestic supply because of possible bacterial contamination.

SURFACE WATER

The quantity and quality of streamflow in the Joplin area varies areally, seasonally, and from year to year. In order to provide information for present and future development of surface water supplies in the area, the results of the study are defined in terms of frequency, duration and areal variability of flows, storage requirements, and quality of the water.

Appendix IV presents the location, type of streamflow information, and other pertinent data for all gaging stations in the area.

VARIABILITY OF FLOW

There would be few water supply problems in the Joplin area if the streams discharged at their average rate at all times. However, seasonal and daily

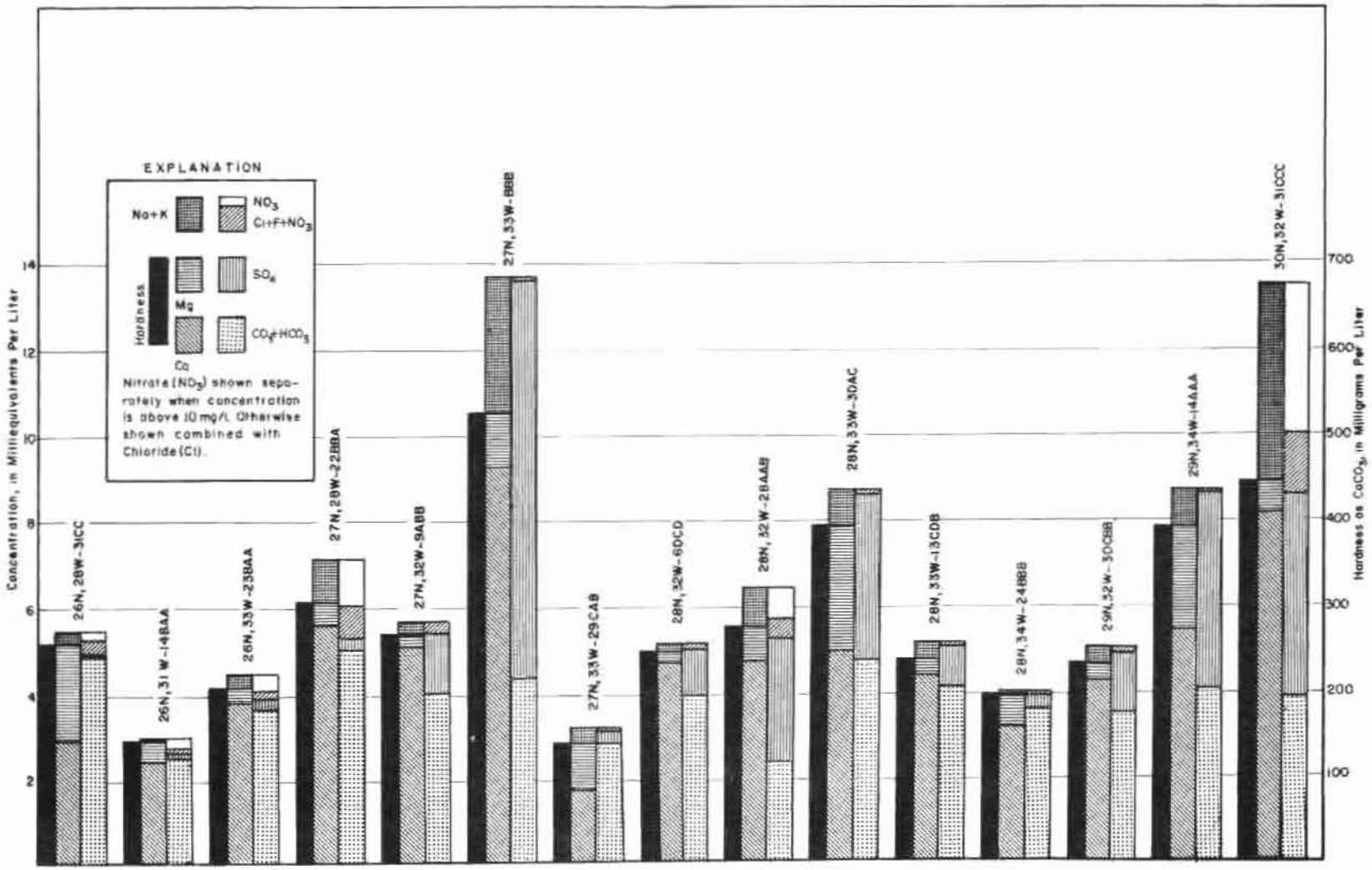


Figure 17. Bar diagrams showing variations in chemical character of water from wells in the shallow aquifer.

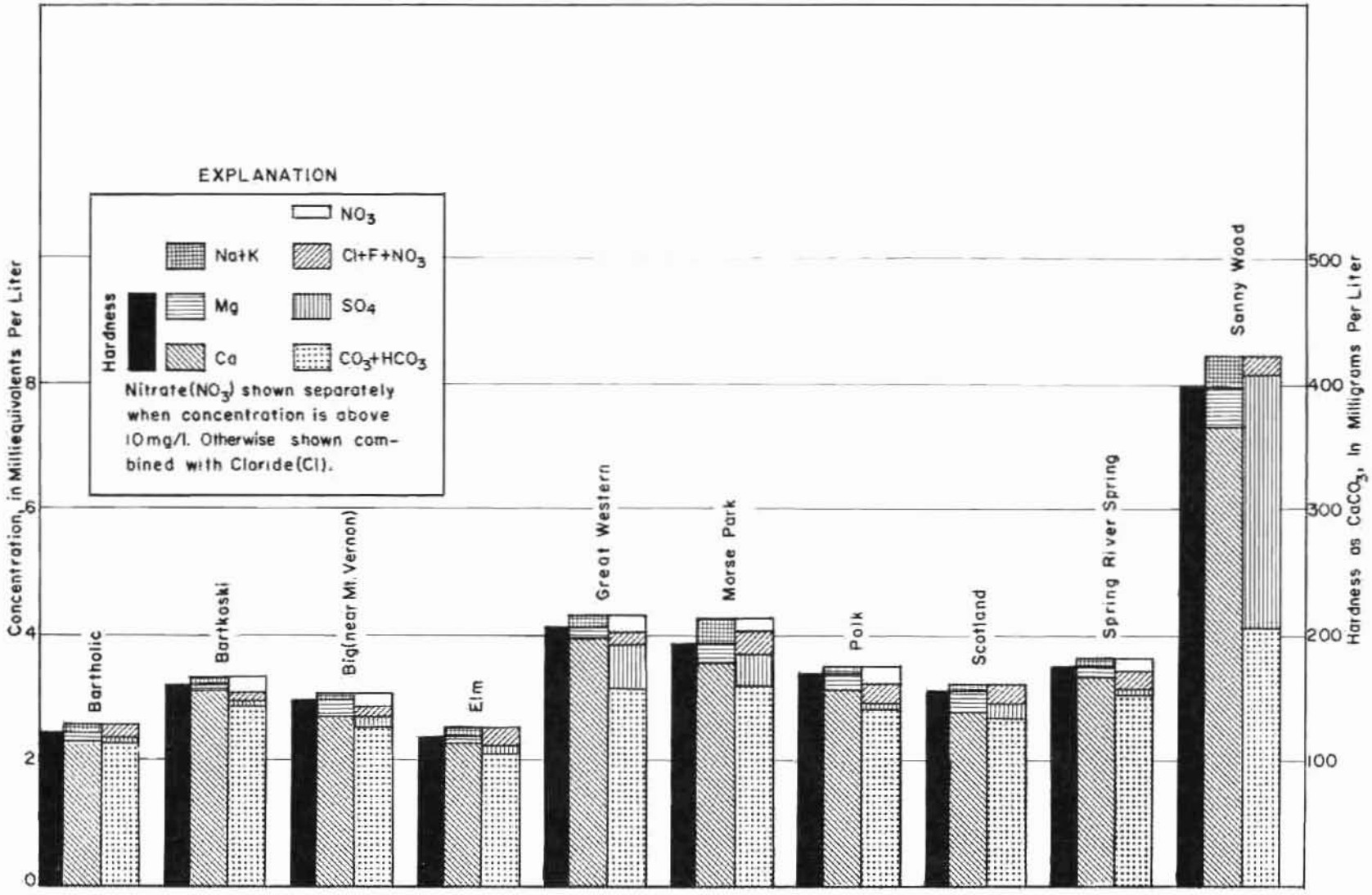


Figure 18. Bar diagrams showing variations in the chemical character of water from springs.

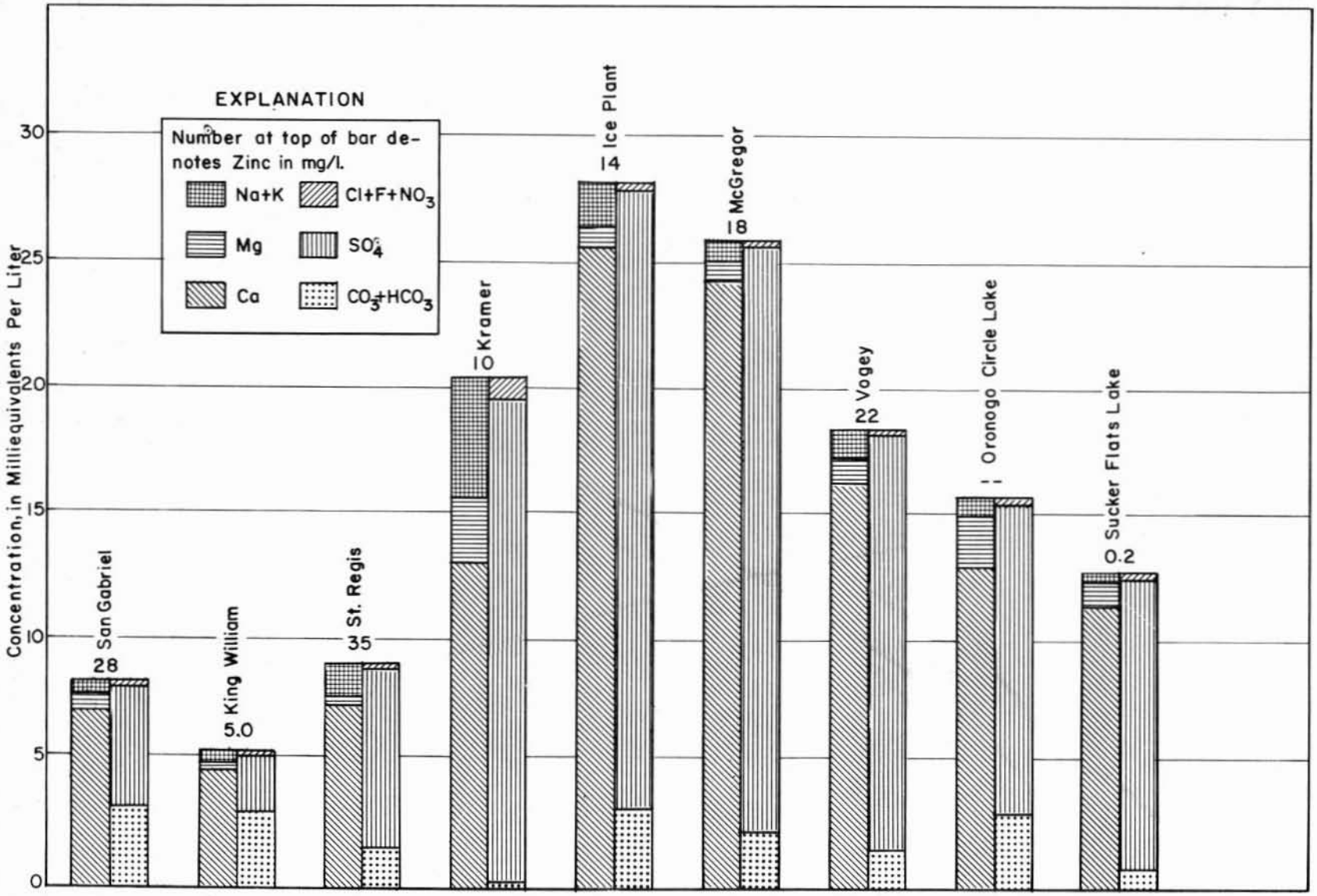


Figure 19. Bar diagrams showing variations in the concentration and chemical character of water from mine shafts and open pit lakes.

variations in runoff rates combine to produce considerable variations in total runoff from year to year. The variability of yearly runoff is indicated by the long-time record of Spring River near Waco (fig. 20). Supply is more variable than demand in the Joplin area, but the variability of each contributes to the problem because the peak demands occur during minimum streamflow periods and the largest streamflows occur in periods of low demand.

Minimum streamflows in the area usually occur during the fall or late summer. At the long-time gaging stations, far more minimum flows have occurred in September than in any other month with October and August in second and third place, respectively. The lowest streamflows ever recorded in the area occurred in August and September 1954.

Flooding resulting from heavy rains may occur during any month, but occurs most frequently during the spring and early summer, April to July. The greatest known floods in the area occurred in May 1943.

DURATION OF FLOWS

Flow duration data provide an excellent comparison of the flow characteristics of streams because the slope of the duration curve is a quantitative measure of the variability of streamflow. Thus, the slopes of flow duration curves representing different streams or different reaches of one stream may be compared to determine relative base-flow and flood-flow characteristics.

Flow duration curves of Shoal Creek above Joplin and Spring River near Waco (fig. 21) illustrate graphically the differences in streamflow characteristics from north to south in the study area. The portion of the curves exceeding 90 percent duration represents ground water discharge to the streams according to Stuart (written communication) and shows that base flows in the southern part of the project area are better sustained. This occurs as a result of the greater capacity of the geologic formations to store and yield water. (See discussion of stratigraphy).

The shape of the upper left part of the curves reflects the amounts of overland runoff from the basins during periods of excessive precipitation. The unit runoff of the northern tributaries of Spring River is greater during these periods than that of other streams in the area because they drain areas of Pennsylvanian shales where runoff rates are high. Above 5 percent the duration curves are practically identical because the slope of the curve in this range is dependent on parameters which are very similar in the two basins; i.e., the pattern and type of precipitation and the relief of the watersheds.

The flow duration curves presented in figure 21 represent the long-time distribution of future flows in the Spring River and Shoal Creek basins provided no significant man-made changes occur.

FLOOD FLOWS

Magnitude and Frequency of Floods

Flooding of streams in the area may increase in severity and cause considerable damage in the future because of increased urbanization and encroachment of industrial and domestic structures upon the flood plains of the streams. Therefore, water managers and consultants working in the Joplin area need information about the magnitude and frequency of flooding to insure proper planning and design of water facilities.

Sandhaus and Skelton (1968) defined statewide flood-frequency equations from an analysis of flood data available from continuous-record and crest-stage stations throughout the State. These equations, which are presented in table 6, are applicable to the

Table 6
Equations for determining magnitude and frequency of floods on unregulated streams†

Frequency of flood (years)	Magnitude of flood (cfs)	Standard error estimate (%)
1.2	$61.5\ A^{0.651}\ S^{0.191}$	50.7
2.33	$72.3\ A^{0.719}\ S^{0.330}$	44.1
5	$82.3\ A^{0.743}\ S^{0.411}$	44.8
10	$90.1\ A^{0.757}\ S^{0.462}$	45.6
25	$74.8\ A^{0.776}\ S^{0.654}$	36.9
†† 50	$70.4\ A^{0.804}\ S^{0.680}$	36.9

† Equations are applicable to drainage areas greater than 0.1 square miles.

†† Fifty-year flood-frequency estimates at gaging stations were obtained from drainage areas in excess of 50 square miles. There is no evidence to support the use of the 50-year equation for drainage areas less than 50 square miles. The equations do not apply near the mouths of streams draining into larger streams because of possible backwater effects.

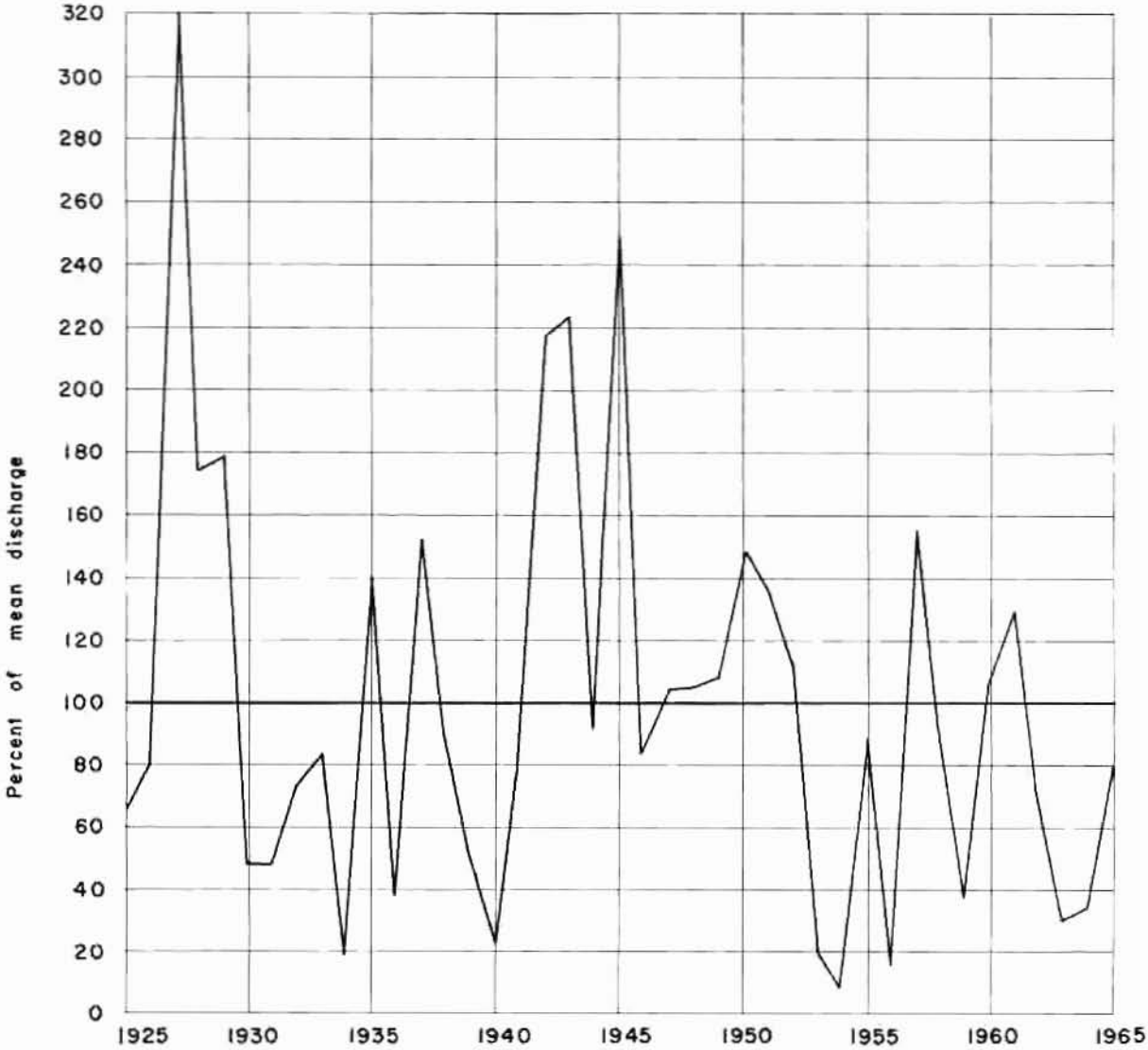


Figure 20. Hydrograph of annual mean flows, Spring River near Waco, Mo., showing variability of streamflow.

Station number (Plate 1)	Station name	Record used in analysis	Drainage area, sq. mi.	Low-flow frequency data							Draft-storage frequency data	
				Period, days	Annual low-flow in cfs for indicated recurrence interval, in years						Recurrence interval, years	Amount of storage (in thousands of acre-feet) for draft rate (in cfs) indicated in column headings (not corrected for reservoir evaporation, sedimentation, and seepage)
					2	5	10	20	30	50		
7-1854---	Williams Creek near Mount Vernon	1954, 1962-64	---------	7	4.7	------	2.0	------	------	------		4 cfs / 6 cfs
											20	0.22 / 1.50
7-1856.5-	Spring River near Stotts City	1943-44 1946-47, 1949, 1954, 1962-64	---------	7	42	------	18	------	------	------		40 cfs / 70 cfs
											20	2.50 / 27.0
7-1857----	Spring River at Larusse[1]	1957-64	306	7	47	28	20	------	------	------		60 cfs / 70 cfs
				15	48	30	22	------	------	------		
				30	53	32	24	------	------	------	20	12.5 / 20.8
7-1857.5--	White Oak Creek near Avila[b]	1954, 1962-64	---------	7	0	------	0	------	------	------		0.8 cfs / 2.5 cfs / 4 cfs
											20	0.28 / 1.00 / 1.88
7-1858----	Spring River near Neck City[b]	1954, 1962-64	---------	7	53	------	(c)	------	------	------		60 cfs / 70 cfs
											20	9.00 / 14.5

Table 7. Low-flow frequency and draft-storage-frequency data at continuous-record and low-flow partial-record stations.[a]

Station number (Plate 1)	Station name	Record used in analysis	Drainage area, sq. mi.	Low-flow frequency data: Period days	Annual low-flow in cfs for indicated recurrence interval, in years: 2	5	10	20	30	50	Draft-storage frequency data: Recurrence interval, years	Amount of storage (in thousands of acre-feet) for draft rate (in cfs) indicated in column headings (not corrected for reservoir evaporation, sedimentation, and seepage)				
7-1858.5--	North Fork Spring River at Lamar[b]	1943, 1946, 1962-63	--------	7	0.1	-----	0	----	-----	-----		2.5 cfs	7 cfs	12 cfs		
											20	0.84	3.00	5.64		
7-1860----	Spring River near Waco	1925-62	1,164	7	58	28	19	11	7.2	3.8		30 cfs	40 cfs	50 cfs	55 cfs	61 cfs
				15	65	33	21	12	8.2	5.0						
				30	74	35	23	14	9.6	5.4	10	0.42	1.19	2.58	3.47	4.56
				60	94	44	27	16	11	7.0	20	1.63	3.47	5.75	7.04	8.92
				90	120	54	33	21	16	11	30	2.58	4.66	7.34	8.82	10.7
				183	250	96	61	42	35	28						
				274	430	175	105	66	52	38						
7-1861----	Center Creek near Sarcoxie	1954, 1962-64	--------	7	16	-----	6.8	----	-----	-----		18 cfs	27 cfs			
											20	2.48	9.90			
7-1862----	Center Creek near Fidelity	1962-64	--------	7	24	----	8.0	----	-----	-----		20 cfs	40 cfs			
											20	1.38	13.8			
7-1864----	Center Creek near Carterville[d]	1962-64	232	7	26	-----	(e)	----	-----	-----		25 cfs	45 cfs			
											20	3.75	17.2			

Table 7 (continued). Low-flow frequency and draft-storage-frequency data at continuous-record and low-flow partial-record stations.[a]

Station number (Plate 1)	Station name	Record used in analysis	Drainage area, sq. mi.	Low-flow frequency data: Period days	Annual low-flow in cfs for indicated recurrence interval, in years: 2	5	10	20	30	50	Draft-storage frequency data: Recurrence interval, years	Amount of storage (in thousands of acre-feet) for draft rate (in cfs) indicated in column headings (not corrected for reservoir evaporation, sedimentation, and seepage): 50 cfs	75 cfs
7-1864.2--	Center Creek near Webb City[b]	1962-64	--------	7	35	----	(e)	----	----	-----	20	12.3	36.2
7-1864.6--	Center Creek near Carl Junction	1943, 1946, 1949, 1952, 1954, 1956, 1962-64	-------	7	38	----	(e)	----	----	-----	20	13.8	37.2
7-1867----	Shoal Creek near Fairview	1954, 1962-64	--------	7	17	----	7.6	----	----	-----	20	1.02	6.00
7-1868----	Capps Creek near Berwick	1962-64	-------	7	20	----	11	----	----	-----	20	0.40	
7-1868.5--	Clear Creek near Ritchey	1954, 1962-64	--------	7	7.0	----	2.2	----	----	-----	20	1.40	
7-1868.8--	Shoal Creek at Ritchey	1954, 1962-64	------	7	54	----	20	----	----	-----	20	10.7	

Table 7 (continued). Low-flow frequency and draft-storage-frequency data at continuous-record and low-flow partial-record stations.[2a]

Station number (Plate 1)	Station name	Record used in analysis	Drainage area sq. mi.	Low-flow frequency data: Period, days	Annual low-flow in cfs for indicated recurrence interval, in years: 2	5	10	20	30	50	Draft-storage frequency data: Recurrence interval, years	Amount of storage (in thousands of acre-feet) for draft rate (in cfs) indicated in column headings (not corrected for reservoir evaporation, sedimentation, and seepage)				
7-1868.9--	Shoal Creek at Neosho	1941-43, 1945-46, 1949, 1952, 1954, 1962-64	-------	7	60	----	23	----	----	-----		60 cfs	70 cfs			
											20	5.70	10.5			
7-1869----	Hickory Creek at Neosho	1941, 1962-64	--------	7	9.8	----	3.9	----	----	-----		9 cfs				
											20	1.28				
7-1870----	Shoal Creek above Joplin	1942-62	410	7	92	54	35	22	17	-----		50 cfs	55 cfs	60 cfs	70 cfs	78 cfs
				15	96	56	38	25	19	-----						
				30	102	60	42	28	22	-----	10	0.40	0.71	1.19	2.60	4.36
				60	120	70	50	35	29	-----	20	2.78	3.97	5.35	8.53	11.1
				90	130	78	55	39	32	-----	30	4.16	6.05	7.73	11.5	14.5
				183	170	100	71	49	39	-----						
				274	240	155	115	82	66	-----						

[a]Data are not shown for Turkey Creek gage. The flow of this stream is regulated by sewage effluent.

