EVALUATION OF GROUND-WATER QUALITY DATA FROM KENTUCKY

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations
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By Craig L. Sprinkle, R. W. Davis, and D. S. Mull

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CONVERSION FACTORS

For use of readers who prefer to use International System of Units (SI), conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
foot (ft)	0.03048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
million gallons per day (Mgal/d)	0.0438	cubic meters per second
inches per year (in/yr)	25.40	millimeters per year
micromho (μmho)	1.000	microsiemens
pico curie (pCi)	0.03700	becquerel

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

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ABSTRACT

In 1980, ground water was used by more than 375,000 people in Kentucky, and industrial use was more than 133 million gallons per day. Continued use of the resource is dependent on the chemical quality of the water. This report reviews and summarizes 10,578 chemical analyses from 2,362 wells and springs in Kentucky. These water-quality data were collected prior to September 30, 1981, and are available in computer files of the U.S. Geological Survey. The principal water-bearing rocks in Kentucky were combined into 10 major groups to aid in data summary preparation and general description of the ground-water quality of the State. The main criteria for