[b]Discontinued partial-record station.

[c]Insufficient data for estimate.

[d]Continuous-record station which was analyzed as a partial-record station because of scant data.

[e]Estimate not feasible because of significant low-flow augmentation by industrial operations during extended droughts.

Table 7 (continued). Low-flow frequency and draft-storage-frequency data at continuous-record and low-flow partial-record stations.[a]

Joplin area and should be used in computation of magnitude and frequency of floods at any site in the area. To supplement these data, a listing of peak stages and discharges for the period of record at continuous-record and crest-stage stations is presented in Appendix IV.

The solution of the equations is somewhat laborious; therefore, graphical solutions are presented in figure 22 A-F for convenience. A hypothetical problem illustrating the use of the flood-frequency equations is presented in Appendix V.

The interpretation of the standard error column in table 6 should be made in the following ways, using the equation for the 50-year flood as an example:

1. A statement that the actual value for the 50-year flood lies within 1 standard error (36.9 percent) of that obtained from the equation will be correct 2 times out of 3, on the average.

2. A statement that the actual value for the 50-year flood lies within 2 standard errors (73.8 percent) of that obtained from the equations will be correct 19 times out of 20, on the average.

The values of the standard error are given so that the user will be able to evaluate the accuracy of the results from the statewide equations.

LOW FLOWS

Low-Flow Frequency

Low-flow frequency data relate recurrence interval to lowest average discharge for periods of various length during each climatic year. These data were computed by statistical methods described by Skelton (1966) and are presented in table 7.

An example of low-flow frequency curves for Shoal Creek above Joplin is shown in figure 23. Each of the curves represents a continuous period of different length between 7 and 30 days. The scale at the left of the figure shows the average discharge in cfs for any of these periods. The scale at the bottom shows the average recurrence interval in years at which average discharges not exceeding those shown can be expected to occur as an annual minimum.

Data from low-flow partial-record stations and continuous records of less than five annual minimums are indadequate to define frequency curves of annual values. These data were related to long-time gaging stations in the area and the resulting graphical regression was used to estimate the median annual minimum 7-day flow (7-day Q2) and the 7-day 10-year recurrence interval flow as shown in table 7.

Estimates of low-flow characteristics at ungaged sites may be obtained by using methods described by Skelton (1966). Hypothetical problems presented in Appendix VI illustrate these procedures.

Seasonal versus Annual Frequency Curve. The 3-month period, June-August, is especially important from an agricultural standpoint because it includes most of the growing season. Low-flow frequency estimates included in table 7 are based on the lowest periods during each climatic year, regardless of the season in which they occur. For this reason, a ratio (1.6:1) was computed to provide a comparison between estimates based on growing season data and annual minimum 7-day data. For example, if the user wishes to get an idea of the June-August 7-day Q_2 for Spring River near Waco (7-1860), he should multiply the annual 7-day Q_2 (58 cfs from table 7) by 1.6 to obtain the seasonal 7-day Q_2 of about 93 cfs. The ratio should not be used to estimate any time period or recurrence interval except 7-day 2-year because the relation between seasonal and annual curves is not uniform throughout.

Seepage Runs

In the summer and fall of 1964, three seepage runs were made in the study area (fig. 24). Measurements of discharge and specific conductance were made during the investigations to pinpoint areas of streamflow gains or losses and determine which reaches are affected by effluent from mines, industry, or other sources. The measurements were made during base flow periods with an estimated recurrence interval of about 3 years. Although the discharge measurements were not made during periods of exceptionally low base flows, they delineate areas where base flow gains or losses may be expected during any dry period.

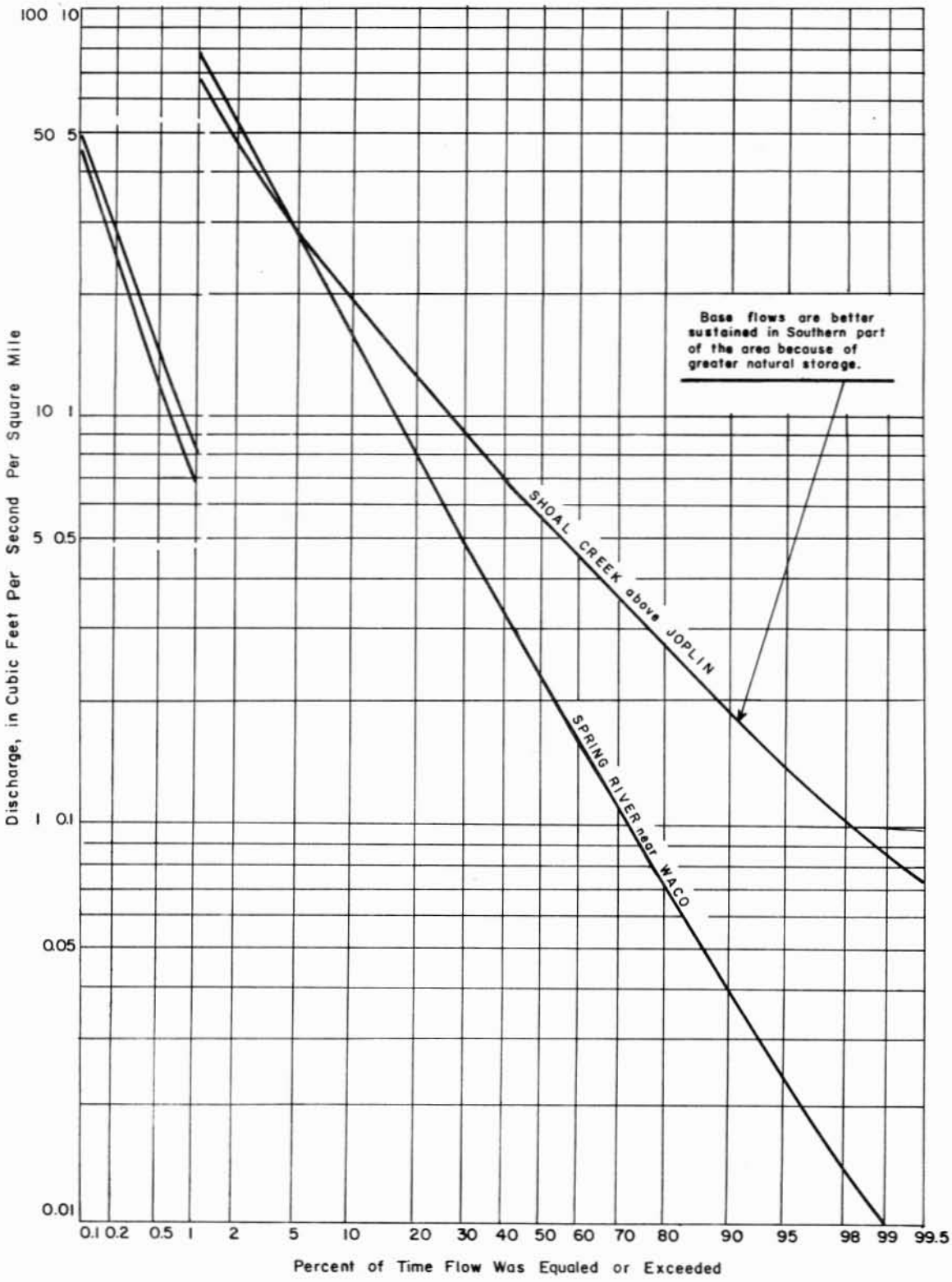


Figure 21. Flow-duration curves for concurrent periods showing relative base-flow and flood-flow characteristics of streams.

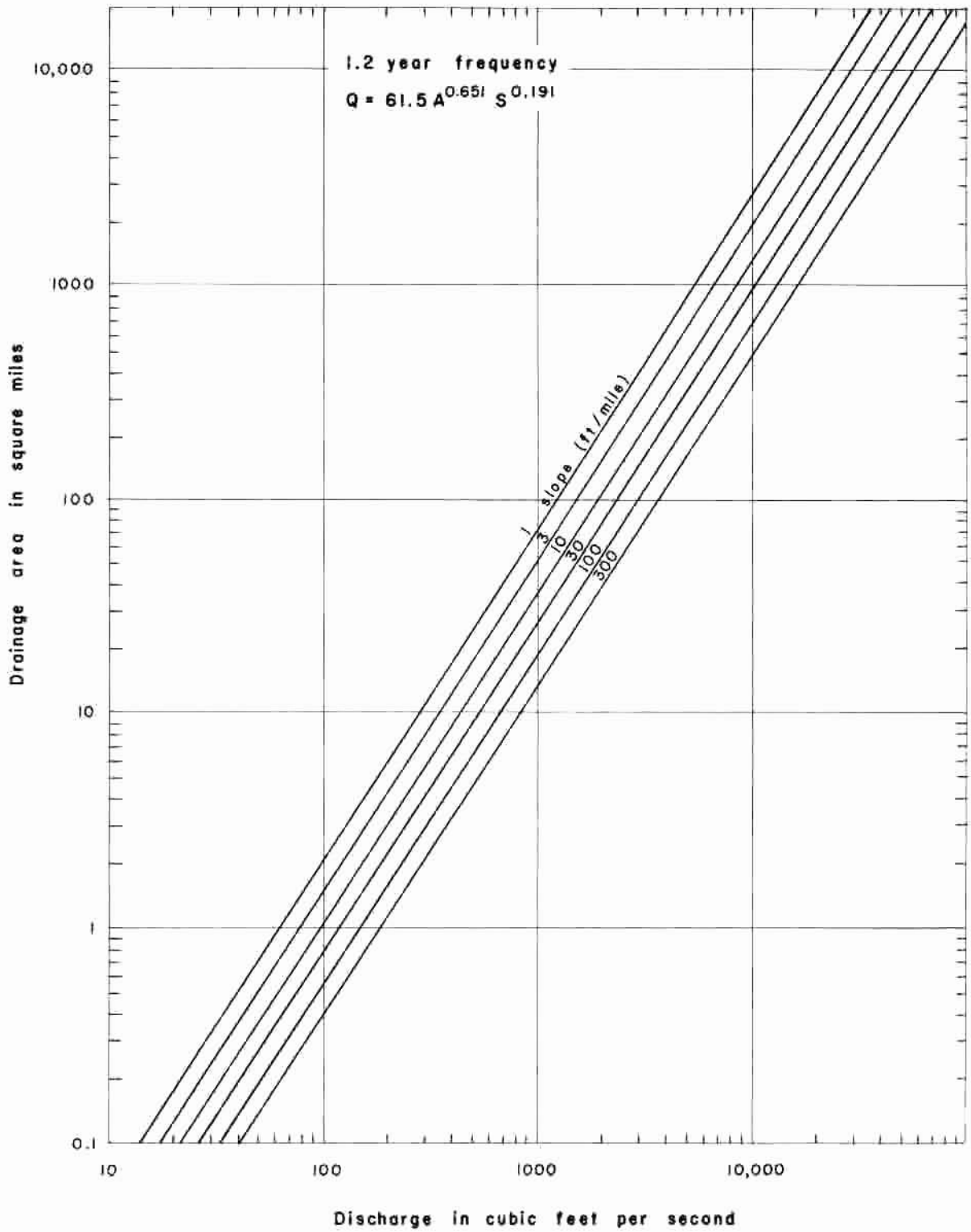


Figure 22 A. Graphical solutions of 1.2-year flood-frequency equation.

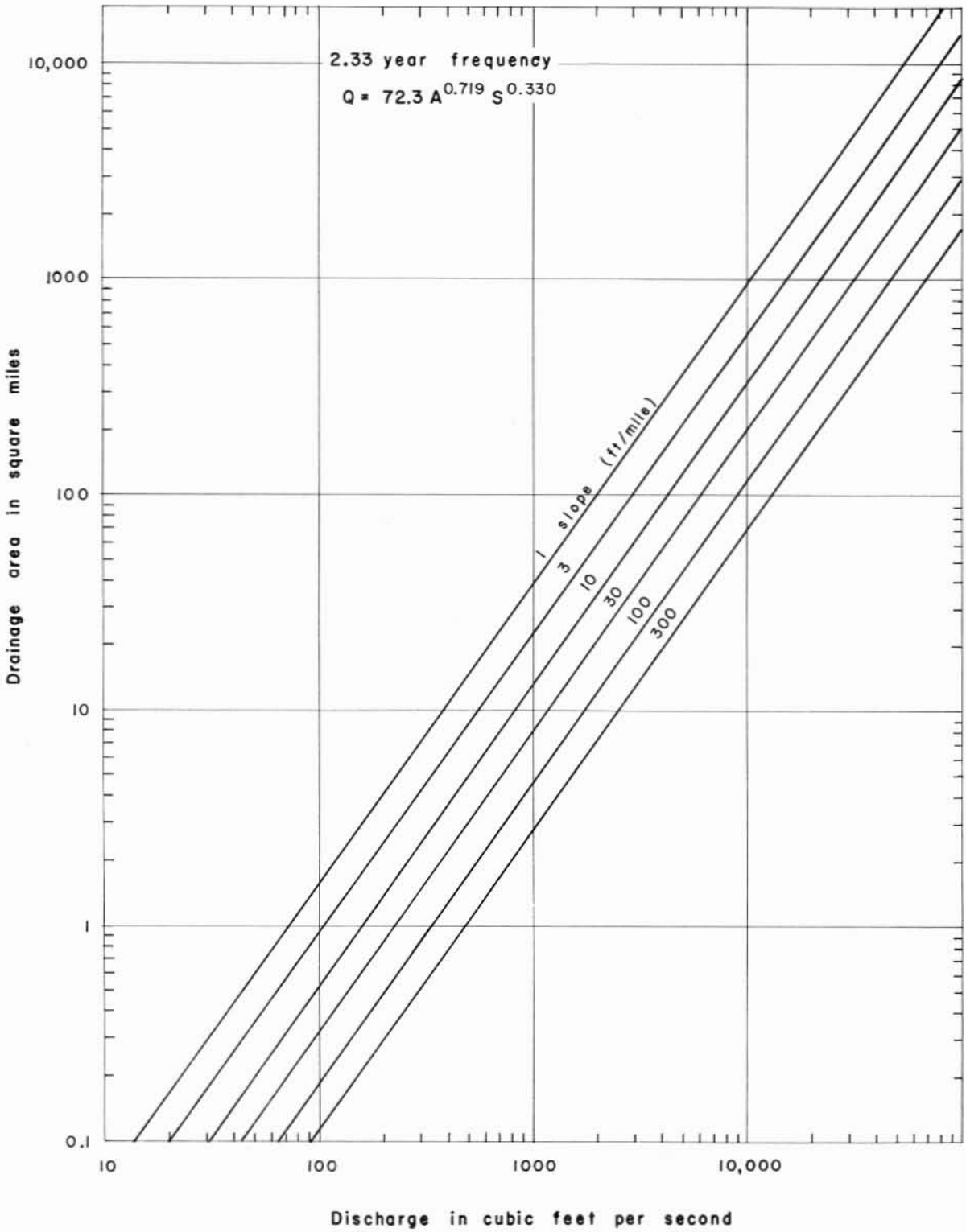


Figure 22 B. Graphical solutions of 2.33-year flood-frequency equation.

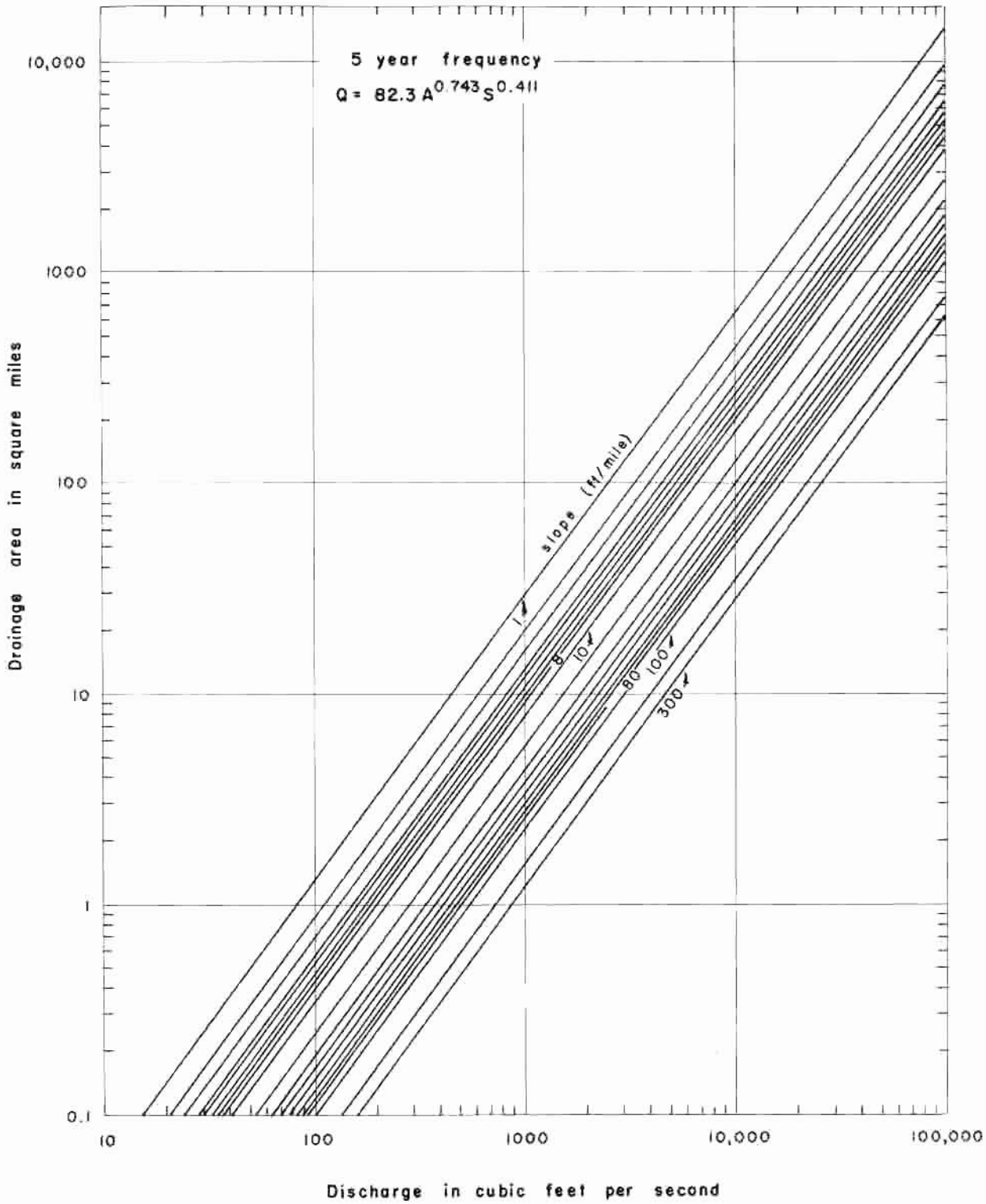


Figure 22 C. Graphical solutions of 5-year flood-frequency equation.

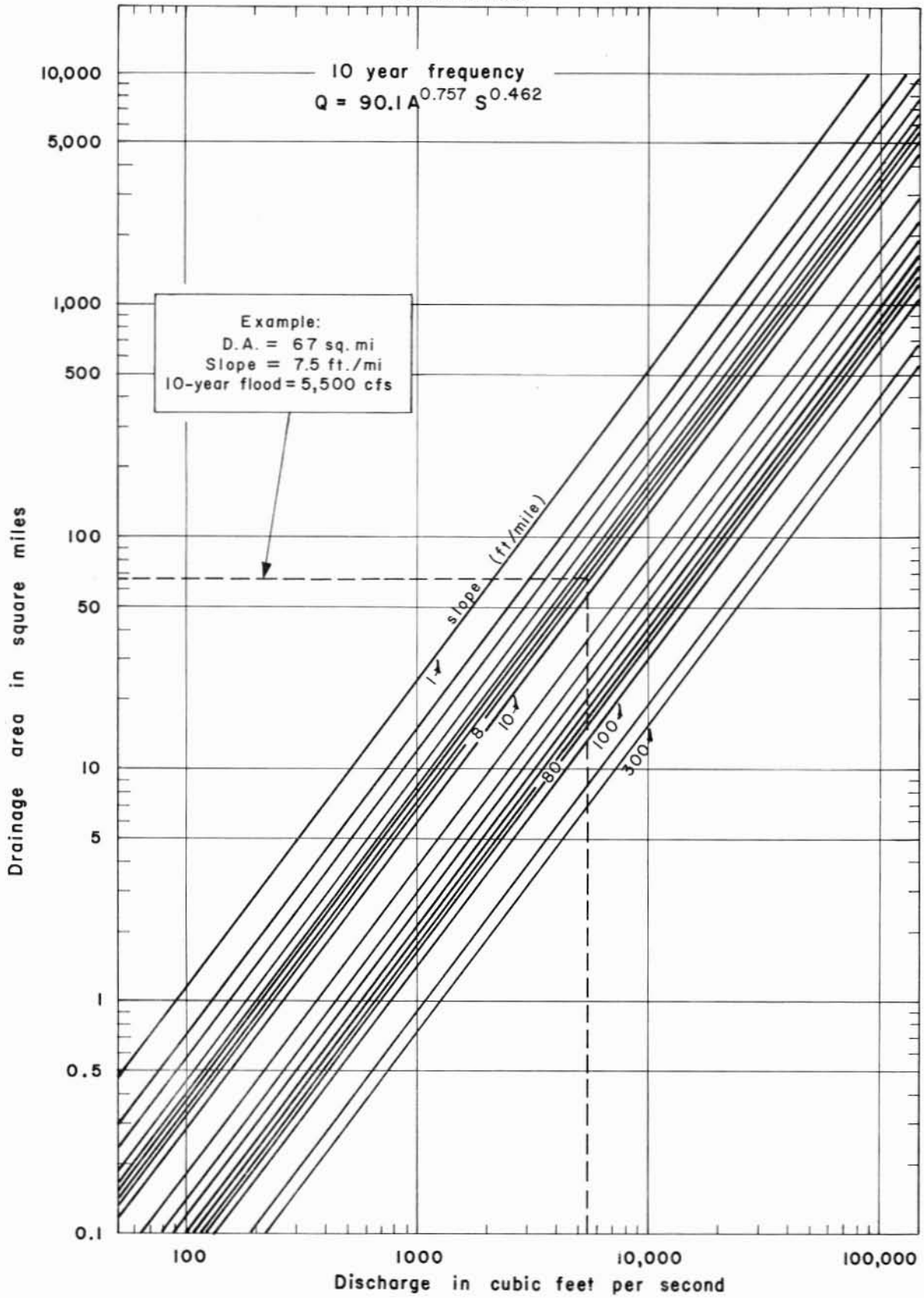


Figure 22 D. Graphical solutions of 10-year flood-frequency equation.

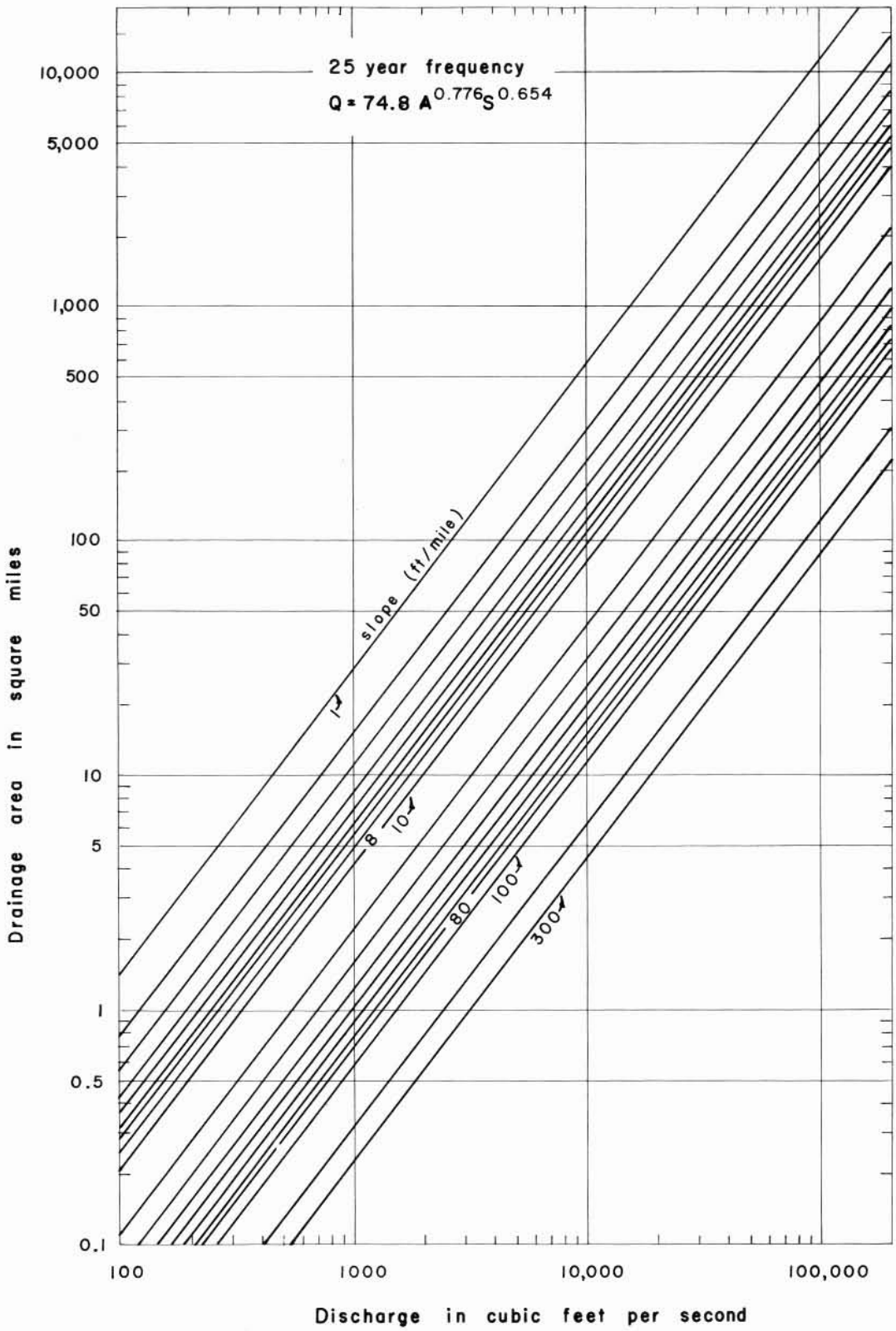


Figure 22 E. Graphical solutions of 25-year flood-frequency equation.

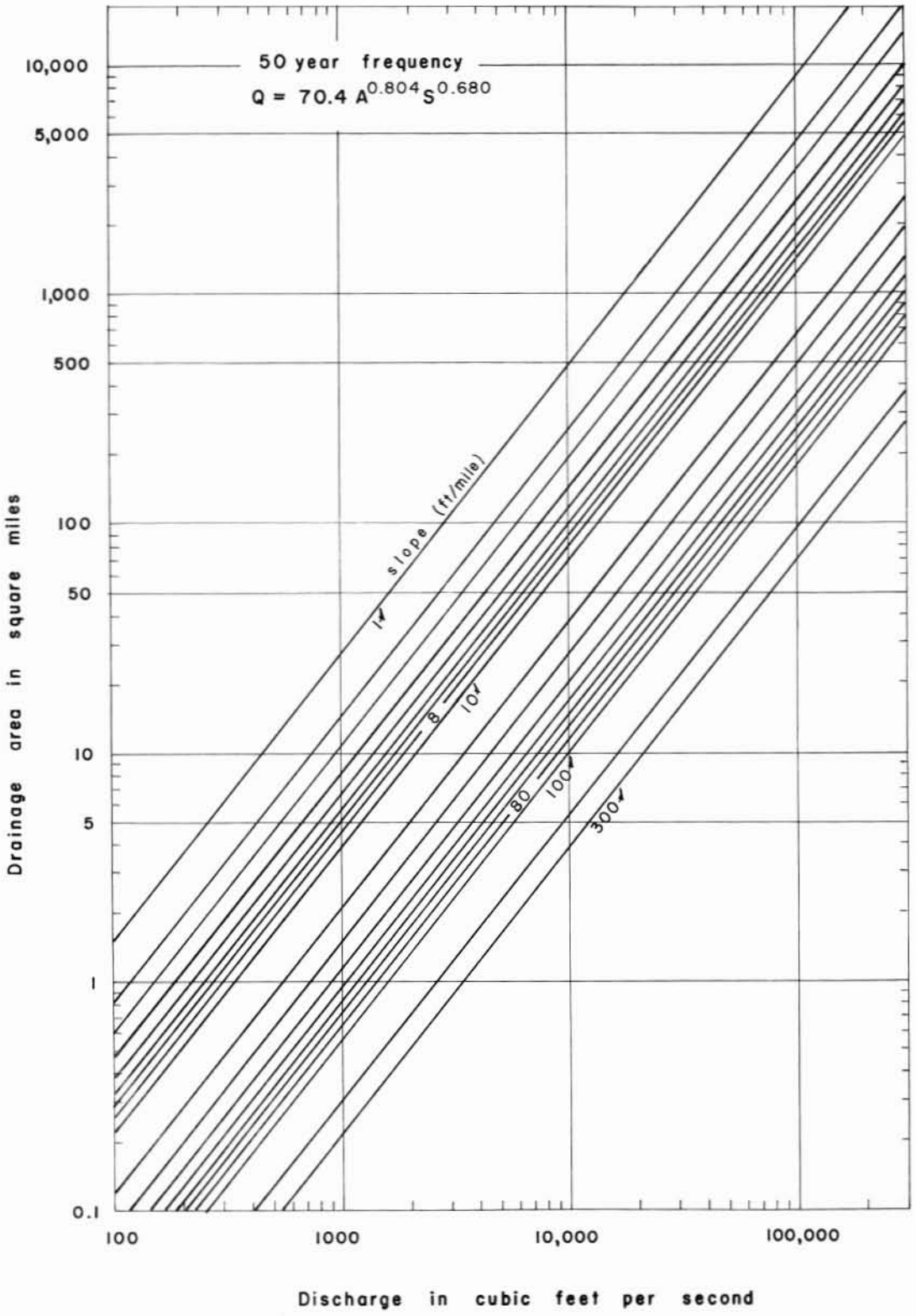


Figure 22 F. Graphical solutions of 50-year flood-frequency equation.

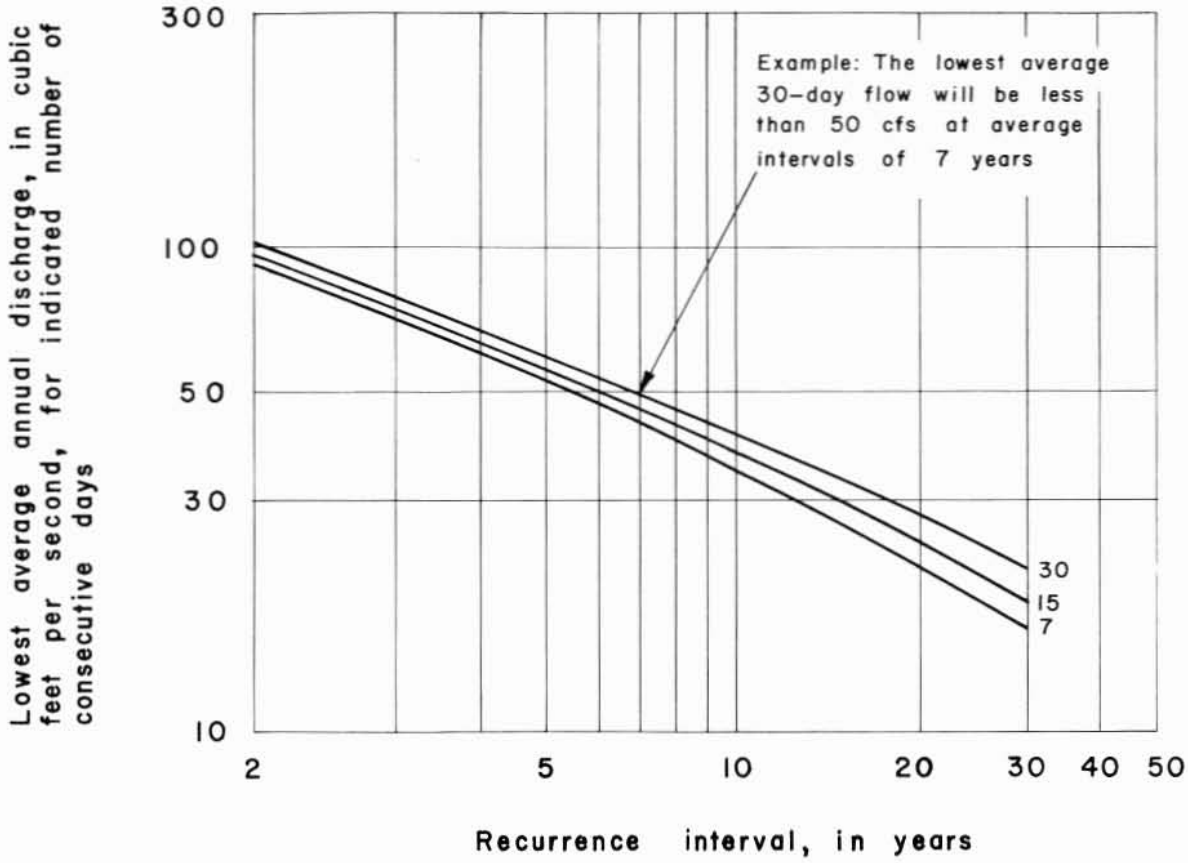


Figure 23. Low-flow frequency curves, Shoal Creek above Joplin, Mo.

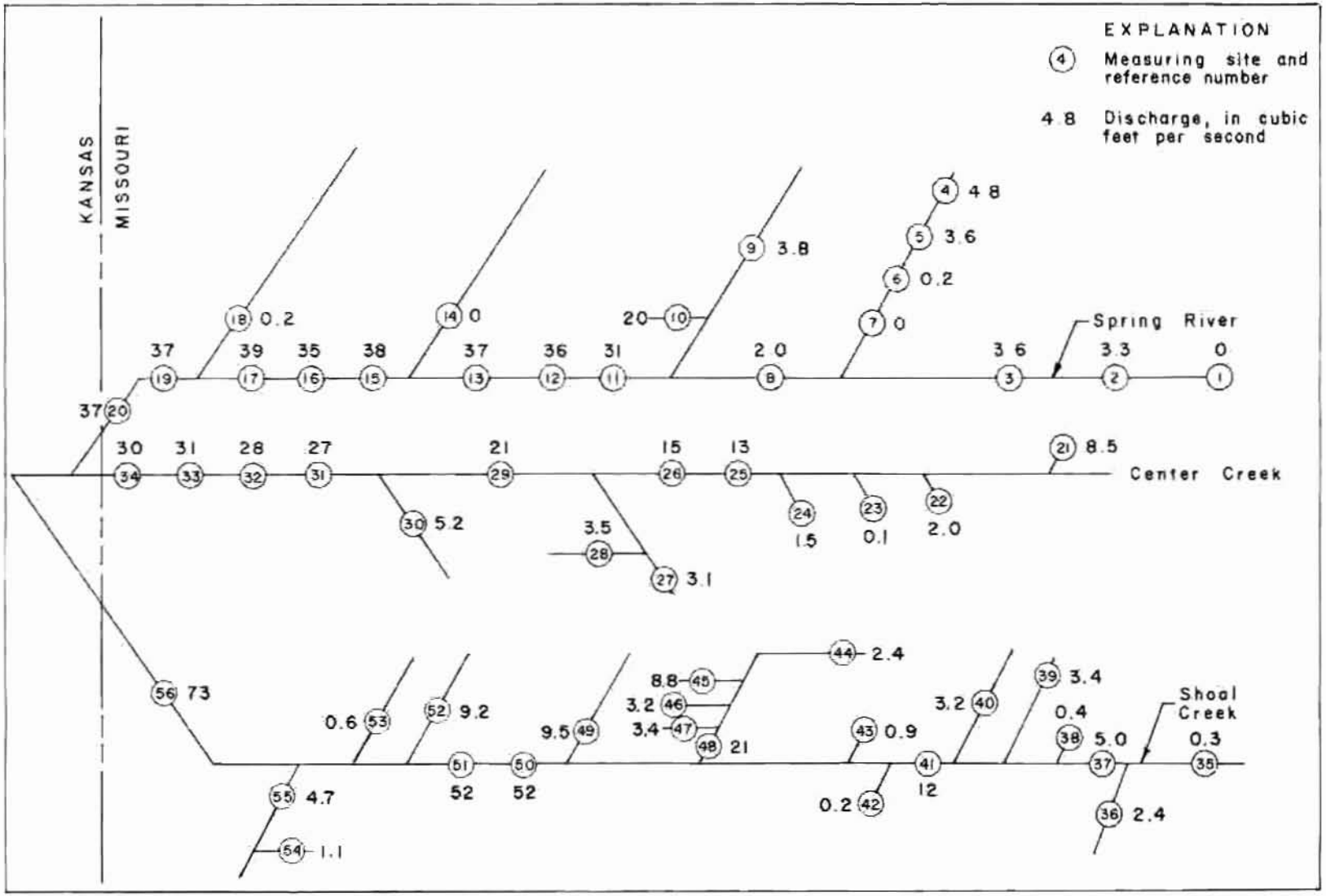


Figure 24. Diagrams showing discharge measurements made in the summer and fall of 1964 in Spring River, Shoal Creek, and Center Creek basins during base-flow period with recurrence interval of approximately 3 years indicate areas of losses and gains in unregulated streamflow.

In general, the measurements show that the base flow of Shoal Creek, Center Creek, and Spring River originates in the headwater areas with little or no increases and some losses in the lower reaches of Center Creek and Spring River. The northern tributaries of Spring River comprise about half of its drainage area in Missouri but drain Pennsylvanian shale which contributes practically nothing to the base flow of the stream.

Streamflow losses were encountered in several reaches along Spring River and Center Creek. Discharge measurements in the vicinity of Honey Creek in the Spring River basin showed that losses from Honey Creek and Spring River in the area between stations 3 and 8 (see fig. 24) amounted to approximately 3,000 gpm. Smaller losses were observed between stations 15 and 16, and 17 and 19 in Spring River basin and between stations 33 and 34 in Center Creek basin.

An industrial complex along Grove Creek in the Center Creek basin utilizes mine water, deep well water, and spring water in its operations. The pumpage from mines and deep wells usually increases during extended droughts and may significantly augment the base flow of Grove Creek and Center Creek downstream from Grove Creek. However, the pattern of water use by the industrial plants is quite erratic and varies markedly from day to day. At the time of the seepage run these operations were causing a regulated flow of 5.2 cfs and a specific conductance of 2,200 micromhos in Grove Creek (station 30). As a result, the conductance of Center Creek increased from 290 micromhos at station 29 to 695 micromhos at station 31.

Mine water drainage into the streams was found to be a significant factor in only one area, a reach of Center Creek between stations 32 and 33. A total of 3 cfs of highly mineralized mine water was entering the stream at various points in the reach. At station 32, for example, about 90 gallons per minute with a specific conductance of 890 micromhos was being added to the creek by a gravel washing operation which used mine water for this purpose. The drainage from the mines raised the specific conductance of the water from 600 micromhos at station 32 to 695 micromhos at station 33.

Base-Flow Recession Curve

Base flow recession curves are valuable tools in the prediction of future base flow. These data are most often used in (1) evaluating streamflow for municipal and domestic water supplies to determine possible need for supplemental supplies, (2) evaluating adequacy of streamflow for waste dilution to determine if wastes should be temporarily stored or accelerated treatment begun, and (3) administering water laws, particularly those concerned with withdrawal.

Base-flow recession curves (fig. 25) were prepared for the stations, Spring River near Waco, Mo. and Shoal Creek above Joplin, Mo., to provide a means of making short-term forecasts of base flow at continuous-record stations in the study area. The curves enable the user to start with a known base flow at a gaging station and predict base flows for any period up to 20 days in the future. The length of the period of estimate should be 20 days or less because short segments of base flow were used in the derivation of the curves. Rainfall during the period of the forecast will require that a new estimate be made after the stream again reaches base flow.

Two curves are presented for each gaging station. Curve A represents the average experience at the gaging station. Use of Curve A is recommended when evapotranspiration losses are normal. Curve B should be used when these losses are abnormally high. The curves are essentially enveloping curves which cover the range of conditions to be expected at the stations.

Storage Requirements to Augment Low Flows

When water supplies larger than those provided by unregulated streamflow are required, storage reservoirs are needed. Water can then be stored during periods of high flow for use during succeeding dry periods.

For this report, draft-storage estimates were made for 19 continuous-record and low-flow partial-record stations. The estimates are presented in table 7 and are based on within-year storage analyses using the frequency-mass-curve method described by Skelton (1968). The draft rates selected are those which can be maintained by storage that will be replenished each year. Higher draft rates can be obtained by addi-

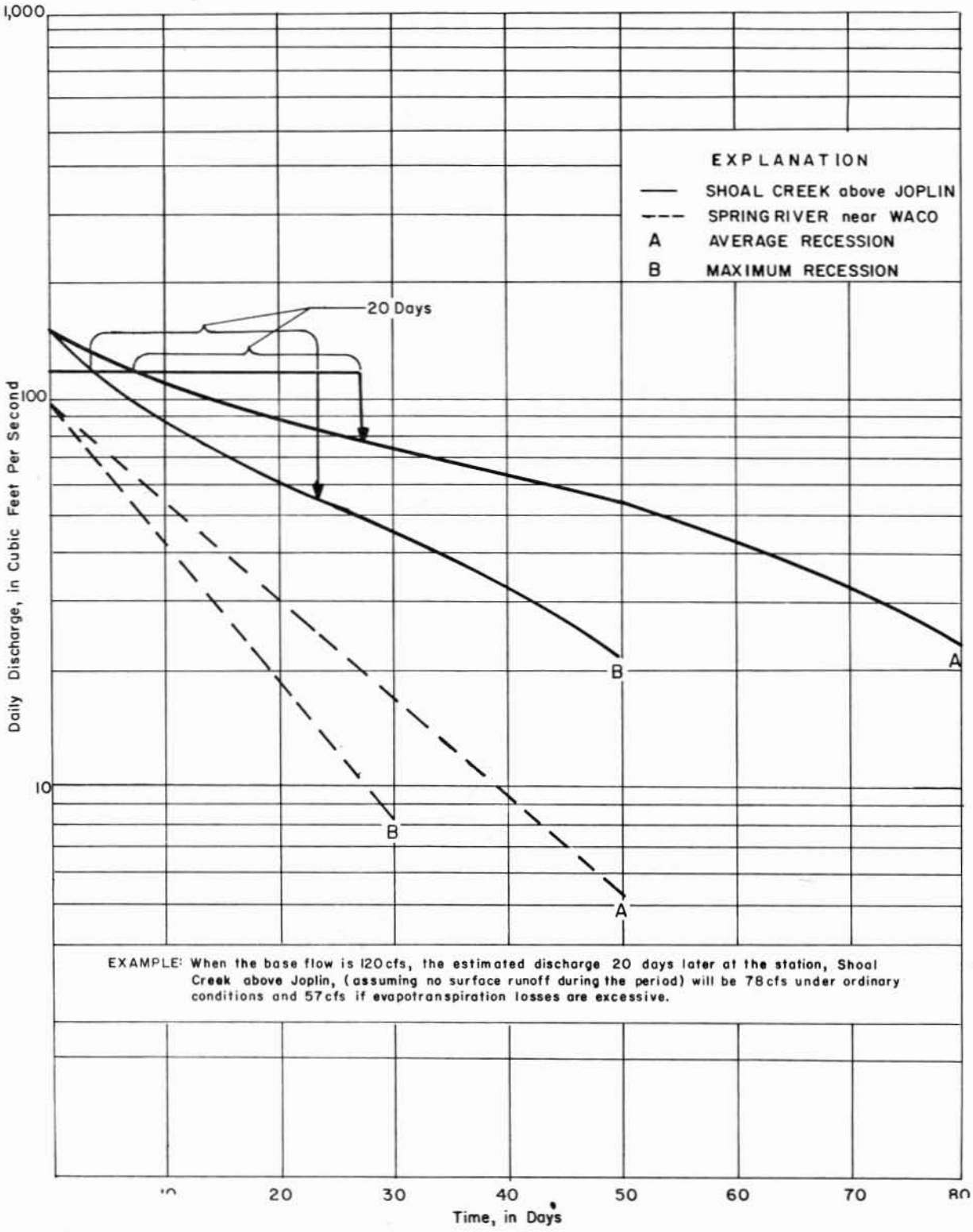


Figure 25. Base-flow recession curves, Shoal Creek above Joplin, Mo., and Spring River near Waco, Mo.

tional annual carry-over storage for years of deficient flow.

The data are useful primarily in making preliminary estimates of potential development and in comparing the development possibilities of different streams. However, these estimates will often be adequate for the final design of small, multi-purpose reservoirs.

Development of Areal Draft-Storage Curves. To obtain estimates of storage requirements at partial-record stations and ungaged sites, areal draft-storage curves (fig. 26) based on a drought of 20-year recurrence interval were developed from data computed for long-time continuous-record stations in southwest Missouri.

The curves were used to estimate storage requirements at all partial-record stations where 7-day Q_2 could be defined and was greater than zero.

Partial-record stations and ungaged sites with 7-day Q_2 of zero.— — In order to estimate storage requirements for a drought with recurrence interval of 20 years at partial-record stations and ungaged sites with 7-day Q_2 of zero, a constant storage requirement was determined for selected draft rates as shown in table 8.

Table 8.— — Constant storage requirements for partial record stations and ungaged sites with 7-day Q_2 of zero

Draft rate (cfsm)	.02	.06	.10
Storage required (acre-feet per square mile)	17	60	120

These average values were determined by computing data from continuous-record stations in southwest Missouri and extrapolating areal draft-storage curves.

Application of areal draft-storage curves to ungaged sites.— —Reservoirs are rarely located at sites where long streamflow records are available. Therefore, the areal draft-storage curves of figure 26 or the constant storage requirement shown in table 8 are used to make estimates of storage requirements at ungaged sites.

The following steps are necessary in making estimates of storage requirements at ungaged sites.

1. Determine the drainage area upstream from the site.

2. Estimate the 7-day Q_2. The estimate may be obtained from a few base-flow measurements, as described by Skelton (1966, p. 25). In the Springfield Plateau area (see fig. 1) it is imperative that three or four base-flow measurements are obtained, preferably on different recessions in different years, before any estimate of the 7-day Q_2 is made. Large water losses or gains may be experienced in short reaches of Plateau streams.

3. Enter figure 26 with 7-day Q_2 in cfsm, intersect the appropriate areal draft curves and read the estimated storages required in acre-feet per square mile from the ordinate scale.

4. If the 7-day Q_2 is estimated to be zero, use the constant storage requirements shown in table 8 to make estimates of storage requirements.

Hypothetical problems are presented in Appendix VI to illustrate the use of areal draft-storage curves and to show methods for estimating reservoir losses.

Reservoir Losses.

Evaporation Loss. — The gross water supply in a reservoir is inevitably lessened by evaporation, making the estimation of this loss an important factor in reservoir planning. The design of major storage projects often includes detailed study of observations made at the proposed reservoir sites, but for lesser projects, generalized estimates of free-water evaporation may be adequate.

Generalized estimates of annual and May-October evaporation losses from water surfaces are contained in U. S. Weather Bureau Technical Paper No. 37, "Evaporation Maps for the United States", 1959. This publication shows an average annual evaporation loss of 44 inches from lakes in the Joplin area.

The evaporation loss appropriate to adjust within-year storage occurs during the critical 4-to 7-month period when evaporation losses are greatest. Therefore,

NOTE: Draft rate is uniform. Storage required is not adjusted for reservoir seepage, sedimentation, and evaporation.

Use constant storage requirements shown in Table 8 if 7-Day Q_2 is less than 0.001 cfsm

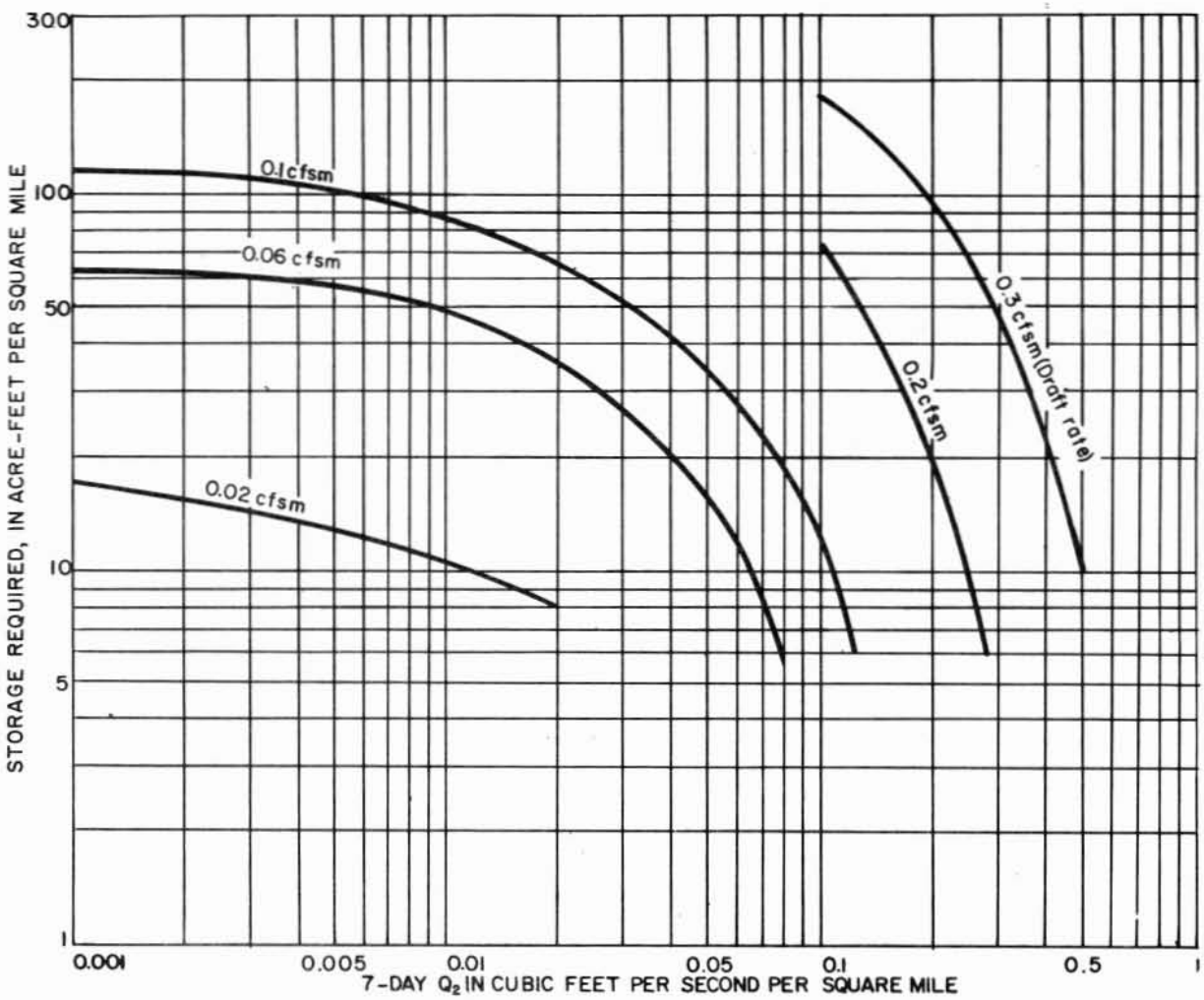


Figure 26. Areal draft-storage curves, showing storage requirements for selected draft rates for a drought of 20-year recurrence interval.

the average annual lake evaporation of 44 inches should be adjusted by a factor of 74 percent to obtain an average evaporation loss of 33 inches for the critical May-October period. This figure should be used in all computations of evaporation losses in the study area.

Reservoir Sedimentation.— — Sediment deposition occurs in any reservoir constructed to impound the waters of a flowing stream and in time robs most reservoirs of their capacity to store water.

No sediment data have ever been collected in the project area; however, sediment deposition surveys (U. S. Dept. of Agriculture, 1964) have been made on a limited number of reservoirs in Missouri. The survey results from two of the reservoirs were selected for presentation in table 9 because they reflect deposition rates which might be expected from streams in southwest Missouri.

The annual rate of capacity loss can be converted to total capacity loss by selecting a time period, for example 20 years, as a basis for planning. This 20-year total to be allocated for sediment storage can then be added to the original reservoir capacity estimate to provide for the amount of capacity lost during the 20-year period. This approach is conservative since the storage space allocated to sediment is actually filled with sediment gradually during the 20-year period.

The reader should use total capacity loss estimates as reconnaissance-type information during preliminary studies.

Seepage Losses.— — An evaluation of potential seepage losses is an integral part of reservoir design. Although a study of the reservoir site is necessary for a precise evaluation of this factor, a general appraisal of seepage losses will be of value in the design of small, general-purpose reservoirs.

According to James H. Williams, Missouri Geological Survey and Water Resources (written communication):

"Seepage losses are directly related to physiography in the study area. In the Springfield Plateau area, permeable cherty clay soils and permeable residuum underlain by moderately cavernous bedrock have contributed to a high rate of seepage with comparatively little surface runoff except during intense storms. Topographically the region is relatively level. Locally, intense sinkhole development surrounded by areas of broad and poorly defined valleys, which in effect are sinkholes from the aspect of a high surface water loss, create tremendous pollution and reservoir leakage hazards. The Osage Plains area is underlain by Pennsylvanian deposits of sandstones, shales and thin limestones. Soil cover is thin in this region, and seepage is slow."

LIMITATIONS OF DATA

Streamflow data presented in this report are applicable only if no appreciable man-made changes occur in the area. Changes in the stream regimen are brought about when natural conditions are altered. Estimates should be used with caution if significant man-made changes such as canalization occur in a specific area of interest.

The amounts of storage required to sustain indicated draft rates at the stations listed in table 7 are hydrologically possible to attain. However, it is the responsibility of the designer to determine if such storage requirements are physically possible. The terrain may not be suitable for reservoir construction. It is not the purpose of the report to define the feasibility of specific projects. Therefore, hydrologic data alone are presented with no analysis of reservoir construction sites. The draft rates selected are those which can be maintained by storage that will be repelnished each year. Higher draft rates can be obtained by utilizing excessive annual flows in years of deficient flow. It is also assumed that the reservoirs will spill each year in the spring runoff and the reservoir will be full at the beginning of each period of calculation.

QUALITY OF SURFACE WATER

The chemical character and dissolved-solids content of surface waters in the Spring River basin are relatively uniform throughout the basin, except for Grove Creek, the lower reaches of Center Creek, and Turkey Creek where the water has been polluted

Reservoir	Stream	Nearest town	Physiographic region	Contributing drainage area, sq. mi.	Date of Survey	Storage capacity, acre-ft.	Avg. annual sediment accumulation in acre-feet per sq. mi.
McDaniel Lake ------	Little Sac River	Spring-field	Plateaus	41.5	---- 1929 June 1940	3,452 3,207	-- 0.54
Grisham ---	Lost Creek (drains mining area)	Bismarck	Plateaus	0.45	Oct. 1930 July 1939	24.05 19.56	1.13

Table 9. Average annual sediment accumulation in McDaniel Lake, near Springfield, Mo., and Grisham reservoir, near Bismarck, Mo.

by industrial and municipal wastes, and the natural discharge of water from old mine workings. The chemical analyses of water from streams (Appendix III)show that in the areas where the chemical quality of water has not been affected by waste discharges into the streams, the dissolved-solids content of the water ranges from about 130 to 200 mg/l with the larger concentrations occurring during periods of lower flows. The waters are a calcium bicarbonate type (fig.27) throughout the ranges of streamflow sampled. In figure 27A it was necessary to plot the combined calcium and magnesium value because in most of the analyses for Shoal Creek calcium and magnesium were determined collectively and reported as hardness as $CaCO_3$. Other analyses indicate an average Ca:Mg ratio of 10:1 milliequivalents per liter reflecting the calcium carbonate character of the bedrock in the basin. The concentration of other constituents is variable but usually low.

Although the chemical character and dissolved solids content of unaltered surface waters are similar, slight differences in each basin do exist. The results of specific conductance measurements made during seepage runs on Shoal Creek, Center Creek and Spring River (fig. 28) show downstream variations in water quality, and they also indicate that water in Shoal Creek has a lower dissolved-solids content, the unaltered portion of Center Creek is slightly higher than Shoal Creek, and water in Spring River contains more dissolved solids than the other two streams. These differences are related largely to the length of time the water is in transit underground before it is discharged to the streams. This underground transit time is controlled largely by the solutional development in each basin. Formerly this entire area was covered with Pennsylvanian rocks. As erosion caused the Pennsylvanian outcrop to retreat to the northwest, solution could proceed more readily in the uncovered Mississippian limestone. Evidence of more extensive solution development in the southeast is the large number of springs and the higher base flow in Shoal Creek, and the virtual absence of springs and the low base-flow yields in much of the Spring River drainage.

Shoal Creek

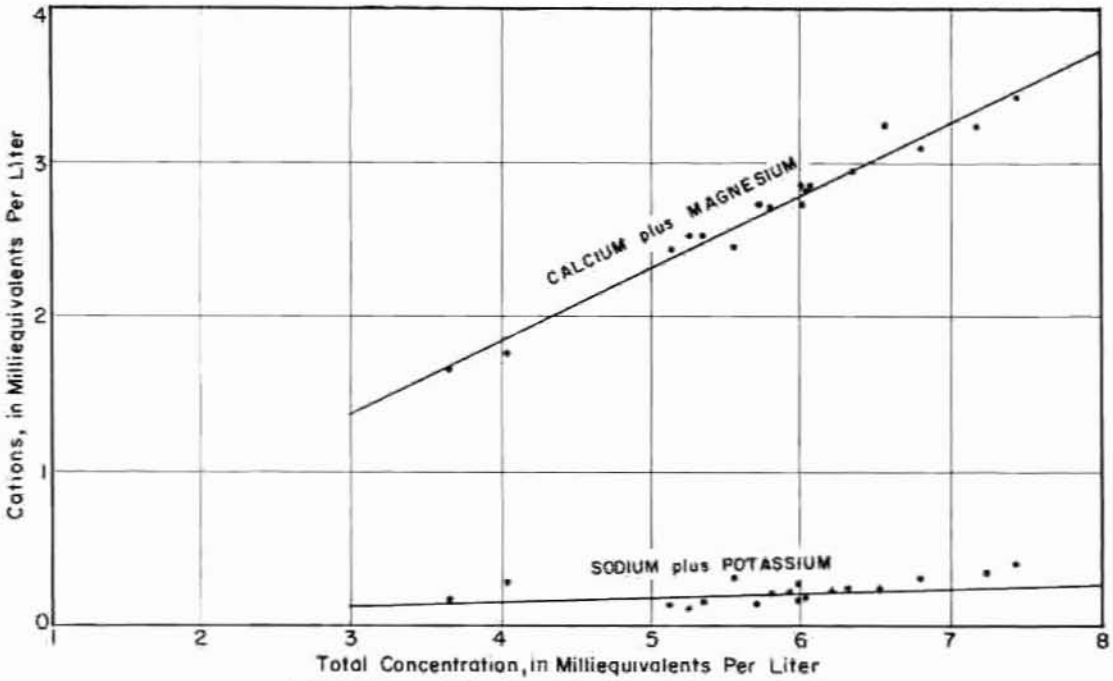
The chemical analyses of monthly samples of water from Shoal Creek above Joplin, Mo. (Appendix III) are representative of the chemical quality over a large part of the range in discharge. The analyses show that the water in Shoal Creek is a hard, moderately mineralized calcium bicarbonate type. At discharges ranging from 82 cfs to 452 cfs the dissolved solids content of the water was relatively uniform ranging from 145 to 172 mg/l. Hardness of the water ranged from 122 to 146 mg/l. The turbidity values, ranging from 2 to 30 mg/l as silica, indicate that the stream is clear most of the time; however, turbidity values are not available for flood flow and it is likely that they are quite a bit higher during floods or during rapid rises of the stream. The iron and manganese content of the water probably does not exceed 0.10 mg/l. The analyses of samples collected in April and June of 1966 indicate a zinc content of water in Shoal Creek ranging from 0.0 to 0.2 mg/l. Except for hardness, and possibly turbidity during high flows, water in Shoal Creek is of good quality and it is suitable for most uses. For some uses, however, softening would be desirable.

Spring River

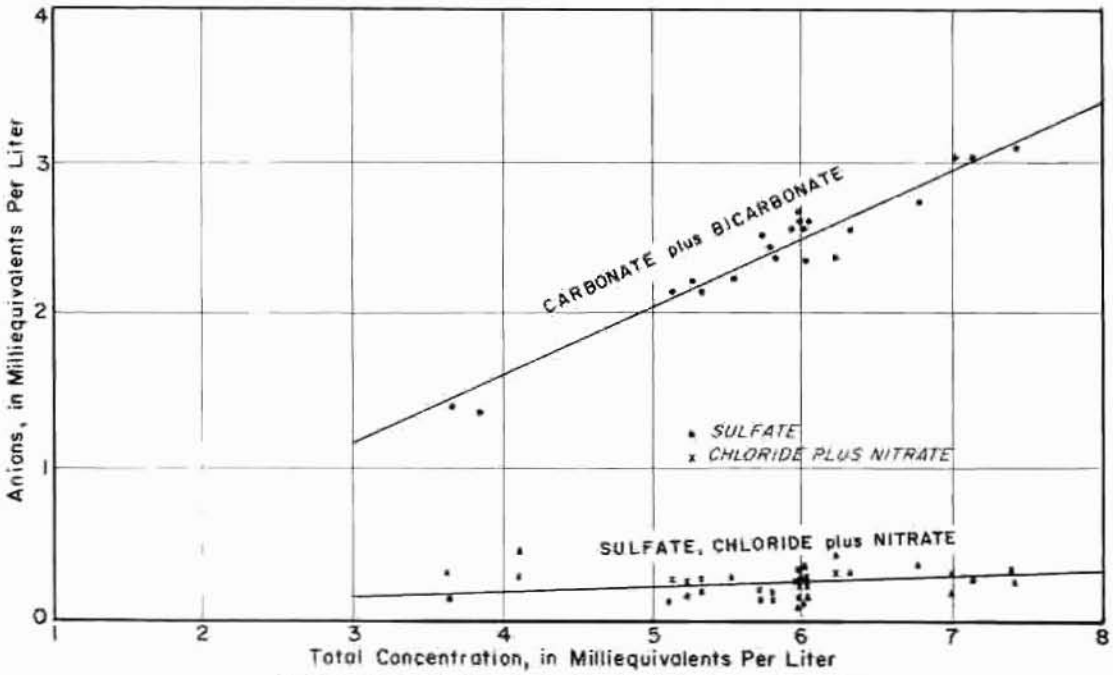
Water in Spring River is a hard, moderately mineralized calcium bicarbonate type. The dissolved-solids content ranges from 131 to 196 mg/l at flows ranging from 98 cfs to 2,430 cfs. Hardness of the water ranges from 84 to 171 mg/l. The sulfate content of water in Spring River near Waco is higher than that found in its headwaters due to addition of water from the Pennsylvanian rocks in the northern part of the basin. The iron and manganese are also slightly higher and at times the combined value exceeds the 0.3 mg/l limit recommended by the U. S. Public Health Service (1962) for potable waters. The analyses of samples collected in April 1966 indicated that the zinc content of water in Spring River is less than 0.05 mg/l. The observed turbidity values range from 5 to 100 mg/l as silica. The turbidity of water during floods or heavy runoff from the Osage Plains area of the basin likely is much higher than the observed maximum. Water in Spring River is adequate for most uses, but for municipal and some industrial uses the hardness and, at times, the combined iron and manganese content and the turbidity are excessive.

Center Creek

The water in Center Creek above Grove Creek is like the water in Shoal Creek. Grove Creek discharges waste into Center Creek which contains large



A. Relation of Cations to Total Concentration



B. Relation of Anions to Total Concentration

Figure 27. Graphs showing relation of cations and anions to total concentration, Spring River basin, except Center Creek below Grove Creek and the lower reach of Turkey Creek.

Source	Quantity available	Quality available
Deep aquifers		
Wells ----------	40 to 500 gpm Most yield between 100-300 gpm	Observed range of total dissolved solids 140-290 mg/l, median value 227 mg/l Major constituents, Ca, Mg, HCO_3 Significant minor constituents, SO_4, silica
Shallow aquifers		
Mines ----------	50 to 1,000 gpm Most yield between 200-500 gpm	Observed range of total dissolved solids 329-2,200 mg/l, median value 1,080 mg/l Major constituents, Ca, SO_4, HCO_3 Significant minor constituents, Zn, Mn, Fe
Wells ----------	5 to 300 gpm Most yield between 10-50 gpm	Observed range of total dissolved solids 162-981 mg/l, median value 288 mg/l Major constituents, Ca, HCO_3 Significant minor constituents, NO_3, SO_4
Springs ----------	25 to 9,000 gpm Most yield between 100-500 gpm	Observed range of total dissolved solids 123-520 mg/l, median value 186 mg/l Major constituents, Ca, HCO_3 Significant minor constituents, NO_3
Streams 1/		
Spring River near Waco, Mo. ----------	Period of continuous discharge record 1924 to 1966 Max. discharge - 103,000 cfs Min. discharge - 4.2 cfs Avg. discharge - 814 cfs Discharge exceeded 90% of time = 56 cfs	Observed range of total dissolved solids 131-196 mg/l Major constituents, Ca, HCO_3 Significant minor constituents, observed turbidity range 5 to 100 mg/l as silica
Shoal Creek above Joplin, Mo. ----------	Period of continuous discharge record 1941 to 1966 Max. discharge - 62,100 cfs Min. discharge - 12 cfs Avg. discharge - 369 cfs Discharge exceeded 90% of time = 76 cfs	Observed range of total dissolved solids 145-172 mg/l Major constituents, Ca, HCO_3 Significant minor constituents, observed turbidity range 2 to 30 mg/l as silica
Center Creek near Carterville, Mo. --------	Period of continuous discharge record 1962 to 1966 Max. discharge - 5,180 cfs Min. discharge - 16 cfs Avg. discharge - insufficient data (regulated stream) low flow affected by industrial discharge	Observed range of total dissolved solids 153-545 mg/l Major constituents, Ca, HCO_3 Significant minor constituents, Zn, F, NO_3, NH_4PO_4
Turkey Creek near Joplin, Mo. ----------	Period of continuous discharge record 1963 to 1966 Max. discharge - 3,520 cfs Min. discharge - 1.8 cfs Avg. discharge - insufficient data (regulated stream) low flow affected by sewage effluent	Observed range of total dissolved solids 316-610 mg/l Major constituents, Ca, HCO_3 Significant minor constituents, detergents, phosphates components of the nitrogen cycle. Observed range of oxygen saturation 11 to 134 percent.

1/ Data collected at continuous-record station

Table 10. Summary of quantity and quality of water supplies available in the Joplin area, Mo.

quantities of fluoride, nitrate, phosphate, and ammonia nitrogen. Much of the waste water was pumped from old mine workings which contribute manganese, zinc, and sulfate to Center Creek. In addition, the natural discharge of 3-6 cfs of ground water from the Oronogo-Duenweg mining belt to Center Creek adds to the loads of these constituents already present in the stream. Overland runoff from tailings piles also contributes to the chemical loads in Center Creek. Since most of this action occurs during heavy rains dilution reduces the effect. Zinc contents as high as 69 mg/l have been measured in drainage from tailings piles. Analysis of samples collected on a seepage run on Center Creek on August 4, 1966 indicate that zinc content of water in Center Creek comes from Grove Creek and from influent seepage below Grove Creek. At Fidelity, Mo., the zinc content of water in Center Creek was 0.0 mg/l. In Grove Creek the zinc content was 9.7 mg/l, and at the gaging station on Center Creek the zinc content was 0.82 mg/l. Downstream from the gaging station the zinc content varied from 0.41 to 1.0 mg/l.

Monthly samples show that the dissolved-solids content of water in Center Creek ranges from 153 to 595 mg/l; however, the maximum conductance obtained by a continuous recorder at this site was 1,510 micromhos indicating that at times the dissolved-solids content has been as much as 1,000 mg/l. Although the dissolved-solids content of the water generally is not excessive, the large concentrations of fluoride, nitrate, and phosphate render the water below Grove Creek unfit for many uses.

TURKEY CREEK

Water in Turkey Creek is a calcium bicarbonate-sulfate type. Most of the streamflow is derived from municipal and industrial effluents in Joplin; consequently, the concentrations of most constituents are higher than those found in other streams in the area. The dissolved-solids content of the water ranges from 233 to 610 mg/l. Hardness of the water ranges from 153 to 367 mg/l. The effects of municipal and industrial wastes are shown by the concentrations of detergents, phosphates, components of the nitrogen cycle, and dissolved oxygen. Detergents as MBAS, (methylene blue active substances) range from 0.1 to 3.2 mg/l; phosphorus as PO_4 ranges from 0.81 to 22 mg/l; nitrate ranges from 0.2 to 26 mg/l; organic and ammonia nitrogen ranges from 0.33 to 10 mg/l. The dissolved oxygen content ranges from 1.0 to 11.2 mg/l and the oxygen saturation ranges from 11 to 134 percent.

POTENTIAL AND CONSEQUENCES OF DEVELOPMENT

The utility of a water supply at a given location depends upon its quantity, quality, cost of extraction, and the cost of disposal of the used water. The sources of water in the Joplin area are wells in the deep and shallow aquifers, streams, springs, and Mines. The quantity and quality of water available from the various sources in the Joplin area are summarized in table 10. The shallow aquifer supplies water to wells springs, mines, and streams. The shallow aquifer also recharges the deep aquifer. Due to the intimate relationship of the various sources which comprise the area's hydrologic system, plans for development of any part of the system will have to include consideration of the effects on other parts of the system.

The average daily use of water by municipalities and industries in the Joplin area for 1965 is shown in table 11. In addition to the quantity of water used by municipalities and industries, households and farms use a total of about 1 mgd of water principally

	Deep wells	Mines	Springs	Streams	Totals
Municipal	4.8 mgd	0.0	0.0	7.2 mgd	12.0 mgd
Industrial	1.3 mgd	2.8 mgd	1.4 mgd	0.9 mgd	6.4 mgd
					18.4 mgd

Table 11. Average daily use of water by municipalities and industries

wells. Some water from streams and wells is used for irrigation in the area, but intermittent use makes estimates difficult. The average daily use of irrigation water in 1965 was about 1 mgd. However, most irrigation occurs during dry periods so that the pumping rate at those times would be much higher than 1 mgd.

An idea of the potential of the Joplin area's water supply for further development can be illustrated by comparing the average outflow from the area, about 1,000 mgd, to the average use in 1965, about 20 mgd. Even the lowest recorded average annual outflow (about 100 mgd, 1954 water year) was substantially greater than the 1965 usage. Of course localized water shortages may develop during dry periods, or individual wells may have insufficient yields, but proper management of the area's water supply should eliminate major water supply problems.

DEEP AQUIFERS

Wells in the deep aquifers are generally capable of greater yields than wells in the shallow aquifer. In the vicinity of Joplin and Carl Junction well yields are generally less than 100 gpm, while in other portions of the area yields of 300 gpm are common. Outside the vicinity of Joplin and Carl Junction properly spaced wells will generally provide enough water for a moderate-sized municipality or industry.

The water is of good quality and uniform temperature. Because the head difference between the deep and shallow aquifers favors downward leakage, the deep aquifers are susceptible to contamination from the shallow aquifer. When new wells are completed and old wells are abandoned, care should be taken to prevent contamination from the shallow aquifer.

SHALLOW AQUIFER

Wells and Springs

Because of the generally small yields of wells in the shallow aquifer, most of its future development will be restricted to small capacity domestic and farm wells. Well yields from the shallow aquifer generally range between 10 and 25 gpm, but yields of up to 300 gpm can be obtained in breccia areas or from solution channels. Geophysical methods and test drilling may be used to find water supplies in solution channels. The location of breccia areas can be obtained from maps (Mo. Geol. Survey, 1942) and from resistivity surveys.

The chemical quality of water in the shallow aquifer is quite variable. Changes in the natural calcium bicarbonate character of the water are caused principally by contact of the water with sulfide mineral deposits and by seepage of contaminated water from the land surface. The end result of exposure to sulfide minerals is an increase in the calcium, sulfate, and dissolved-solids content. Contamination from surface sources is indicated by an increase in the nitrate and chloride content of the water. Due to the rapid circulation of water in limestone aquifers, and their inability to filter contaminated water, the danger of contamination of the shallow aquifer is always present. Where shallow well water is used for human or stock consumption the water should be sampled periodically for bacteriological contamination. The Division of Health in the Department of Public Health and Welfare in Jefferson City, Mo., can furnish information on having samples analyzed. Contamination of the shallow aquifer also affects springs; therefore springs should also be tested before being used for human consumption.

Both springflow and the base-flow of streams are dependent on ground water from the shallow aquifer for their supply. Excessive pumping from a well located near a spring can reduce or stop springflow if a connection exists between the two sources. This reduction can become important during dry periods. A large increase in numbers of wells pumping from the shallow aquifer in an area could reduce the base-flow contribution of that area. During a drought the use of well water would probably increase resulting in not only a reduction in base flows, but a diversion from storage in the ground. This water would have to be replaced before the streamflow could be restored. Problems could develop due to reductions of streamflow. In the Shoal Creek basin, where most of the base flow is supplied by springs, consumptive use of these springs could drastically reduce base flow during dry periods.

Mines

Abandoned mines in the vicinity of Joplin contain large quantities of water, and if the quality of water, in a mine is adequate for the intended use, the mines are potential sources of water supply. Yields over 500 gpm are common, and some workings should yield over 1,000 gpm. In addition to high-sustained yields some mines contain billions of gallons in storage. Because interference between neighboring users

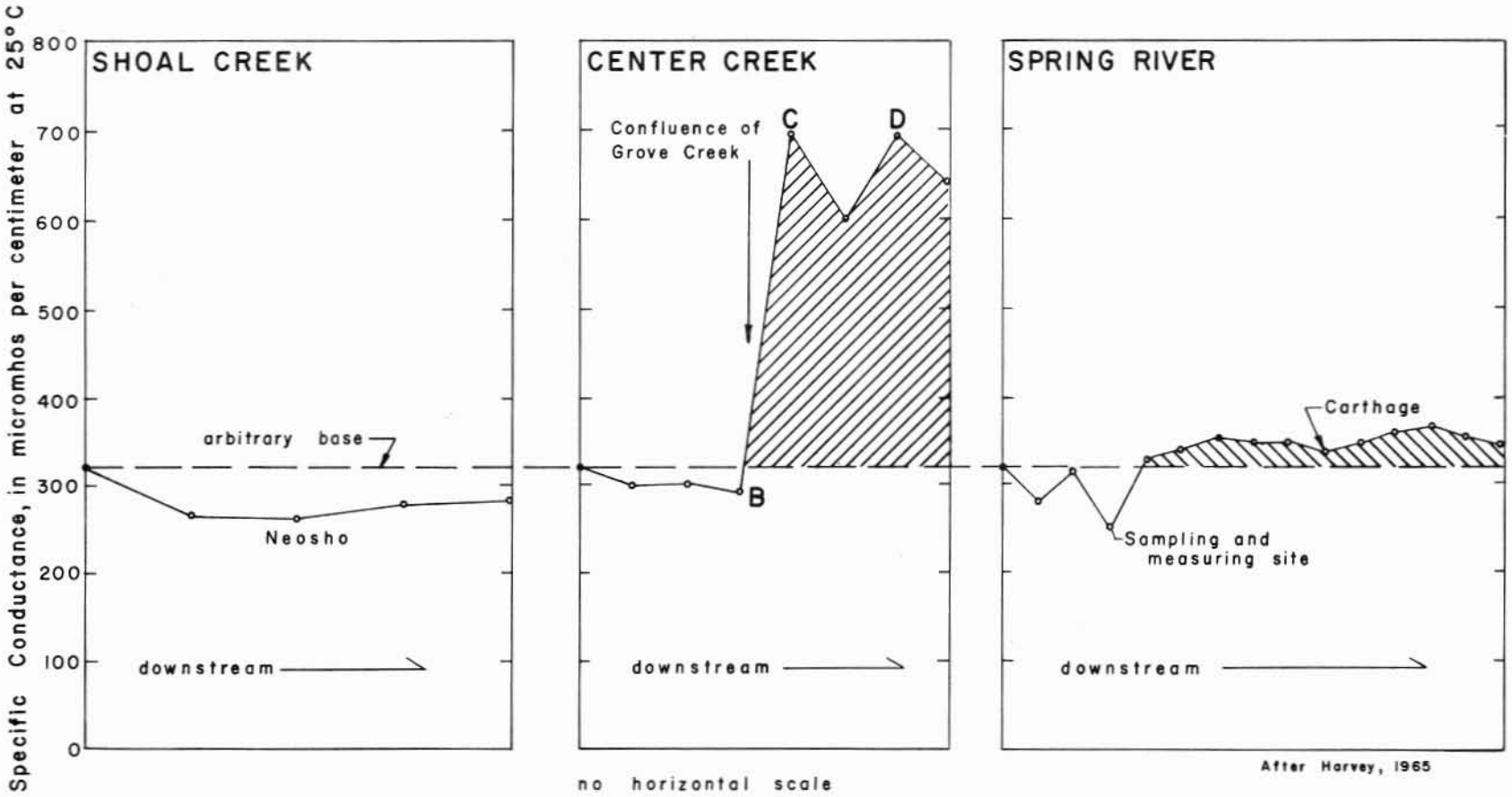


Figure 28. Graphs showing comparison of specific conductance of water in Shoal Creek, Center Creek, and Spring River, August 1964.

could reduce the yield of individual mines in a hydrologically continuous mining field like the Oronogo-Duenweg belt, coordination of withdrawals among users is essential for optimum development.

The mine waters are, in general, of much poorer quality than water from other sources, and the disposal of waste water from mines could create problems in the receiving stream. Because of the many variables which control the chemical quality of water in the mines and the chemical reactions after the water is discharged to the stream, it is difficult to predict the extent of deterioration in the quality of water in the receiving stream.

Discharge measurements on Center Creek during low-flow indicate that the natural discharge of the creek, from mines in the Oronogo-Duenweg belt, is in the range of 3 to 6 cfs. The zinc content or the concentration of other constituents can be calculated from the following formula, assuming no chemical reactions,

$$Q_1C_1+Q_2C_2=Q_3C_3,$$

where Q_1= discharge in creek upstream from mine water seepage,

C_1= zinc content of creek upstream from mine water seepage,

Q_2= mine water seepage to creek,

C_2= zinc content of mine water,

Q_3= discharge of creek downstream from mine water seepage,

C_3= zinc content of creek downstream from mine water seepage.

Assuming mine water seepage of 3 cfs, a zinc content of mine water of 7.7 mg/l (median zinc content of mines, from table 5), the 7-day Q_2 of Center Creek above the mines of 35 cfs (Center Creek near Webb City, table 7), and the zinc content in Center Creek upstream from the mine seepage is 0.0 mg/l, the zinc content of water in Center Creek below the mine seepage would be $\frac{3x7.7+35x0}{38}$=0.6 mg/l of zinc, assuming no precipitation or adsorption. If other conditions remained the same and mine seepage increased to 6 cfs the zinc content of water in Center Creek would be $\frac{6x7.7+35x0}{41}$=1.1 mg/l of zinc. These calculations are indicative of the range in zinc concentration. In order to measure the effects of the disposal of mine water into Center Creek, discharge measurements were made and zinc samples were collected on Grove Creek (which was discharging pumped mine water to Center Creek) and on Center Creek above and below Grove Creek on August 4, 1966. The discharge and zinc concentration in Center Creek above Grove Creek (Station 411) was 24.9 cfs and 0.0 mg/l zinc; for Grove Creek (Station 424) 4.17 cfs and 9.7 mg/l and for Center Creek near Carterville (Station 412) 29.1 cfs and 0.82 mg/l. The calculated zinc content of water in Center Creek below Grove Creek is $\frac{24.9x0.00+4.17x9.7}{29.1}$=1.4 mg/l but the determined zinc content near Carterville was 0.82 mg/l. The difference in the calculated and determined zinc concentrations is probably a result of precipitation and/or adsorption of the zinc in the bed of the stream.

If the mines were heavily pumped or completely dewatered and the water discharged into a stream, the chemical quality of water in the stream would deteriorate. In March 1905, during a period of intensive mining and dewatering in the vicinity of Joplin, samples collected from streams in the area showed zinc concentrations ranging from 0.3 to 732 mg/l and dissolved-solids content ranging from 180 to 3,800 mg/l (Bailey, 1911). The analysis of waters in mines during a period of mining activity (date not given) shows the zinc content ranging from 73 to 4,867 mg/l.

As the water level in a mine is lowered, sulfide minerals are again exposed to rapid oxidation and solution, thereby increasing the zinc and dissolved-solids contents of the mine water. Though final concentrations cannot be predicted, the concentration of calcium, sulfate, and heavy metals will generally increase. Plans based on chemical analysis of mine water before pumping will generally have to be revised because of water chemistry changes as pumping proceeds.

STREAMS

QUANTITY AVAILABLE

The streams of the area offer the greatest potential for development of large water supplies. Up to now droughts have not seriously endangered water

supplies from streams and proper development of the streams in the area will reduce the threat of water shortages during droughts. Storage facilities for low-flow augmentation, and deep wells used to supplement stream supplies, are the two best solutions to potential shortages.

Substantial quantities of water are available for storage impoundments, but care must be exercised in locating the structures because of the possibility of large seepage losses in some areas. Studies of 12 lake sites by the Missouri Geological Survey and Water Resources (written communication) indicate that small lakes are not feasible in the area south of Interstate Highway 44 because of cavernous bedrock and permeable residuum.

The best sustained yields to base flow occur in the southern and eastern portion of the area, where the shallow aquifer has the greatest capacity to store and transmit water. The eastern quarter of the Spring River and Center Creek basins supply about 80 and 40 percent of the respective streams' base flow. The eastern half of the Shoal Creek basin in the southern portion of the area contributes approximately two-thirds of the base flow. Measurable base-flow losses occur in the western portions of Center Creek and Spring River basin during low-flow periods. Pumping plants along these reaches would be especially susceptible to shortages during droughts.

QUALITY OF WATER

The chemical quality of water in Shoal Creek, Spring River, and in Center Creek above Grove Creek is relatively uniform and suitable for most uses. Of these three streams, Shoal Creek has the lowest dissolved-solids content.

Center Creek downstream from the mouth of Grove Creek, and Turkey Creek carry industrial and municipal wastes and under present conditions are unsuitable for many uses. Low-flow augmentation or additional treatment is needed on these streams in order to improve their quality to acceptable levels. Low-flow augmentation could alleviate some problems on these streams, but not all of them. Under present conditions the average discharge of Center Creek upstream from Grove Creek, which is the theoretical maximum draft which could be obtained from a storage facility, is not sufficient to dilute all the objectionable constituents in the creek to acceptable levels. For example, the average fluoride content of 50 water samples collected at the Center Creek station near Carterville was 16 mg/l. With a discharge of 26 cfs (7-day Q_2) and fluoride content of 16 mg/l, it would take an additional 250 cfs to dilute the fluoride to the level of 1.5 mg/l. However, the 170 cfs estimated average discharge of Center Creek above Grove Creek is insufficient to dilute the fluoride content to an acceptable level.

During low-flow periods the flow in Turkey Creek is mostly sewage waste effluent, and the only way to improve the quality of water in this stream is to increase the degree of treatment of the wastes before they are discharged to the stream.

Abandoned coal strip mines and proposed new coal mining operations in the northwestern portion of the Spring River basin are a potential source of pollution in the North Fork of Spring River. However, at the present time (1968) no pollution is occurring. Intense local thunderstorms, which are common in the area, could wash a slug of acid mine water or acid from spoil banks, into the stream causing a temporary deterioration in water quality, possibly resulting in a fish kill. Despite the very low flows of North Fork of Spring River during base-flow periods (7-day Q_2, 0.1 cfs) the stream contains numerous large pools which store enough water to dilute most small slugs to safe limits within a short distance downstream.

FLOODS

Although floods have not been a serious problem in the past, future development of the area may create problems. Increased urbanization will reduce infiltration of precipitation. That portion of a rainfall which would have infiltrated into the soil, is prevented from doing so by paved streets, buildings, parking lots, etc., and becomes part of the overland runoff to streams. The result is that, as urbanization spreads, similar rainfalls will cause constantly increasing flood peaks. Industrial and domestic structures which encroach on flood plains will not only be subject to larger and more frequent floods, but constrictions in the channel caused by structures on the flood plain will result in higher flood stages. In general, developments which are highly susceptible to flood damage or which seriously retard overbank flows should not be located within the flood-plain areas.

Some action should be taken toward the adoption of suitable flood-plain regulations for the area. Some of the various actions that could be taken are (1) establishment of channel and floodway encroachment lines (2) zoning ordinances (3) sub-division regulations (4) building codes (5) open area regulation, and (6) floodproofing requirements.

With proper management of its water resources the Joplin area should have no serious water problems in the foreseeable future.

CONCLUSIONS

1. In 1965 about 20 mgd of water was used in the area. This is about 2 percent of the average daily outflow and 20 percent of the lowest daily flow on record (1954). Almost half of the water used in the area is pumped from streams. The remainder is pumped from mines, wells, and springs. Due to the interrelationships between the various sources of water in the area, plans for development of any part of the hydrologic system will have to include consideration of the effects on other parts of the system.

2. The deep aquifers are an important source of water for future development by small towns and industries. Because of the good chemical quality of the water it generally requires no treatment. However, the aquifers are susceptible to contamination by leakage from the overlying aquifers and improperly constructed wells. Therefore, proper well construction is essential to protect the quality of water.

3. Springs and wells in the shallow aquifer furnish water supplies for farms and industries. Water from this same aquifer maintains the base flow of the area's streams. Most wells in the shallow aquifer yield 10 to 50 gpm, but wells in brecciated areas can yield up to 300 gpm. The shallow aquifer is highly susceptible to contamination from waste disposal systems, feed lots, mines, etc., and can affect the streams.

4. The old mine workings contain large quantities of water in storage. The water generally is of poorer quality than that from other sources, but it is adequate for some industrial uses. The disposal of large quantities of mine water into the streams would probably raise the concentrations of some constituents above the limits imposed by the proposed water quality standards for streams in the area so that facilities for the treatment of mine water waste effluents may be required.

5. The streams in the area have the greatest potential for the development of large water supplies. Storage impoundments can make substantial additional quantities of water available during dry periods. The use of deep wells to supplement stream water withdrawals during dry periods should be considered. Spring River, Shoal Creek, and Center Creek (upstream from Grove Creek) have good quality water, but Center Creek downstream from Grove Creek and Turkey Creek have sufficient waste to render them unsuitable for certain uses. Treatment will be required to bring them up to quality standards proposed for interstate streams.

6. Floods are not a serious problem at present. However, increasing urbanization without proper zoning in the Joplin-Webb City-Carthage area could create problems.

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APPENDIX I

WELL DATA FROM SELECTED WELLS IN FORMATIONS OF CAMBRIAN AND ORDOVICIAN AGE, JOPLIN AREA, MO.

Formation symbols: Pcc, Cherokee Group; Mbk, Burlington and Keokuk Limestones; Mw, Warsaw Formation; Mg, Elsey Formation; Or, Roubidoux Formation; Og, Gasconade Dolomite; Єe, Eminence Dolomite; Єdd, Derby-Doerun Dolomite; PЄ, Precambrian. (Data compiled from Ground-Water Maps of Missouri, Well Data, 1963, by Charles E. Robertson, Missouri Geological Survey and Water Resources.)

Map number Plate 1	Mo. Geol. Survey log Number	City well	Location	Surface formation	Basal formation penetrated		Well depth (ft)	Casing depth (ft)	Static water level feet below land surface	Yield in gpm		Specific capacity gpm/ft of drawdown	
					Formation	Depth penetrated				Before acidizing	After acidizing	Before acidizing	After acidizing
200	7,170	Aurora 1	T26N,R26W, sec. 12	Mbk	Єe	5	1,240	327	195	250	350	1.5	6.0
201		Aurora 2	T26N,R26W, sec. 12	Mbk	Og	365	1,275	376	252	150	350	2.5	2.1
205	4,238	Mt. Vernon 2	T28N,R26W, sec. 31	Mbk	Єe	10	1,115	266	129	450	---	12.3	---
207	2,106	Pierce City 1	T26N,R28W, sec. 21	Mbk	Og	70	1,000	295	120	233	---	---	---
208	11,891	Pierce City 2	T26N,R28W, sec. 21	Mbk	Og	215	1,160	409	38	320	---	4.6	---
210	17,949	Exeter	T23N,R28W, sec. 34	Mg	Or	170	990	334	81	200	---	1.6	---
212	13,984	Monett 5	T26N,R29W, sec. 30	Mbk	Єdd	55	1,600	500	180	162	185	---	2.1
213	14,322	Monett 6	T26N,R27W, sec. 31	Mbk	Єdd	20	1,550	500	198	15	100	0.2	1.0
214	11,439	Purdy	T24N,R28W, sec. 2	Mbk	Og	22	931	392	105	260	---	3.5	---
215	17,737	Diamond	T26N,R31W, sec. 10	Mbk	Єe	25	1,250	518	40	30	---	0.3	---
223	9,511	Carthage 1	T28N,R31W, sec. 5	Mw	Єe	25	1,250	430	110	360	400	1.2	2.6
225	16,906	Duenweg 2	T27N,R32W, sec. 10	Mbk	Og	298	1,228	342	90	100	---	1.1	---
235	2,731	Webb City 7	T28N,R32W, sec. 18	Mw	Єe	165	1,415	---	242	240	---	---	---
236	4,142	Golden City 2	T31N,R29W, sec. 26	Mw	Og	148	893	400	155	150	---	5.2	---
239	9,604	Monett 1	T26N,R27W, sec. 31	Mg	Єe	25	1,200	415	184	350	---	2.1	---
240	1,872	Carthage 6	T28N,R31W, sec. 3	Mw	PЄ	17	1,854	---	170	242	---	1.9	---
241	12,618	Lamar 2	T32N,R30W, sec. 18	Pcc	Og	35	981	575	247	30	320	---	5.6

APPENDIX II

A METHOD FOR ESTIMATING THE DEPTH A WELL MUST BE DRILLED TO PENETRATE THE DEEP AQUIFER

To estimate the depth a well must be drilled to penetrate the deep aquifers, the following procedure can be used.

1. Locate the proposed well site on a topographic map and determine the altitude at the site.

2. Locate the site on figure 5 and determine the altitude of the top of the Ordovician.

3. Subtract the altitude of the top of the Ordovician from the altitude at the site to obtain an estimate of the depth to the Ordovician.

4. Determine the approximate thickness of the deep formations overlying the desired aquifer from table 1. More exact determinations of formation thickness can be obtained by referring to logs on file with the Missouri Geological Survey and Water Resources, Rolla, Mo.

5. The approximate footage to be drilled is equal to the sum of the depth from the surface to the top of the Ordovician and the thickness of formations overlying the desired aquifer.

APPENDIX III

CHEMICAL ANALYSES OF WATERS FROM THE JOPLIN AREA, MO.

Chemical analyses of water from wells in Cambrian and Ordovician rocks (data in milligrams per liter [1] except as indicated)

Map number (Plate 1)	Owner	Owner's well number	County	Depth	Date of collection	Temperature (°C)[2]	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$: Calcium Magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color	Turbidity
200	City of Aurora	1	Lawrence	1,240	1-10-62	--	8.0	0	44	22	2.4		240	3.7	3.9	0.1	0.1	263	200	6	---	7.5	--	0.1
201	City of Aurora	2	Lawrence	1,275	2-2-61	--	11	0.3	43	22	1.8		238	5.8	3.6	---	.1	229	200	4	---	7.5	--	.1
202	City of Aurora	4	Lawrence	1,196	1-21-63	--	6.0	.01	45	18	2.6	1.5	240	---	4.3	.1	.1	191	186	0	---	7.6	--	.1
203	City of Marionville	1	Lawrence	1,000	8-24-61	--	9.0	.02	34	18	2.7		187	4.1	3.2	---	.0	185	160	8	---	7.6	--	.2
204	City of Miller		Lawrence	1,075	8-15-60	--	8.0	.02	40	18	2.7		204	6.6	5.5	---	.5	236	176	8	---	7.4	--	.2
205	City of Mt. Vernon	2	Lawrence	1,115	6-6-47	--	8.0	.06	42	18	3.5		205	7.4	5.9	---	.1	---	177	9	---	7.4	--	.1
206	Mo. State Sanatorium	2	Lawrence	1,108	1-16-63	--	6.0	.02	33	16	1.8	.8	178	4.1	4.3	.1	.0	167	150	4	---	7.8	--	.2
207	City of Pierce City	1	Lawrence	1,000	10-8-62	--	8.0	.10	32	17	2.3	.7	182	8.0	4.8	.1	.0	161	150	1	---	8.4	--	1.2
208	City of Pierce City	2	Lawrence	1,160	6-14-57	--	8.0	.07	30	16	1.6		162	7.6	3.9	---	.2	175	142	9	---	7.6	--	.1
209	City of Verona	3	Lawrence	1,100	5- -46	--	---	.04	31	12	30		250	14	4.0	---	----	215	145	0	---	--	--	0
210	City of Exeter		Barry	990	4-24-61	--	12	.09	43	21	2.8		227	8.4	4.1	.1	.1	248	196	10	---	7.6	--	.1
211	City of Monett	4	Barry	1,270	8-13-62	--	8.0	.02	51	21	12	1.0	209	39	22	.1	.0	283	214	45	---	7.6	--	.1
212	City of Monett	5	Barry	1,600	6-25-56	--	6.0	.10	30	16	8.5		156	15	8.8	---	.1	191	140	12	---	7.6	--	.6
213	City of Monett	6	Barry	1,550	9-1-61	--	8.0	.05	37	21	2.8		206	12	4.5	---	.1	208	180	14	---	7.6	--	.1
214	City of Purdy		Barry	931	10-17-62	--	8.0	.06	43	18	2.9	.6	222	13	5.2	.1	.0	232	184	2	---	7.5	--	.1
215	City of Diamond		Newton	1,250	5-1-63	--	6.0	.35	35	17	2.9	1.8	178	12	5.2	.1	.0	194	158	12	---	7.6	--	.4
216	City of Granby	1	Newton	968	5-15-62	--	8.0	.07	38	18	6.1		203	13	6.9	.1	.0	201	168	4	---	7.6	--	.1
217	Reddings Mill		Newton	710	10-18-62	--	6.0	.90	27	14	11	.8	157	14	7.8	.2	.0	166	126	0	---	7.7	--	.2
218	City of Alba		Jasper	986	1-10-62	--	7.0	.04	46	18	7.9		221	12	8.2	.2	.1	290	186	7	---	7.4	--	.1
219	City of Asbury		Jasper	925	1-31-62	--	8.0	.35	42	17	9.3		209	14	3.9	.5	.0	227	174	5	---	7.6	--	.8
220	Atlas Chemical*	6	Jasper	1,402	6-4-65	20	9.4	.00	44	16	6.2	1.8	175	47	2.8	.2	.2	214	176	32	369	7.7	6	--
221	City of Carl Junction	1	Jasper	900	3-25-63	--	8.0	.24	45	20	7.2	1.8	228	18	6.9	.5	.1	227	196	9	---	7.4	--	.2
222	City of Carl Junction	2	Jasper	860	2-12-58	--	7.0	.40	47	22	8.8		235	23	7.7	---	.0	270	208	15	---	7.5	--	.0
223	City of Carthage*	1	Jasper	1,250	6-4-65	18	9.6	.01	74	11	6.5	1.3	245	27	7.2	.1	12	284	230	28	467	7.8	5	--
224	Conner Hotel		Jasper	1,300	6-9-37	--	7.2	1.2	50	16	8.8		168	60	9.3	.2	.0	270	191	54	---	--	--	--
225	City of Duenweg	2	Jasper	1,228	5-1-63	--	5.0	---	37	19	3.4	2.0	194	12	4.8	.1	.0	253	168	9	---	7.6	--	.1
226	Hercules Powder*	3	Jasper	1,473	6-4-65	20	9.6	.80	40	16	8.8	1.7	204	14	3.8	.4	.0	186	166	0	347	8.0	6	--
227	City of Jasper		Jasper	601	6-8-62	--	8.0	.14	33	16	15		184	12	11	.3	---	186	148	0	---	7.7	--	.4
228	Junge Baking Co.		Jasper	990	3-1-32	--	6.8	.20	29	15	8.8		257	13	2.8	---	2.7	229	136	15	---	---	--	--
229	City of Oronogo	1	Jasper	1,335	10-1-58	--	10	1.7	38	19	14		209	17	9.0	---	.0	276	175	5	---	7.6	--	1.6
230	City of Oronogo	2	Jasper	925	9-26-61	--	6.0	.3	38	19	12		209	16	8.6	---	.1	236	176	7	---	---	--	2.0
231	City of Purcell		Jasper	865	9-21-62	--	8.0	.04	46	19	9.8	1.1	234	13	11	0.2	0.0	218	196	4	---	7.5	--	0.1
232	City of Sarcoxie	1	Jasper	1,100	8-2-49	--	6.0	.06	27	13	4.4		130	13	6.3	---	1.7	268	122	15	---	7.6	--	.1
233	City of Sarcoxie	2	Jasper	1,258	11-6-62	--	7.0	.04	25	12	2.0	.8	120	12	4.8	.1	.0	140	112	14	---	7.9	--	.1
234	City of Webb City*	1	Jasper	850	6-4-65	19	9.3	.04	42	18	3.7	2.0	207	18	1.7	.2	.0	197	179	10	351	7.9	6	--
235	City of Webb City*	7	Jasper	1,415	6-4-65	20	10	.39	64	21	4.3	1.6	228	68	1.7	.1	.0	284	246	59	474	7.8	7	--
236	City of Golden City	2	Barton	893	5-28-63	--	7.0	.40	29	15	3.7	1.5	154	9.9	5.6	.1	.0	183	134	8	---	7.9	--	.2
237	City of Lamar	1	Barton	971	12- -53	--	6.0	.20	44	22	17		210	40	8.7	.3	.7	270	198	26	---	7.3	--	.2

*Analysis by U.S.G.S. All others by Missouri Division of Health or Missouri Geological Survey and Water Resources.

1/ In this concentration range milligrams per liter and parts per million are numerically equal.

2/ °F = 9/5 (°C) + 32.

APPENDIX III (continued)

Spectrographic analyses of water from wells in Cambrian and Ordovician rocks
(data in micrograms per liter)

Map Number (Plate 1)	Well Number	Aluminum (Al)	Barium (Ba)	Beryllium (Be)	Boron (B)	Chrominum (Cr)	Cobalt (Co)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Lithium (Li)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Rubidium (Rb)	Silver (Ag)	Strontium (Sr)	Tin (Sn)	Titanium (Ti)	Vanadium (V)	Zinc (Zn)	Zirconium (Zr)
220	Atlas Chemical No. 6	8	110	<0.7	47	< 3	< 3	0.8	9	< 4	12	6	1	< 2	3	<.2	100	< 3	< 2	< 2	<100	< 3
223	Carthage No. 1	8	80	< .9	30	< 4	< 4	4	8	< 4	3	5	< .9	< 2	1	<.2	90	< 4	< 2	< 2	150	< 4
226	Hercules Powder No. 3	9	130	< .7	54	< 3	< 3	1	70	< 3	13	5	.6	< 2	2	<.2	90	< 3	< 2	< 2	<100	< 3
234	Webb City No. 1	12	100	< .7	37	< 3	< 3	.5	50	10	16	4	< .7	< 2	4	<.2	90	< 3	< 2	< 2	<100	< 3
235	Webb City No. 7	18	120	< .9	33	< 4	< 4	.5	360	< 5	11	15	< .9	3	3	<.2	90	< 4	< 2	< 2	270	< 4

Analyses by U. S. Geological Survey

APPENDIX III (continued)

Chemical analyses of water from wells in rocks of Mississippian age
(data in milligrams per liter except as indicated)

Map number (Plate 1)	Well number	County	Depth	Date of collection	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Zinc (Zn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$: Calcium Magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
1	26N-28W-31cc	Barry	252	4-26-66	15	10	.13	.01	1.4	38	18	3.8	.5	297	1.6	13	.2	13	284	240	10	500	7.6	1
2	26N-31W-16bcc	Newton	120	4-29-66	17	8.5	.00	.01	.1	48	6.2	3.0	.5	154	6.2	2.3	.4	18	167	146	29	290	7.4	0
3	26N-33W-5bcd	Newton	---	6-8-65	18	9.5	0.10	0.00	1.5	40	5.1	5.7	1.0	264	11	11	0.9	4.6	270	238	19	471	8.1	0
4	26N-33W-23bda	Newton	---	6-9-65	18	9.7	.00	.00	.9	70	4.5	4.0	.5	222	12	5.2	.1	23	260	208	26	425	7.7	2
5	27N-28W-9aa	Lawrence	158	4-22-66	19	8.7	----	.00	.2	59	14	3.0	.6	216	14	3.9	.8	23	235	205	28	420	7.3	1
6	27N-28W-22bba	Lawrence	600	6-26-66	13	13	---	.00	5.8	112	6.8	16	5.1	306	13	36	.6	61	435	308	56	676	7.0	1
7	27N-31W-17bca	Jasper	123	6-3-65	17	9.0	.01	.00	.9	43	77.5	5.2	.6	170	3.6	1.0	.0	8.2	162	138	0	285	8.1	0
8	27N-32W-9abb	Jasper	170	6-3-65	19	9.0	.13	.02	2.7	102	5.7	5.3	1.0	244	88	4.1	.0	9.2	333	270	70	592	8.0	0
9	27N-32W-19abc	Newton	200	6-3-65	18	7.2	2.4	.00	.4	73	9.1	88	6.4	188	55	130	.0	28	502	220	66	877	7.7	0
10	27N-33W-7cba	Jasper	100	6-10-65	17	11	.19	.00	1.2	82	1.4	4.7	.4	186	60	3.4	.2	7.4	284	211	58	430	7.7	1
11	27N-33W-8bbb	Jasper	---	6-10-65	20	11	.82	.2	6.7	187	15	64	1.6	266	468	2.2	.1	1.5	881	575	310	1,170	7.9	3
12	27N-33W-25bdc	Newton	135	6-9-65	18	9.0	.00	.00	.2	63	9.8	3.2	.6	245	6.0	2.2	.0	3.8	224	203	7	392	8.3	0
13	27N-33W-28bad	Newton	255	6-9-65	18	12	.06	.00	1.2	58	1.3	4.4	.3	168	3.4	5.7	.1	16	203	153	13	315	7.6	1
14	27N-33W-29cab	Newton	---	6-8-65	17	8.6	.02	.00	----	33	14	5.6	2.0	171	15	1.3	.3	.4	164	140	0	293	7.9	6
15	27N-34W-13cb	Jasper	337	6-9-65	18	8.2	.32	.00	.9	68	76.7	7.6	.5	224	20	1.8	.2	2.5	230	189	5	389	7.8	1
16	28N-32W-2bab	Jasper	285	6-13-65	16	8.8	.22	.00	1.0	67	4.4	6.0	4.3	148	31	12	.1	46	257	185	66	416	7.9	4
17	28N-32W-6dcd	Jasper	206	6-2-65	17	5.6	.26	.01	1.0	48	5.4	3.2	.6	239	54	1.8	.0	4.2	295	244	52	478	8.2	0
18	28N-32W-16aaa	Jasper	255	6-3-65	17	8.3	.63	.03	1.1	75	14.9	3.9	.7	225	29	.2	.0	.0	235	204	19	395	8.0	0
19	28N-32W-28aab	Jasper	---	6-3-65	17	8.9	.26	.01	.9	95	10	20	3.5	143	141	17	.0	45	427	278	161	649	7.6	0
20	27N-32W-3b	Jasper	500	4-28-64	16	10	.58	.03	.4	80	1.9	8.0	2.5	[b] 245	17	1.0	.0	.2	244	208	8	403	8.3	3
21	28N-33W-3bc	Jasper	285	6-12-65	18	7.0	1.1	.02	.8	99	36	16	2.0	288	189	2.2	.4	.3	573	395	159	765	8.1	2
22	28N-33W-13cdb	Jasper	250	6-11-65	15	9.2	.50	.00	.2	69	4.5	5.9	.7	252	42	2.1	.2	.0	290	238	32	468	8.0	1
23	28N-33W-20aab	Jasper	100	6-10-65	19	9.6	.89	.00	.2	64	5.2	10	2.4	114	60	13	.2	40	289	181	88	425	7.5	4
24	28N-33W-22aba	Jasper	---	6-10-65	19	9.5	.82	.00	.5	109	5.6	7.2	.9	226	122	1.6	.3	.0	385	295	117	576	7.8	1
25	28N-33W-28cad	Jasper	263	6-10-65	21	7.9	.70	.02	1.2	76	6.4	4.5	.6	270	6.6	1.8	.2	.0	248	216	9	414	8.1	1
26	28N-33W-32bcc	Jasper	115	6-10-65	18	8.0	.03	.00	.1	69	17	11	2.8	310	15	4.1	.4	.6	283	242	0	496	8.2	5
27	28N-33W-35a	Jasper	260	4-29-64	16	9.6	.29	.03	.2	125	8.8	26	1.0	339	53	48	.0	.6	518	348	70	794	7.8	3
28	28N-34W-2aad	Jasper	---	6-11-65	16	22	.32	.00	.5	71	8.0	7.9	2.9	188	43	16	.4	10	300	210	52	455	7.6	2
29	28N-34W-24bbb	Jasper	---	6-10-65	17	8.8	.57	.00	.03	64	9.9	3.5	.5	220	17	1.0	.2	.0	218	197	16	378	8.0	2
30	28N-34W-36cad	Jasper	210	6-11-65	17	11	.89	.1	1.0	54	4.3	12	2.0	72	114	7.4	.4	.0	254	154	95	382	7.5	1
31	29N-31W-19bbb	Jasper	263	6-15-65	16	10	.01	.00	.9	221	13	17	4.9	326	86	55	.1	277	981	597	330	1,390	7.8	10
32	29N-31W-32bcb	Jasper	170	6-16-65	17	8.6	.23	.00	1.1	60	.5	4.2	3.4	139	23	7.2	.0	27	206	152	38	347	7.7	10
33	29N-32W-17bda	Jasper	60	6-13-65	16	12	.00	.00	1.4	122	2.8	8.8	1.1	339	24	9.8	.1	30	379	316	38	635	8.1	5
34	29N-32W-30cbb	Jasper	280	6-13-65	17	3.2	1.6	.04	.8	85	5.0	8.8	.5	214	57	4.6	.1	4.0	300	233	57	470	8.1	4
35	29N-33W-10abd	Jasper	---	6-11-65	16	3.4	.99	.01	.05	150	29	26	2.0	272	311	2.2	.3	.0	702	493	270	943	7.9	3
36	29N-33W-36cdb	Jasper	300	6-2-65	22	4.0	1.9	.00	.2	80	7.5	7.5	7.1	293	54	4.0	.1	.8	288	231	41	470	8.1	0
37	29N-34W-14aaa	Jasper	300	6-17-65	18	8.3	.44	.02	.5	109	30	15	2.9	248	222	1.7	.2	.0	526	396	193	774	8.2	5
38	30N-30W-16cd	Jasper	240	4-28-66	15	9.0	----	.02	3.1	136	16	62	13	174	69	107	.6	235	778	406	263	1,200	6.1	1
39	30N-32W-31ccc	Jasper	240	6-14-65	17	13	.22	.00	.4	164	9.1	106	20	236	228	50	.2	118	925	447	253	1,230	8.1	4

[a] Includes equivalent of 2 mg/l of carbonate (CO_3)

[b] Includes equivalent of 4 mg/l of carbonate (CO_3)

Analyses by U. S. Geological Survey

APPENDIX III (continued)

Chemical analyses of water from mine shafts and open pit lakes in rocks of Mississippian age

(data in milligrams per liter except as indicated)

Map number (Plate 1)	Mine name	Location	Depth	Date of collection	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Lead (Pb)	Zinc (Zn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum of constituents)	Hardness as $CaCO_3$: Calcium Magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
100	Athletic	27N-32W-3b1	245	2-5-64	16	10	2.7	0.6	0.07	0.04	11	254	8.4	9.9	0.8	219	508	4.5	0.5	0.1	980	669	489	1,180	7.3	1
101	San Gabriel	27N-32W-9b2	240	2-5-64	15	9.0	.05	.00	.06	.08	2.8	141	8.0	7.3	.8	197	232	4.5	.1	3.0	337	385	224	727	7.6	0
102	King William	27N-32W-3c1	209.1	2-5-64	14	8.8	.18	.00	.02	.02	5.7	96	3.3	4.2	.7	189	104	3.3	.0	3.1	329	248	93	514	7.7	0
103	St. Regis	27N-32W-3c2	210	2-5-64	--	8.0	.15	.4	.02	.02	35	144	4.7	6.8	1.2	94	344	7.0	.5	1.3	673	574	302	783	7.3	0
104	Gibson	27N-33W-6d	180.2	6-25-64	16	8.0	.00	.3	----	----	----	260	15	16	1.3	188	570	4.4	.3	.4	1,030	711	356	1,270	7.7	2
105	Kramer	27N-34W-2a	258	2-5-64	14	11	.65	5.4	.13	.05	10	260	31	81	12	32	956	13	5.9	9.2	1,510	777	767	1,720	5.8	4
106	Ice Plant	28N-32W-7d	188.2	2-5-64	13	12	.81	1.8	.05	.15	14	311	9.3	14	2.6	193	1,180	9.0	1.4	.7	1,970	1,310	1,160	2,050	7.1	0
107	Moer 8	28N-32W-8c1	139.9	6-24-64	15	14	1.3	1.9	----	----	8.8	330	14	14	4.0	257	1,210	9.5	1.7	8.6	2,030	1,380	1,250	2,130	7.0	3
108	Rhea	28N-32W-8c2	128.9	6-24-64	16	11	1.4	1.0	----	----	14	453	12	12	2.6	200	1,010	9.5	1.5	.0	1,730	1,190	1,020	1,880	7.4	1
109	McGregor	28N-32W-21r	173.3	6-24-64	17	17	2.3	.6	----	----	18	486	9.8	9.3	7.2	136	1,120	4.5	1.4	.9	1,860	1,250	1,140	1,960	7.0	2
110	Florine	28N-32W-28b1	201.2	6- -64	17	23	2.4	.2	----	----	6.0	378	5.1	8.7	2.6	75	900	3.5	1.1	.1	1,460	965	903	1,600	6.5	2
111	George B.	28N-32W-28b2	-----	7-10-64	16	26	33	1.0	----	----	23	357	11	9.0	2.9	76	1,350	2.6	1.1	.4	2,200	1,440	1,370	2,200	7.0	1
112	Nemnia	28N-32W-28c	190.6	6- -64	17	10	.17	.3	----	----	7.7	127	6.4	4.0	.7	242	232	2.5	.5	.8	663	344	227	676	7.2	2
113	Hyde Park	28N-32W-34d1	208.7	6-25-64	16	9.3	.14	.00	----	----	3.4	114	5.4	6.2	.7	190	155	4.5	.2	11	421	319	164	627	7.4	2
114	Vogey	28N-32W-34d2	173	2-5-64	16	18	.54	1.2	.02	.05	23	322	13	10	1.8	94	748	4.0	.7	.2	1,320	908	831	1,450	6.8	1
115	Holly	28N-33W-1d	154	6- -64	15	10	.37	.8	----	----	16	435	14	11	1.9	199	986	7.0	1.4	.0	1,630	1,140	981	1,840	7.2	3
116	No. 43	28N-33W-12a	168.1	6-26-64	18	9.8	7.8	1.1	----	----	25	468	12	17	2.2	197	1,080	7.0	1.2	.0	1,770	1,220	1,060	1,920	7.0	1
117	Bonny Wood	28N-33W-15c	90	7-10-64	15	11	.19	.00	----	----	.5	171	7.0	6.8	1.3	252	244	3.8	.0	1.0	603	456	249	868	7.8	4
118	Anderson	28N-33W-31c1	113.8	6-25-64	15	10	.10	.02	----	----	2.0	194	16	13	2.1	268	598	8.0	.4	.4	1,160	800	580	1,380	7.9	3
119	Anderson	28N-33W-33c2	125	4-29-64	14	11	.06	.00	----	----	2.2	304	9.3	16	2.0	277	576	9.5	.0	.3	1,130	797	570	1,360	7.4	3
120	Grumpy Girls Lake	27N-33W-36d	20	4-29-64	--	8.1	.06	.02	----	----	----	149	28	17	2.1	174	588	8.5	.4	.8	1,050	757	540	1,200	7.8	4
			70	4-29-64	17	8.1	.08	.02	----	----	----	256	23	12	1.9	183	596	7.0	.4	.5	1,080	742	592	1,260	7.5	5
			150	4-29-64	11	8.3	.02	.01	.04	.04	7.4	173	15	12	2.0	179	596	6.5	.4	.6	1,080	751	594	1,230	7.6	5
121	Unnamed Lake	28N-33W-7b	10	4-30-64	18	6.6	.06	.00	----	----	.5	137	8.2	5.0	2.4	122	272	2.0	.6	.1	500	376	276	687	8.0	5
			50	4-30-64	9	11	.09	.01	----	----	.6	276	15	8.3	2.0	199	571	5.0	.7	5.8	1,080	756	592	1,280	7.3	3
			55	4-30-64	9	9.1	.08	.00	----	----	.3	180	11	6.8	2.6	153	368	5.0	.6	1.4	700	494	369	895	7.3	5
122	Unnamed Lake	28N-32W-6c	25	4-29-64	14	15	.66	.6	----	----	6.5	173	21	8.6	1.0	220	652	8.0	.6	.6	1,120	768	670	1,280	6.9	5
123	Sucker Flats Lake	28N-32W-19b	surface	4-30-64	20	2.5	.00	.00	----	----	.2	129	12	11	4.3	52	558	4.5	.4	.3	890	612	369	1,040	7.2	5

Analyses by U. S. Geological Survey

APPENDIX III (continued)

Chemical analyses of water from springs (data in milligrams per liter except as indicated)

Map number (Plate 1)	Spring	Measured discharge (cfs)		Date of collection	Discharge (cfs)	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color
		Max.	Min.																	Calcium Magnesium	Noncarbonate			
300	Bartholic	0.83	0.29	8-64	0.4±	14	10	0.00	0.00	46	1.7	2.8	0.2	140	3.8	6.3	0.0	2.3	147	122	7	244	7.4	0
301	Bartkoski	----	----	8-64	.90	15	10	.01	.00	63	.7	2.8	.9	176	3.6	4.9	.0	15	201	160	16	317	7.2	5
302	Big	26	6.0	5-66	23.5	14	11	.02	.00	55	3.0	3.5	.9	157	7.6	5.4	.1	12	186	150	21	290	7.3	2
303	Big	3.1	.50	7-64	2.67	14	7.8	.05	.00	57	2.4	8.2		151	13	7.3	.1	13	202	152	28	322	7.4	-
304	Boy Scout Camp	7.66	.46	8-64	.7	14	8.2	.06	.00	65	2.4	5.1		195	2.6	4.8	.0	8.9	207	172	12	335	7.3	-
305	Clarkson	27	4.6	9-25	8.6	--	9.4	.29	----	54	2.9	1.1		171	3.5	5.8	---	7.6	169	148	8	---	---	-
306	Elm	3.2	.25	8-64	.3±	15	9.2	.00	.00	46	1.2	4.3	.9	132	4.8	7.2	.0	6.4	149	120	12	245	7.4	0
307	Fly	----	----	8-64	3.2	16	10	.00	.00	46	2.7	4.0	.9	136	6.6	6.6	.0	11	155	126	14	256	7.7	5
308	Gibson	8.0	.80	8-64	.8	16	9.2	.00	.00	50	1.7	4.0	.9	148	8.2	5.9	.0	7.9	168	132	11	270	7.4	5
309	Great Western	----	----	7-64	----	--	8.6	.08	.01	80	2.4	5.4	1.5	194	35	7.2	.0	16	252	210	50	434	7.9	2
310	Haddock	6.0	.80	8-64	.8	14	6.7	.06	.00	60	1.8	8.5		176	5.2	4.8	.1	8.9	198	156	11	310	7.8	-
311	Hearell	1.1	.26	8-64	.8	14	9.0	.00	.00	46	4.6	8.2	1.6	136	18	8.8	.1	11	184	134	22	296	7.5	5
312	McMahon	14.6	.59	8-64	1.7	18	11	.05	.00	50	.7	3.3	1.0	140	6.2	6.6	.0	9.3	157	128	13	260	7.8	5
313	Morse Park	----	----	8-64	.3	14	11	.00	.00	72	3.5	5.1	1.8	196	24	13	.0	12	254	194	33	406	7.7	0
314	Ozark Trout Farm	1.9	.70	11-65	1.46	16	10	.00	.00	56	1.4	3.8	.6	158	4.0	4.3	.0	18	178	146	16	292	7.4	0
315	Pierce City	----	----	7-25	----	--	10	.77	----	51	1.3	3.9		a125	10	9.6	---	12	160	132	29	---	---	-
316	Pioneer	----	----	8-64	.20	15	9.8	.01	.00	58	.4	4.6	.7	168	2.6	3.1	.0	8.3	187	146	8	301	7.5	0
317	Polk	6.9	1.9	8-64	3.57	15	9.6	.00	.00	63	3.2	3.4	.9	172	6.4	9.8	.0	16	201	170	29	328	7.4	0
318	Radar Station	----	----	7-64	.3	15	11	.03	.02	77	3.9	6.1	1.4	184	60	4.0	.1	6.8	261	208	57	433	7.9	4
319	Sagamount	----	----	9-64	.25	15	19	.02	.00	31	3.8	2.8	1.0	111	4.2	3.0	.1	7.1	132	93	2	206	8.2	0
320	Saginaw	----	----	9-64	.85	--	14	.00	.00	31	3.7	2.8	.8	110	5.2	2.9	4.1	4.5	123	92	2	201	8.2	1
321	Scotland	3.1	2.7	8-64	2.7	14	6.4	.06	.00	56	3.8	5.2		165	10	4.8	.1	9.9	189	154	18	301	7.0	-
322	Spiva	----	----	9-64	.31	--	14	.06	.00	46	2.9	3.5	.7	b142	8.0	6.2	.1	9.2	169	127	11	272	8.3	1
323	Spout	----	----	11-64	.022	14	27	.02	.1	59	.9	4.0	.7	167	7.4	4.0	.2	13	199	151	14	324	8.1	1
324	Spring River	7.7	2.8	8-66	4.77	17	9.6	.05	.00	67	2.2	4.7	.8	186	5.4	10	.0	12	214	176	24	338	7.3	0
325	Sonny Wood	.53	.19	4-64	.55	17	9.6	.09	.01	147	7.3	10	1.5	253	192	9.0	.0	1.3	520	397	190	741	7.7	5
326	Talbert	----	----	8-64	.40	14	9.6	.00	.00	48	2.4	4.8	1.0	140	1.2	11	.0	11	159	130	15	267	7.6	5
327	Verona	.73	.02	5-53	----	12	5.2	.22	.00	35	2.2	6.9		90	8.1	5.3	---	6.6	128	96	22	---	7.1	-
328	Wallace	8.8	6.0	8-64	8.77	15	5.0	.09	.00	55	7.1	5.6		171	6.7	7.3	.1	1.1	199	166	26	330	7.9	-

a Includes equivalent of 5 mg/l of carbonate (CO_3)

b Includes equivalent of 1 mg/l of carbonate (CO_3)

Analyses by U. S. Geological Survey and Missouri Geological Survey and Water Resources

APPENDIX III (continued)

Chemical analyses of water from Station 423, Shoal Creek above Joplin, Mo.
(data in milligrams per liter except as indicated)

Date of collection	Mean discharge (cfs)	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Organic and ammonia nitrogen (N)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Detergents (MBAS)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$: Calcium Magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color	Turbidity	Dissolved oxygen: Milligrams per liter	Dissolved oxygen: percent saturation
8-25-62	a85	25	---	---	---	---	---	4.5	---	---	164	7.0	4.8	---	0.7	0.06	---	---	138	4	---	8.0	--	10		
9-10-62	452	21	---	0.02	0.00	46	2.6	3.2	1.9	0.36	134	9.6	6.0	0.1	5.7	0.03	0.0	149	126	16	227	7.8	5	30		
10-11-62	415	21	---	---	---	---	---	3.4	---	1.4	135	6.8	5.0	---	1.3	.31	---	b148	126	14	234	8.1	--	7		
11-8-62	229	11	---	---	---	---	---	3.8	1.3	.92	156	16	6.0	---	6.1	.48	---	b164	146	18	258	8.0	--	5		
12-7-62	181	7	---	---	---	---	---	3.9	1.3	.56	160	6.8	5.5	.1	5.1	.29	---	b168	142	11	264	7.9	--	7		
1-11-63	253	6	---	---	---	---	---	1.7	---	2.1	150	12	3.0	---	6.6	.30	---	b159	135	12	251	7.8	--	7		
2-6-63	146	8	---	---	---	---	---	4.1	---	1.4	c153	6.8	3.6	---	6.6	.44	---	b152	136	10	256	8.7	--	4		
3-14-63	318	9	---	---	---	---	---	1.1	---	1.1	131	6.8	4.5	---	9.1	.35	---	b145	122	14	239	7.7	--	4		
4-12-63	160	15	---	---	---	---	---	1.9	---	.16	d154	6.6	7.8	---	3.0	.18	---	b154	135	10	243	8.5	--	4		
5-10-63	111	26	6.4	.00	.00	51	2.4	4.3	1.5	1.0	157	7.6	6.4	.0	1.8	.24	.0	161	137	8	256	8.1	5	10		
6-7-63	101	25	---	---	---	---	---	4.5	---	1.8	159	8.6	5.8	---	4.1	.21	---	b163	142	12	257	8.0	--	8		
8-28-63		27	11	.00	.00	50	2.9	3.0	1.6	2.8	157	7.6	7.0	.2	3.3	.13	.1	172	133	8	278	8.1	7	10		

a Mean daily discharge

b Calculated from specific conductance

c Includes equivalent of 12 mg/l of carbonate (CO_3)

d Includes equivalent of 8 mg/l of carbonate (CO_3)

Analyses by U. S. Geological Survey

APPENDIX III (continued)

Chemical analyses of water from Station 409, Spring River at Waco, Mo.
(data in milligrams per liter except as indicated)

Date of collection	Mean discharge (cfs)	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Organic and ammonia nitrogen (N)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphorus (PO_4)	Detergents (MBAS)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$: Calcium Magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color	Turbidity	Dissolved oxygen: Milligrams per liter	Dissolved oxygen: Percent saturation
11-1-65	114	15	3.6	0.21	0.00	58	4.5	5.3	1.5	0.11	a184	9.2	7.7	0.0	5.6	0.10	0.0	195	163	12	340	8.5	5	5	12.7	126
12-6-65	98	8	.9	.07	.01	62	4.0	6.7	1.3	.32	190	12	8.8	.4	5.7	.16	.0	196	171	16	348	8.0	6	6	10.8	91
1-10-66	376	5	10	.07	.00	46	5.2	5.4	1.6	.22	142	15	6.4	.0	11	.00	.0	179	137	20	300	8.0	2	10	9.3	73
2-12-66	2,430	9	9.2	.00	.00	32	2.2	4.5	3.2	2.5	74	21	4.4	.3	8.2	.16	.0	148	89	28	230	7.8	25	50	6.8	59
3-12-66	486	11	6.9	.09	.00	54	2.6	5.3	.9	.08	145	20	4.9	.1	11	.12	.1	183	145	26	320	7.8	9	5	7.9	72
4-16-66	331	18	4.8	.13	.00	52	2.7	5.5	1.6	.17	144	17	6.9	.0	6.8	.08	.0	173	141	22	320	8.0	4	100	7.8	82
6-7-66	274	22	12	.18	.10	59	1.9	5.0	1.3	.32	168	17	6.0	.1	8.0	.23	.0	193	155	18	335	8.0	6	10	6.2	70
6-26-66	140	31	10	.01	.01	59	3.6	5.2	1.3	.22	b184	13	6.9	.1	5.9	.40	.0	196	162	11	340	8.4	3	10	6.2	82
7-25-66	187	28	35	.20	.10	47	1.4	5.8	2.8	.34	136	14	6.8	.2	4.0	.51	.0	186	123	12	280	7.7	2	38	4.5	58
8-24-66	730	22	9.6	.03	.00	31	1.5	3.1	3.0	.41	84	7.4	7.2	.1	6.2	.24	.0	131	84	14	190	7.4	42	65	6.5	73

a Includes equivalent of 12 mg/l of carbonate (CO_3)

b Includes equivalent of 2 mg/l of carbonate (CO_3)

Analyses by U. S. Geological Survey

APPENDIX III (continued)

Chemical analyses of water from Station 412, Center Creek near Carterville, Mo.
(data in milligrams per liter except as indicated)

Date of collection	Mean discharge (cfs)	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Organic and ammonia nitrogen (N)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphorus (PO_4)	Detergents (MBAS)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$: Calcium Magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color	Turbidity	Dissolved oxygen: Milligrams per liter	Dissolved oxygen: Percent saturation
9-10-62	82	21	----	0.02	0.02	64	13	9.0	2.6	15	94	87	9.0	18	55	23	0.3	379	213	136	492	7.0	25	7	----	----
10-11-62	183	21	----	----	----	----	-----	5.7	---	2.5	124	33	6.0	5.5	17	7.6	---	a205	156	54	308	7.6	--	5	----	----
11-8-62	82	10	----	----	----	----	-----	8.8	1.8	3.4	124	50	7.0	3.8	21	33	---	a243	178	72	365	7.5	--	8	----	----
12-7-62	59	5	----	----	----	----	-----	9.1	1.7	6.7	129	46	6.0	2.3	32	16	---	a262	177	72	394	7.5	--	2	----	----
1-11-63	112	6	----	----	----	----	-----	6.7	---	7.3	103	45	4.0	10	31	9.1	---	a228	160	76	342	7.2	--	5	----	----
2-6-63	56	8	----	----	----	----	-----	9.1	---	20	46	78	6.0	14	32	59	---	a329	192	155	494	7.0	--	6	----	----
3-14-63	140	8	----	----	----	----	-----	4.9	---	6.1	102	34	5.2	14	28	9.1	---	a210	154	60	316	7.2	--	7	----	----
4-12-63	62	15	----	----	----	----	-----	11	---	13	100	80	10	16	91	15	---	a292	201	119	438	7.5	--	1	----	----
5-10-63	39	26	15	.00	.00	87	3.5	16	2.2	22	74	131	14	5.8	60	50	.0	421	232	171	638	7.5	5	10	----	----
6-7-63	47	25	----	----	----	----	-----	12	---	16	106	88	11	7.8	47	25	---	a355	220	101	533	7.6	--	8	----	----
8-28-63	26	29	30	.08	.02	72	4.2	17	2.2	25	61	119	18	32	40	25	.1	347	197	147	610	7.1	7	6	----	----
9-17-63	25	26	17	.04	.80	99	7.1	21	2.2	22	22	180	12	26	57	46	.1	479	276	258	787	6.9	3	10	9.4	115
10-8-63	23	22	38	.02	.80	72	11	26	2.8	42	4	195	15	15	88	59	.2	525	225	222	750	7.0	--	6	9.2	104
10-29-63	23	13	46	.02	.9	103	12	27	2.8	35	14	213	16	40	77	50	.3	595	307	295	850	6.7	--	5	8.2	78
12-18-63	23	0	23	.04	.7	84	8.8	22	2.2	27	67	124	18	16	47	49	.2	490	246	191	800	7.4	5	20	13.9	95
1-20-64	18	7	12	.00	.6	75	6.2	16	3.3	52	114	159	18	12	40	7.6	.2	458	213	119	625	7.0	2	10	11.6	96
2-9-64	22	7	32	.18	1.1	103	6.6	20	2.4	19	39	202	17	39	25	47	.1	498	284	252	875	6.5	4	30	12.4	102
3-9-64	53	6	15	.10	.6	68	4.2	20	3.4	54	126	158	22	20	38	16	.2	478	187	84	910	7.3	7	25	11.5	91
3-30-64	33	9	20	.07	.3	68	9.7	13	1.8	23	38	120	14	24	36	57	.2	406	210	179	650	6.7	0	20	12.3	100
4-20-64	96	22	16	.02	.2	60	2.6	5.8	1.4	12	90	44	7.5	12	34	19	.1	259	160	86	360	7.4	0	15	7.8	89
5-19-64	56	25	21	.06	.7	67	4.5	8.8	1.7	9.8	93	69	9.5	12	53	15	.1	326	186	110	490	7.7	3	9	7.0	84
6-8-64	90	26	15	.02	.2	56	2.8	6.2	1.2	3.6	103	41	7.1	4.7	24	9.3	.1	222	151	66	340	7.6	10	30	6.1	74
7-9-64	58	26	20	.01	.4	69	6.6	11	1.3	9.7	88	80	7.3	18	45	9.6	.1	321	199	127	505	7.1	5	30	7.0	85
8-6-64	----	27	44	.05	.4	86	4.7	14	2.3	10	7	126	11	27	74	20	---	426	234	229	645	4.8	7	--	----	----
8-10-64	22	28	40	.21	.8	88	5.7	14	2.6	9.3	56	148	14	30	57	20	.1	457	243	197	600	6.8	12	15	6.8	86
9-11-64	43	23	39	.00	.8	81	6.6	16	2.5	12	0	117	14	29	50	19	.2	387	229	227	590	6.8	5	3	5.7	66
10-6-64	17	14	50	.00	1.2	104	11	20	2.7	15	38	195	24	39	30	36	.1	549	305	274	750	6.8	6	10	10.0	97
11-3-64	23	18	38	.01	.8	86	9.5	17	2.6	22	100	133	20	26	80	22	.1	506	254	172	645	7.2	7	20	8.1	85
12-3-64	45	5	19	.01	.2	67	7.8	10	1.6	15	98	75	20	26	53	26	.2	369	199	119	565	7.2	8	9	10.4	81
12-28-64	26	6	26	.01	.6	79	5.9	11	1.7	17	54	98	9.5	36	38	23	.2	372	221	177	580	7.1	5	20	12.0	95
1-25-65	41	9	17	.00	.4	68	5.0	9.3	1.5	6.4	102	71	9.4	16	28	16	0.1	300	190	107	450	7.3	9	8	10.7	93
2-17-65	41	5	20	.14	.4	70	4.0	13	1.4	12	85	79	12	24	48	20	.1	346	191	122	555	7.1	3	20	10.2	80
3-16-65	120	10	10	.02	.00	55	1.6	9.4	1.1	9.8	114	29	8.0	6.2	35	5.6	.1	236	144	50	355	7.6	0	5	9.5	84
4-13-65	406	17	12	.01	.00	47	2.1	4.9	1.2	2.3	105	20	4.3	3.2	19	2.4	.1	180	126	40	276	7.4	3	15	8.5	87
5-12-65	164	19	12	.07	.00	46	.7	6.4	1.3	9.8	93	21	6.0	5.5	38	5.3	.0	198	118	42	295	7.2	8	45	7.0	74
6-15-65	270	21	12	.54	.00	33	2.1	3.9	2.4	.26	69	20	3.5	5.0	11	4.4	.0	153	91	34	220	6.9	30	140	6.2	69
7-13-65	86	26	13	.00	.00	52	2.0	8.6	1.7	4.3	122	30	7.3	5.6	31	6.0	.1	233	138	38	360	6.8	2	15	6.0	73
8-10-65	36	22	22	.00	.3	60	6.2	11	1.8	19	94	69	11	18	50	16	.1	312	175	98	525	7.3	12	15	6.2	70
9-8-65	45	26	22	.02	.3	59	5.0	14	.2	13	61	55	11	19	64	14	.2	313	168	118	500	6.7	10	30	5.3	65
10-5-65	b 88	16	15	.14	.00	57	3.5	11	1.4	12	136	31	6.7	9.5	62	3.8	.2	275	157	45	418	7.9	0	10	8.4	84
11-3-65	42	13	21	.06	.02	57	8.3	13	1.7	13	88	57	13	22	47	13	.2	301	176	104	520	7.6	5	20	6.6	63
12-7-65	33	7	26	.02	.4	76	10	12	1.4	24	12	95	14	36	94	14	.2	385	231	223	758	5.6	5	3	8.4	69
1-11-66	78	8	15	.02	.00	55	3.5	9.7	1.3	6.0	96	36	6.0	12	44	8.3	.1	244	152	73	420	7.3	0	15	8.6	73
2-13-66	301	8	14	.00	.00	43	2.6	4.0	1.3	3.2	98	20	4.6	7.2	20	.83	.1	185	118	37	295	7.5	80	30	6.8	57
3-12-65	146	12	12	.07	.01	54	3.3	6.6	.8	4.2	85	31	2.3	1.0	33	19	.1	209	148	78	385	6.9	8	7	7.8	72
4-16-66	74	20	9.7	.05	.01	57	2.6	8.3	1.2	19	152	35	7.8	4.4	81	12	.1	290	153	34	540	8.0	1	7	8.6	93
6-1-66	104	21	21	.06	.2	57	2.4	6.4	1.2	3.3	116	32	5.3	13	28	10	.1	264	152	57	390	7.0	4	10	5.6	62
6-26-66	54	26	17	.00	.2	65	.9	11	1.3	12	128	56	11	13	42	7.0	.1	287	166	60	470	7.5	6	3	6.0	73
7-27-66	35	29	28	.03	.38	72	3.1	20	2.4	5.5	117	101	14	8.4	80	15	.2	402	193	96	650	7.4	5	8	6.8	88
8-25-66	b 56	23	23	.03	.28	64	4.0	15	2.3	15	84	70	10	19	73	34	.2	356	176	107	580	6.9	5	10	5.3	61

a Calculated from specific conductance

b mean daily discharge

Analyses by U. S. Geological Survey

APPENDIX III (continued)

Chemical analyses of water from Station 415, Turkey Creek near Joplin, Mo.
(data in milligrams per liter except as indicated)

Date of Collection	Mean discharge (cfs)	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Organic and ammonia nitrogen (N)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphorus (PO_4)	Detergents (MBAS)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$: Calcium Magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color	Turbidity	Dissolved oxygen: Milligrams per liter	Dissolved oxygen: Percent saturation
8-28-63	--------	28	14	0.08	0.00	90	2.8	51	20	2.8	193	111	52	0.4	4.1	14	2.1	461	236	78	650	7.8	10	3	---	---
9-17-63	--------	26	5.6	.14	.00	90	7.6	43	10	1.1	176	120	42	.4	11	14	3.1	446	256	112	714	8.1	10	5	11.0	134
10-9-63	6.2	19	11	.34	.00	86	5.4	50	17	1.5	188	108	45	.6	6.0	22	1.4	472	241	87	620	7.6	--	30	3.3	34
10-29-63	6.2	16	10	.24	.00	87	4.6	64	14	1.7	211	111	67	.4	17	20	1.0	502	244	71	550	7.9	--	40	10.2	103
12-18-63	6.4	7	10	.18	.10	94	6.6	60	9.6	5.4	226	125	58	.1	6.3	7.1	3.2	496	262	76	900	7.8	13	8	9.1	65
1-20-64	5.8	8	8.8	.27	.40	96	8.5	51	10	10	226	132	52	.6	1.9	16	2.7	502	275	90	800	8.0	10	14	11.2	94
2-9-64	8.4	9	10	.60	.00	101	8.1	48	13	5.1	206	156	47	.6	4.4	11	2.2	519	336	167	825	7.8	12	25	8.4	69
3-9-64	57	5	4.3	.17	.00	72	7.1	18	5.3	3.0	96	132	18	.3	11	3.5	.4	325	209	130	540	7.9	8	30	9.6	75
3-30-64	16	9	8.0	.34	.30	127	12	29	7.6	4.5	209	210	40	.3	26	7.4	1.3	610	367	196	810	8.0	5	20	9.9	84
4-20-64	18	21	9.8	.31	.30	130	10	31	7.3	8.0	174	225	34	.4	26	11	1.7	593	366	223	835	8.1	8	10	9.8	100
5-19-64	15	24	12	.25	.00	121	10	34	12	2.4	179	204	34	.5	14	9.7	1.1	565	343	185	760	8.0	6	3	9.2	100
6-9-64	18	22	12	.21	.00	120	7.1	34	7.9	3.6	187	176	35	.5	7.2	7.5	1.0	509	329	176	750	7.7	10	10	1.0	11
7-9-64	21	26	10	.22	.30	116	7.8	28	6.1	1.2	179	181	27	.6	4.6	7.0	1.2	492	322	175	751	7.8	6	25	7.7	94
8-10-64	26	26	7.4	.12	.00	74	5.7	16	6.0	1.8	117	119	18	.4	5.8	2.8	.4	327	208	112	450	7.3	18	20	3.4	41
9-11-64	10	23	14	.13	.02	116	7.3	34	8.6	1.4	185	174	39	.5	3.6	7.0	.7	519	320	168	700	7.3	10	10	2.4	28
9-22-64	22	23	12	.19	.20	99	8.9	30	12	1.4	185	153	36	.3	.7	6.7	---	488	284	132	701	7.4	8	---	2.4	28
10-6-64	13	16	13	.18	.02	116	7.1	48	10	1.7	193	176	53	.5	9.6	8.7	.2	549	319	162	900	7.6	10	3	6.7	68
11-3-64	14	18	13	.14	.00	103	10	48	13	2.7	210	156	47	.6	12	8.6	.7	533	298	126	830	7.5	10	27	4.8	50
12-2-64	15	9	13	.22	.04	116	8.5	32	18	4.2	209	190	31	.6	6.6	1.5	.4	552	325	154	845	7.4	10	55	4.8	41
12-29-64	14	8	8.8	.18	.00	121	7.6	29	8.2	3.5	197	196	28	.3	9.9	7.9	1.0	541	333	172	800	7.7	10	20	8.8	74
1-25-65	22	11	8.9	.21	.04	112	6.6	27	7.5	1.8	196	185	27	.3	5.9	5.4	.4	510	307	146	725	7.8	8	20	6.0	54
2-17-65	12	6	9.4	.27	.30	112	8.0	37	18	3.4	222	179	38	.3	1.4	8.7	.7	537	313	131	770	7.7	5	7	6.3	51
3-15-65	30	13	7.5	.20	.00	115	6.9	18	4.1	4.3	193	178	17	.1	4.2	2.9	.6	458	316	156	635	7.9	2	5	8.6	81
4-12-65	66	18	9.7	.02	.00	106	5.7	16	3.2	.42	176	159	15	.3	6.0	1.3	.3	423	288	146	632	7.5	2	6	7.6	79
5-11-65	23	22	10	.33	.00	108	4.7	28	11	2.9	157	172	26	.3	11	6.4	1.0	474	289	161	645	7.4	11	2	9.4	107
6-14-65	132	23	9.0	.28	.00	54	4.5	12	4.4	2.3	123	59	11	.2	3.2	2.2	.3	233	153	52	350	7.4	22	60	4.0	46
7-13-65	9.6	25	13	.36	.00	102	5.3	45	6.8	.62	213	139	41	.4	.2	3.0	.4	476	277	102	665	7.7	8	15	1.9	23
8-10-65	4.2	21	11	.36	.01	99	7.3	51	8.0	.98	175	146	52	.4	7.9	11	.3	491	277	134	780	7.4	21	3	1.6	18
9-8-65	13	26	12	.21	.00	116	7.6	32	8.2	.47	191	186	31	.5	6.8	6.7	.1	506	321	164	1,190	7.6	7	35	2.9	35
10-5-65	19	18	12	.36	.00	123	7.8	34	9.5	.41	218	193	27	.4	.8	6.8	.2	543	339	161	750	8.1	5	5	3.0	32
11-2-65	12	16	12	.26	.01	106	9.3	62	12	3.8	214	180	51	.6	6.5	9.9	.3	564	303	127	860	7.5	13	7	3.3	33
12-7-65	10	8	10	.20	.00	102	10	59	9.5	3.1	168	176	60	.6	14	12	.3	547	296	138	857	7.4	9	4	5.2	44
1-10-66	14	8	10	.23	.02	111	9.0	32	7.5	2.1	183	177	32	.5	6.7	7.8	.3	497	314	164	775	7.3	3	10	5.0	42
2-12-66	40	10	9.9	.12	.00	100	5.0	18	4.9	1.2	160	150	22	.4	5.6	.81	.2	413	270	139	625	7.7	18	3	6.8	60
3-12-66	42	12	6.9	.14	.02	73	5.0	18	3.6	.33	122	110	23	4.0	3.0	3.6	1.4	316	205	103	520	7.6	8	20	4.4	40
4-16-66	14	19	11	.47	.00	112	6.4	46	11	4.0	222	168	46	.6	1.5	11	.2	527	306	124	860	7.5	3	3	5.2	55
5-31-66	28	23	13	.24	.20	121	4.7	32	5.5	2.9	183	182	31	.6	5.4	7.2	.1	502	322	172	740	7.7	7	7	5.1	59
6-27-66	20	26	11	.41	.02	110	6.1	48	9.6	3.7	211	160	52	.4	4.1	12	.1	518	300	127	810	7.7	8	3	3.1	38
7-26-66	18	24	31	.49	.25	98	5.7	40	16	2.2	207	151	35	.5	1.4	10	.2	491	268	98	750	7.4	12	14	1.4	17
8-25-66	10	22	16	.05	.27	106	8.0	61	13	1.8	215	162	62	.5	2.3	8.6	.2	565	298	122	850	7.6	6	3	3.8	43

Analyses by U. S. Geological Survey

APPENDIX IV

LOCATION, TYPE OF STREAMFLOW INFORMATION, AND OTHER PERTINENT DATA FOR ALL GAGING STATIONS IN THE JOPLIN AREA, MISSOURI

For each gaging station, the descriptions show the following information if it is available: location, drainage area, datum of gage, data available, average discharge, extremes of discharge and remarks. The number preceeding the station name is a code number used by the U. S. Geological Survey to place the stations in downstream order. The number following the station name is the map reference number from plate 1.

The location and drainage area are determined from the most accurate maps available.

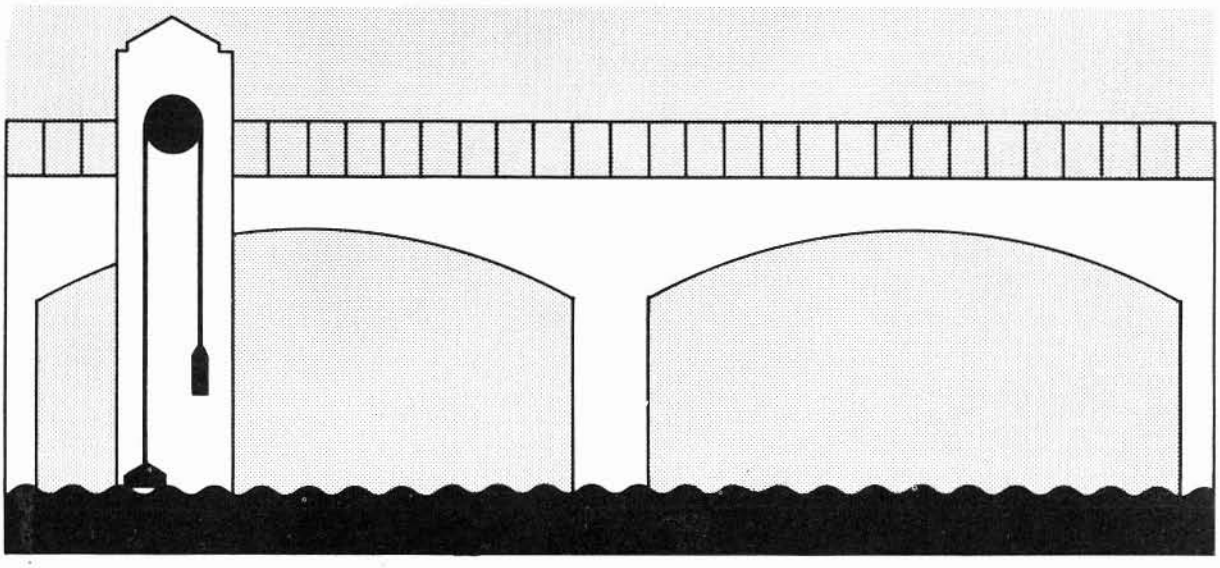
The datum of the gage (elevation above mean sea level of zero on the gage) is shown if it is known.

Under data available are shown the type of information available and the water years during which it was collected.

Average discharge at the continuous-record stations is shown for the period of record.

Under extremes are given the maximum discharge and gage height and the minimum discharge during the period of record. For partial-record stations the maximum or minimum discharge only is shown.

Conditions that affect the natural flow of the streams are noted under remarks.



Gaging stations are located throughout Missouri, including the Joplin area, to maintain a continuous record of streamflow and other pertinent data for the area.

Peak stage and discharge data listed where available. Data from continuous-record and partial-record stations are compiled and published for each water year in the publication "Water Resources Data for Missouri - Part I. Surface Water Records" which may be obtained from District Chief, U. S. Geological Survey, Water Resources Division, P. O. Box 340, Rolla, Mo., 65401.

7-1854 Williams Creek near Mt. Vernon – 400

Location.– NE¼sec. 34, T. 28 N., R. 27 W., at bridge on County Highway V, 2½ miles west of Mt. Vernon, Lawrence County.

Data available.– –1954, 1962-65 (base-flow measurements only).

Minimum discharge measured.– –0.46 cfs Oct. 6, 1953.

7-1855 Stahl Creek near Miller – 401

Location.– SE¼sec. 26, T. 29 N., R. 27 W., at bridge on State Highway 39, 1½ miles south of Miller, Lawrence County.

Drainage area.– –3.86 sq. mi.

Data available.– –1951-59 (Daily discharge available).
1960-65 (Discharge measurements, daily gage-height, and rainfall records available).

Maximum discharge.– –1,440 cfs June 11, 1964.

Water year	Peak stage (feet, msl)	Peak discharge (cfs)
1950	Local datum	745
1951	only	904
1952		363
1953		133
1954		250
1955		497
1956		745
1957		929
1958		1,010
1959		308
1960		1,180
1961		1,430
1962		482
1963		1,000
1964		1,440
1965		593

7-1856 South Fork Stahl Creek near Miller — 402

Location.— NE¼NE¼ sec. 35, T. 29 N., R. 27 W., on left bank at culvert on State Highway 39, 2 miles south of Miller, Lawrence County.

Drainage area.— 0.94 sq. mi.

Data Available.— 1951-65 (peak discharges only).

Maximum discharge.— 818 cfs June 11, 1964

Water year	Peak stage (feet, msl)	Peak discharge (cfs)
1951	Local datum only	90
1952	↓	54
1953		30
1954		54
1955		180
1956		380
1957		260
1958		160
1959		240
1960		295
1961		385
1962		<30
1963		200
1964		818
1965		135

7-1856.5 Spring River near Stotts City — 403

Location.— On line between secs. 13 and 14, T. 28 N., R. 28 W., at bridge on State Highway 97, 2 miles north of Stotts City, Lawrence County.

Data available.— 1943-44, 1946-47, 1949, 1954, 1962-65 (base-flow measurements only).

Minimum discharge measured.— 10.5 cfs Sept. 2, 1954.

7-1857 Spring River at Larussell — 404

Location.— SW¼SW¼ sec. 12, T. 28 N., R. 29 W., at Bower Mills Bridge, ¾ miles north of Larussell, Jasper County.

Drainage area.— 306 sq mi.

Datum of gage.— 1,030 ft (from topographic map).

Data available.— April 1957 to Sept. 1965.

Average discharge.— 8 years, 175 cfs.

Extremes of discharge.— Maximum discharge, 16,300 cfs May 8, 1961 (gage height 15.30 ft); minimum, 15 cfs Dec. 21, 1963, result of ice conditions upstream.

Water year	Approximate peak stage (feet, msl)	Peak discharge (cfs)
1957	1.044	8,190
1958	1.039	2,220
1959	1.038	1,890
1960	1.042	6,160
1961	1.045	16,300
1962	1.040	3,430
1963	1.040	3,130
1964	1.039	2,580
1965	1.043	7,420

7-1857.5 White Oak Creek near Avila – 405
(Station discontinued)

Location.– NE¼NE¼ sec. 12, T. 28 N., R. 30 W., at bridge on State Highway 37, 2 miles southwest of Avila, Jasper County.

Data available.– 1954, 1962-64 (base-flow measurements only).

Minimum discharge measured.– No flow observed several times.

7-1858 Spring River near Neck City – 406
(Station discontinued)

Location.– On line between secs. 1 and 2, T. 29 N., R. 33 W., at bridge on State Highway 43, 2 miles northwest of Neck City, Jasper County.

Data available.– 1954, 1962-65 (Base-flow measurements only).

Minimum discharge measured.– 47.2 cfs Sept. 4, 1963.

7-1858.5 North Fork Spring River at Lamar – 407
(Station discontinued)

Location.– W½ sec. 25, T. 32 N., R. 31 W., at bridge on U. S. Highway 160, ¼ mile east of junction with U.S. Highway 71 at Lamar, Barton County.

Data available.– 1943, 1946, 1962-63 (base-flow measurements only).

Minimum discharge measured.– No flow Sept. 4, 1943 and Aug. 22, 1962.

7-1859 Opossum Creek at Jasper – 408

Location.– NE¼NE¼ sec. 26, T. 30 N., R. 31 W., at bridge on U. S. Highway 71 at Jasper, Jasper County.

Drainage area.– 9.67 sq mi.

Data available.– 1955-65 (peak discharges only).

Maximum discharge.– 1,860 cfs May 8, 1961

Water year	Peak stage (feet, msl)	Peak discharge (cfs)
1955	Local datum only	1,670
1956		330
1957		1,110
1958		840
1959		1,080
1960		1,560
1961		1,860
1962		540
1963		1,240
1964		1,100
1965		730

7-1860 Spring River near Waco – 409

Location.– On line between SE¼ sec. 7 and NE¼ sec. 18, T. 29 N., R. 33 W., at bridge on county highway, 1½ miles east of Waco, Jasper County.

Drainage area.– 1,164 sq mi.

Datum of gage.– 833.23 ft.

Data available.– April 1924 to Sept. 1965

Average discharge.– 41 years, 823 cfs.

Extremes of discharge.– Maximum discharge, 103,000 cfs May 19, 1943 (gage height 30.94 ft); minimum, 4.2 cfs Aug. 28, 1954.

Remarks.– Low flow slightly regulated by gristmills upstream from station.

Water year	Peak stage (feet, msl)	Peak discharge (cfs)
1924	853.35	18,200
1925	843.60	6,550
1926	849.63	13,400
1927	861.83	57,400
1928	854.03	19,000
1929	855.88	25,000
1930	846.19	9,350
1931	845.15	8,140
1932	854.11	19,800
1933	851.07	15,100
1934	840.93	3,950
1935	853.46	18,700
1936	848.93	12,500
1937	852.65	17,200
1938	851.73	16,000
1939	848.57	11,900
1940	844.69	7,700
1941	857.89	38,800
1942	857.63	37,300
1943	864.17	103,000

7-1860 Spring River near Waco – 409 (Continued)

Water year	Peak stage (feet, msl)	Peak discharge (cfs)
1944	849.83	14,200
1945	857.88	38,300
1946	852.33	18,400
1947	857.83	38,300
1948	857.86	38,300
1949	848.73	13,000
1950	857.73	37,800
1951	852.75	19,200
1952	853.31	20,700
1953	840.86	3,710
1954	841.37	4,160
1955	850.93	16,000
1956	841.14	3,680
1957	857.43	34,500
1958	850.43	13,800
1959	849.16	12,200
1960	854.58	22,400
1961	859.13	47,900
1962	844.61	7,480
1963	942.96	5,530
1964	852.77	17,300
1965	852.77	18,400

7-1861 Center Creek near Sarcoxie – 410

Location.– On line between secs. 1 and 2, T. 27 N., R. 30 W., at bridge on State Highway 37, 2 miles northwest of Sarcoxie, Jasper County.

Data available.– 1954, 1962-65 (base-flow measurements only).

Minimum discharge measured.– 9.04 cfs Oct. 21, 1964.

7-1862 Center Creek near Fidelity – 411

Location.– NW¼ sec. 34, T. 28 N., R. 31 W., at bridge on U. S. Highway Alt. 71, 1½ miles north of Fidelity, Jasper County.

Data available.– 1962-65 (base-flow measurements only).

Minimum discharge measured.– 11.6 cfs Oct. 2, 1963.

7-1864 Center Creek near Carterville – 412

Location.– NW¼ NW¼ sec. 24, T. 28 N., R. 32 W., at bridge on County Highway HH, 3 miles east of Carterville, Jasper County.

Drainage area.– 232 sq mi.

Datum of gage.– 913.21 ft.

Data available.– June 1962 to Sept. 1965.

Extremes of discharge.– Maximum discharge, 5,180 cfs Apr. 3, 1965. (gage height 11.22 ft); minimum, 16 cfs Oct. 20, 1964.

Water year	Peak stage (feet, msl)	Peak discharge (cfs)
1963	920.75	2,220
1964	922.76	3,520
1965	924.43	5,180

7-1864.2 Center Creek near Webb City – 413
(Station discontinued)

Location.– On line between secs. 5 and 6, T. 28 N., R. 32 W., at bridge on County Highway D, 2 miles north of Webb City, Jasper County.

Data available.– 1962-65 (base-flow measurements only)

Minimum discharge measured.– 20.2 cfs Oct. 3, 1963.

7-1864.6 Center Creek near Carl Junction – 414

Location.– NE¼ sec. 9, T. 28 N., R. 33 W., at bridge on State Highway 171, 2 miles southeast of Carl Junction, Jasper County.

Data available.– 1943, 1946, 1949, 1952, 1954, 1956, 1962-65 (base-flow measurements only).

Minimum discharge measured.– 14 cfs Sept. 20, 1956.

7-1866 Turkey Creek near Joplin – 415

Location.– NE¼S E¼ sec. 25, T. 28 N., R. 34 W., at bridge on Jasper County Highway P, 2½ miles upstream from mouth and 3 miles northwest of Joplin.

Drainage area.– 41.8 sq mi.

Datum of gage.– 848.80 ft.

Data available.– October 1963 to September 1965. Record collected 1933 to 1939 at point 4.5 miles upstream from present gage.

Extremes of discharge.– Maximum discharge, 3,520 cfs June 13, 1964 (gage height, 9.22 ft.).

Remarks.– Natural flow of stream affected by sewage effluent.

7-1867 Shoal Creek near Fairview –416

Location.– On line between secs. 3 and 10, T. 24, N., R. 29 W., at bridge on State Highway 97, ¼ mile east of junction with County Highway T and 1½ miles east of Fairview, Barry County.

Data available.– 1954, 1962-65 (base-flow measurements).

Minimum discharge measured.– 5.75 cfs Sept. 2, 1954.

7-1868 Capps Creek near Berwick – 417

Location.– NE¼ sec. 15, T. 25 N., R. 29 W., at bridge on county highway, 3 miles south of Berwick, Newton County.

Data available.– 1962-65 (base-flow measurements).

Minimum discharge measured.– 12.9 cfs Nov. 6, 1963.

7-1868.5 Clear Creek near Ritchey – 418

Location.–SE¼ sec. 30, T. 26 N, R. 29 W., 100 feet south of county highway, ¼ mile upstream from mouth, and 2½ miles east of Ritchey, Newton County.

Data available.– 1954, 1962-65 (base-flow measurements only).

Minimum discharge measured.– 4.34 cfs Oct. 3, 1963.

7-1868.8 Shoal Creek at Ritchey – 419

Location.–SW¼ sec. 26, T. 26 N., R. 30 W., at bridge on County Highway O at Ritchey, Newton County.

Data available.–1954, 1962-65 (base-flow measurements only).

Minimum discharge measured.–31.8 cfs Oct. 3, 1963.

7-1868.9 Shoal Creek at Neosho – 420

Location.–SW¼ sec. 7, T. 25 N., R. 31 W., at bridge on county highway at city water works ¼ north of U. S. Highway 60 (Business Route) and ½ mile northeast of Neosho, Newton County.

Data available.–1941-43, 1945-46, 1949, 1952, 1954, 1962-64 (base-flow measurements only).

Minimum discharge measured.–12.9 cfs Sept. 2, 1954.

7-1869 Hickory Creek at Neosho – 421

Location.–SW¼ sec. 18, T. 25 N., R. 31 W., at bridge on U. S. Highway 60 (Business Route) near north city limits of Neosho, Newton County.

Data available.–1941, 1962-64 (base-flow measurements).

Minimum discharge measured.– 3.69 cfs Sept. 2, 1941.

7-1869.5 North Fork Carver Branch at Diamond – 422

Location.–SW¼ SW¼ sec. 4, T. 26 N., R. 31 W., at culvert on County Highway V, 0.8 mile west of Diamond, Newton County.

Drainage area.—0.33 sq mi.

Data available.—1955-65 (peak discharges only).

Maximum discharge.—250 cfs Sept. 22, 1962

Water year	Peak stage (feet, msl)	Peak discharge (cfs)
	Local datum only	
1955		110
1956		92
1957		110
1958		100
1959		<30
1960		191
1961		78
1962		14
1963		28
1965		110

7-1870 Shoal Creek above Joplin — 423

Location.—NE¼ sec. 1, T. 26 N., R. 33 W., at bridge on U. S. Highway 71, 4 miles southeast of Joplin, Newton County.

Drainage area.—410 sq mi.

Datum of gage.—902.37 ft.

Data available.—October 1941 to September 1965.

Average discharge.— 24 years, 376 cfs.

Extremes of discharge.—Maximum discharge, 62,100 cfs May 18, 1943 (gage height, 16.8 ft) minimum 12 cfs Sept. 7, 1954.

Water year	Peak stage (feet, msl)	Peak discharge (cfs)
1942	914.23	11,500
1943	919.17	62,100
1944	912.37	7,260
1945	915.67	24,800
1946	912.93	9,840
1947	915.10	20,400
1948	912.27	7,440
1949	910.44	3,620
1950	915.97	27,300
1951	913.24	10,900
1952	910.05	3,110
1953	908.47	1,300
1954	910.73	4,150
1955	912.33	7,740
1956	912.37	7,740
1957	914.41	16,100
1958	912.71	8,100
1959	911.47	4,710

7-1870 Shoal Creek above Joplin - 423 (continued)

Water year	Peak stage (feet, msl)	Peak discharge (cfs)
1960	915.87	26,500
1961	915.60	20,500
1962	912.30	6,030
1963	908.32	1,230
1964	914.25	10,800
1965	912.57	5,860

7-1862.5 Grove Creek near Scotland – 424
(Station discontinued)

Location.—S½ sec. 25, T. 28 N., R. 32 W., at low-water ford on county highway, 1 mile north of Scotland, Jasper County.

Data available.—1954, 1962-65 (base-flow measurements only).

Minimum discharge measured.— 4.00 cfs Oct. 7, 1953.

Remarks.—Base flow augmented by effluent from an industrial complex that uses mine water and deep well water in its operations.

APPENDIX V

HYPOTHETICAL PROBLEM ILLUSTRATING USE OF FLOOD-FREQUENCY EQUATIONS

Only two variables, drainage area (A) in square miles upstream from the proposed site and average slope (S) in feet per mile between points 10 and 85 percent of total mainstem distance upstream from the site are required to solve the statewide flood-frequency equations presented in table 6. For example, assume that an engineer wishes to design a structure that will pass a 10-year flood from a drainage basin in the Joplin area. The following steps would be necessary in computing the magnitude of this flood:

1. Determine the size of the drainage area from the best topographic maps available. For this example, assume a drainage area of 67 square miles.

2. Compute average slope of the streambed. This should be done as follows: (a) determine elevations from a topographic map at points along the main stem which are 10 percent and 85 percent of the total distance from the proposed site to the basin divide (b) find the arithmetic difference between these elevations and divide by the distance between points. For this problem, assume that the length of the main stem upstream from the gage is 26.7 miles, the elevation at the 10 percent point (2.7 miles) is 500 feet and the elevation at the 85 percent point (22.7 miles) is 650 feet. The average slope of the streambed is $\frac{650 \text{ feet} - 500}{20 \text{ miles}}$ feet or 7.5 feet per mile.

3. Select the applicable equation from table 6 and compute flood magnitude. For this problem, the equation is as follows:

$$\text{10-year flood} = 90.1\ A^{.757} S^{.462}$$

$$=90.1\ (67)^{.757}\ (7.5)^{.462}$$

$$=5{,}520\ \text{cfs}$$

or, select applicable graphical solution. For this problem figure 22D should be used. Interpolating between slopes of 7 and 8 feet per mile provides a value of 5,500 cfs.

APPENDIX VI

HYPOTHETICAL PROBLEMS ILLUSTRATING PROCEDURE FOR ESTIMATING LOW-FLOW CHARACTERISTICS AND STORAGE REQUIREMENTS AT UNGAGED SITES

The procedure for estimating low-flow characteristics and storage requirements at ungaged sites may be illustrated by hypothetical problems:

Problem 1:

An industry wishes to locate several plants at a site in the vicinity of Tipton Ford on Shoal Creek in Newton County within the next 5 years. The plants will require a dependable water supply of 75 cfs at all times. Is the base flow of Shoal Creek large enough to meet these requirements or will storage facilities be required? The stream is located in the Springfield plateau area (see fig. 1) and the drainage area upstream from the proposed site is 370 square miles.

1. The industrial planners realize that large water losses or gains may occur in short reaches of streams draining the Springfield plateau. They first check the tabulation of discharge measurements made during the areal seepage runs (see fig. 24). Measurements were made on Shoal Creek at Neosho and at the continuous-record station near Joplin, but no measurements have ever been made at Tipton Ford. Had there been a measurement near the proposed site, the planner would have had a rough idea of the magnitude of flow during a drought with recurrence interval of about three years. There would have been little need for further discharge measurements.

   The planners decide that three or four base flow measurements must be made at the site in order to estimate low flow characteristics.

2. After base flow measurements are obtained, the 7-day Q_2 can be determined by correlative procedures which involve the use of concurrent base flow discharges at continuous-record stations in the area (see Skelton, 1966, p. 25). Assume that the 7-day Q_2 is approximately 75 cfs.

   The planners realize that the 7-day Q_2 is the median of the annual minimum 7-day discharges, and that there is a 50 percent chance in any year that the annual minimum 7-day average flow will be equal to or less than 75 cfs. They also note from table 7 that the annual minimum 7-day flow for a drought with a five-year recurrence interval at the continuous-record station on Shoal Creek is 54 cfs, and that this station is only four miles downstream from the proposed site. The planners conclude that a dependable flow of 75 cfs cannot be obtained without storage facilities.

3. Entering figure 27 with 7-day $Q_2 = \frac{75\ \text{cfs}}{370\ \text{sq. mi.}} = 0.20$ cfsm, the following storage estimates are obtained for a drought with recurrence interval of 20 years:

Storage required		Draft rate	
cfsm	cfs	acre-feet/sq. mi.	acre-feet
0.2	75	21	7,770
0.3	110	95	35,200

4. After the initial computations are completed, storage estimates must be increased to allow for water lost by evaporation and seepage and storage capacity lost by sediment deposition.

   a. To estimate losses from evaporation, first assume that the effective evaporative area is equal to the surface area of the full reservoir.

      For illustrative purposes, assume that the lake surface for the storage requirements of step 3 are 500 and 1,500 acres respectively.

      The average evaporation for the critical May-October period, as stated in the section on "Evaporation Loss", is 33 inches or 2.8 feet in the Joplin area. The computations necessary to determine estimated losses from evaporation are as follows:

      (500 acres) (2.8 feet) = 1,400 acre-feet

      (1,500 acres (2.8 feet) = 4,200 acre-feet

   b. Quantitative estimates of sediment deposition can be made by use of table 9. For this problem, assume a time period of 20 years for converting annual loss to total capacity loss. Also assume that there have not been extensive mining operations in the Shoal Creek basin.

      McDaniel Lake, with an average annual sediment accumulation of about 0.5 acre-feet per square mile, is located in a region similar to the Tipton Ford area, and this figure should be used to estimate losses from sediment deposition for this problem.

      The computation necessary to determine estimated loss from sediment deposition is as follows:

      (20 years) (370 sq. mi.) (0.5 acre-feet per sq. mi. per year) = 3,700 acre-feet

   c. Quantitative estimates of seepage losses for a specific site cannot be determined from this report. However, the report can be utilized to determine if the possibility of large seepage losses should be investigated more fully.

      The proposed site is located on the Springfield Plateau and, as stated previously, high seepage rates are the rule in this physiographic region. The site should be investigated carefully to determine if corrective measures are necessary to prevent significant seepage losses.

5. After computation of reservoir losses, the estimates of step 3 are finalized as follows:

Draft rate in cfs	Storage required in acre-feet (20-year recurrence interval drought)
75	7,770 + 1,400 + 3,700 = 12,900
110	35,200 + 4,200 + 3,700 = 43,100

From the foregoing procedures the industrial planners learned (1) that storage facilities are necessary at the proposed site to insure a dependable flow of 75 cfs, (2) the approximate amount of storage required to supply their needs during a drought with recurrence interval of 20 years, and (3) the approximate amount of storage required for a greater draft rate than needed.

A more detailed engineering study at the site would be required to determine if the terrain is suitable for construction of a reservoir of the size required.

Problem 2:

City planners are interested in building a storage reservoir on an intermittent stream in northwestern Jasper County. They wish to get a rough idea of the draft-storage relationship at the proposed site. The stream is located in the Osage Plains province (see fig. 1) and the drainage area above the site is 70 square miles. Assume that the stream drains an area of extensive mining operations.

1. The planners know from past experience that the stream ceases to flow for periods of several weeks each year during late summer and early fall, and they conclude that the 7-day Q_2 is zero.

2. The stream is located in the Osage Plains province; therefore, the constant storage requirements shown in table 8 are applicable to this problem.

3. Using the constant storage requirements shown in table 8, the planners obtain the following estimates for a drought with recurrence interval of 20 years:

Draft rate		Storage required	
cfsm	cfs	Ac-ft/sq. mi.	Ac-ft.
.02	1.4	17	1,190
.06	4.2	60	4,200
.10	7.0	120	8,400

4. Storage computations must be increased to allow for water lost by evaporation and seepage and storage capacity lost from sediment deposition.

   a. To estimate evaporation losses, use the same approach as for problem 1. Assume lake surface areas of 100, 400, and 800 acres for the storage requirements of step 3.

      The computations to determine estimated losses from evaporation would be as follows:

      (100 acres) (2.8 feet) = 280 acre-feet

      (400 acres) (2.8 feet) = 1,120 acre-feet

      (800 acres) (2.8 feet) = 2,240 acre-feet

   b. Quantitative estimates of sediment deposition can be made from table 9. Assume a time period of 20 years for converting annual loss to total capacity loss.

      Grisham Reservoir, with an average annual sediment accumulation of about 1.1 acre-feet per square mile, is located in a mining area, and this figure should be used to estimate losses from sediment deposition.

      The computation necessary to determine estimated loss from sediment deposition is as follows:

      (20 years) (70 sq mi) (1.1 acre-feet per sq mi per year) = 1,540 acre-feet.

   c. Quantitative estimates of seepage loss cannot be determined from this report. However, the report can be utilized to determine if the possibility of large seepage losses should be investigated more fully.

      The proposed site is located on the Osage Plains and, as stated previously, seepage is slow in the region. The possibility of large seepage losses can be disregarded for this problem.

5. After computation of reservoir losses, the estimates of step 3 are finalized as follows:

Draft rate in cfs	Storage required in acre-feet
1.4	1,190 + 280+1,540=3,000
4.2	4,200 +1,120+1,540=6,900
7.0	8,400 +2,240+1,540=12,100

From the foregoing procedures the city planners obtain a general knowledge of the draft-storage relationship at the proposed site. A detailed engineering study would be required to determine if the terrain is suitable for construction of a reservoir.

APPENDIX VII

DEFINITION OF TERMS AND CONVERSION OF UNITS

1. Acre-foot.— —The volume of water required to cover one acre to a depth of 1 foot.

   1 acre-foot = 43,560 cubic feet

   = 325,851 gallons

2. Aquifer.— —A rock formation, bed, or zone containing water that is available to wells. An aquifer may be referred to as a water-bearing formation or water-bearing bed.

3. Aquiclude.— —A rock of relatively low permeability that overlies or underlies an artesion aquifer and confines water in the aquifer under pressure. As most aquicludes are leaky, the term aquitard is sometimes used because of its connotation of a retardation rather than a prevention of the movement of water. Such a rock may also be called a confining bed.

4. Artesian water.— —Ground water under sufficient pressure to rise above the level at which the water-bearing bed is reached in a well. The pressure in such an aquifer commonly is called artesian pressure, and the rock containing artesian water is an artesian aquifer. Such an aquifer may also be called a confined aquifer.

   Base flow.— —That portion of the stream discharge which is derived from ground-water outflow.

   Climatic year.— —The 12-month period, April 1 to March 31. The climatic year is designated by the calendar year in which it begins and is used as the annual time unit for the analysis of low-flow data because it does not separate the annual low-flow seasons.

   Confined water.— —Water under artesian pressure. Water that is not confined is said to be under water-table conditions.

   Continuous-record station.— —A site on a stream where continuous records of discharge are obtained.

   Cubic feet per second (cfs).— —The unit expressing rate of discharge. One cfs is the rate of discharge of a stream having a cross-sectional area of 1 square foot and an average velocity of 1 foot per second.

   1 cfs=7.48 U. S. gallons per second

   =449 U. S. gallons per minute

=0.646 millions of U. S. gallons per day

Cfs-day.— —The volume of water represented by a flow of 1 cubic foot per second for 24 hours.

1 cfs-day=1 983 acre-feet

=86,400 cubic feet

=646,317 gallons

Cubic feet per second per square mile (cfsm).— —The average number of cubic feet of water flowing per second from each square mile of area drained, assuming that the runoff is distributed uniformly with regard to time and area. Cfsm is computed by dividing the discharge in cfs by the drainage area in square miles. It should be used with caution in the Springfield Plateau region because low-flow yields may differ widely within the same basin.

Evapotranspiration.— —The movement of water into the atmosphere by the combined processes of direct evaporation and transpiration from plants.

Groundwater.——Water in the zone of saturation or below the water table.

Hydrology.— —The science that relates to the water of the earth.

Infiltration.——The flow or movement of water into the surface soil.

Intermittent stream.— —A stream that flows only part of the time or through only part of its reach.

Mean annual flood.— —The mean of the annual flood peaks. It is descriptive of a drainage basin's flood characteristics and is an index of the geographical variation of flood flows.

Partial-record station.— —A site on a stream where occasional discharge measurements have been collected over a period of years.

Perennial stream.— —A stream that flows continuously, such as Shoal Creek.

Permeability.— — The capacity of a rock to transmit water. The field coefficient of permeability of an aquifer is the coefficient of transmissibility divided by the saturated thickness of the aquifer, in feet.

Piezometric surface.— —An imaginary surface that everywhere coincides with the static level or pressure surface of the water in the aquifer.

Recharge.— —The addition of water to the zone of saturation. Infiltration of precipitation or stream bed seepage are forms of natural recharge; injection of water into an aquifer through wells is one form of artificial recharge.

Recurrence interval.— —The average interval of time within which a given event will be exceeded once. Recurrence intervals are averages and do not imply regularity of occurrence; an event of 50-year recurrence interval might be exceeded in consecutive years or it might not be exceeded in a 100-year period. In other words, a 50-year flood or drought has a 2 percent chance of occurring in any year.

7-day Q_2.— —The annual minimum average discharge for seven consecutive days which will occur on an average of once in two years. This is an index to the low-flow potential of a stream and should be used as a guide in comparing one stream to another.

Specific capacity.— —The yield of a well per unit of drawdown after a specified period of pumping. Generally expressed as gallons per minute (gpm) per foot of drawdown. If a well yields 500 gpm with a drawdown of 25 feet, its specific capacity is $\frac{500}{25}$, or 20 gpm per ft.

Specific conductance.— —A measure of the capacity of water to conduct a current of electricity, expressed in micromhos per centimeter at 25°C. Conductance varies with the quantities of dissolved mineral constituents and with the degree of ionization of the constituents as well as with the temperature of the water. It is useful in indicating the approximate concentration of mineral matter in water.

Unconfined water.— — Water not under artesian pressure. Generally applied to denote water below the water table.

Water table.— —The upper surface of the zone of saturation, where the surface is not confined by impermeable rocks.

Water year.— —The 12-month period October 1 to September 30. The water year is designated by the calendar year in which it ends and which includes nine of the 12 months. Thus, the year ended September 30, 1965 is called the 1965 water year.

Within-year storage.— —That storage which will be replenished each year by the high flow of the stream for release during succeeding low-flow periods. Uniform draft rates less than the minimum annual mean flow are used in computations of within-year storage requirements.

PHOTOGRAPHS: Joplin Chamber of Commerce, p. ii
Joplin Globe Publishing Co., p. ii-iii.

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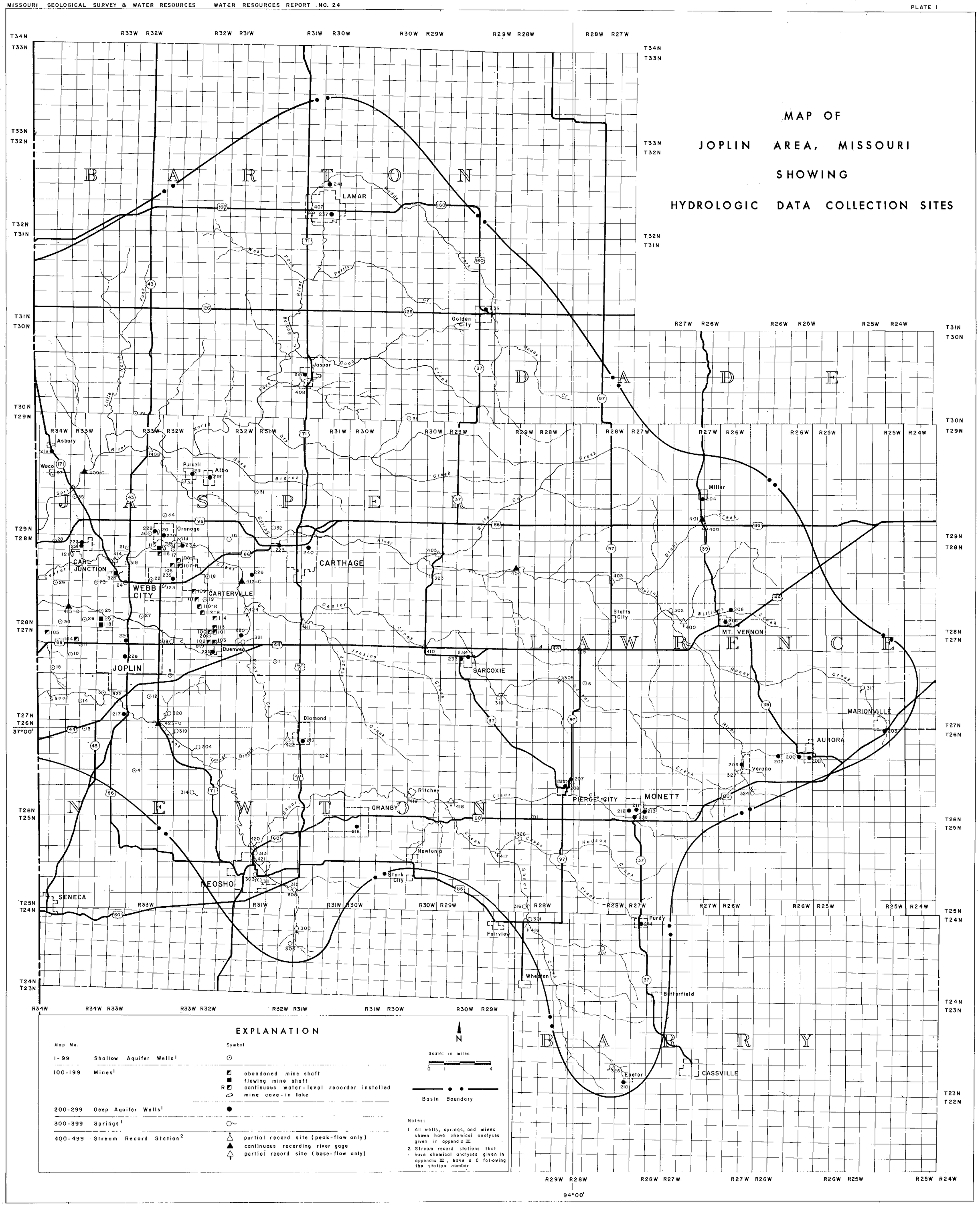
MAP OF
JOPLIN AREA, MISSOURI
SHOWING
HYDROLOGIC DATA COLLECTION SITES
BARTON
JASPER
LAWRENCE
NEWTON
DADE
BARRY
LAMAR
Golden City
Jasper
Asbury
Waco
Purcell
Alba
Oronogo
CARL JUNCTION
WEBB CITY
CARTERVILLE
CARTHAGE
Duenweg
JOPLIN
Diamond
Stotts City
Miller
MT. VERNON
SARCOXIE
MARIONVILLE
AURORA
Verona
Ritchey
GRANBY
PIERCE CITY
MONETT
Newtonia
NEOSHO
Stark City
SENECA
Fairview
Purdy
Wheaton
Butterfield
Exeter
CASSVILLE
EXPLANATION
Map No.
Symbol
1-99 Shallow Aquifer Wells[1]
100-199 Mines[1]
abandoned mine shaft
flowing mine shaft
R continuous water-level recorder installed
mine cave-in lake
200-299 Deep Aquifer Wells[1]
300-399 Springs[1]
400-499 Stream Record Station[2]
partial record site (peak-flow only)
continuous recording river gage
partial record site (base-flow only)
N
Scale: in miles
0 1 4
Basin Boundary
Notes:
1 All wells, springs, and mines shown have chemical analyses given in appendix III
2 Stream record stations that have chemical analyses given in appendix III, have a C following the station number
94°00'
37°00'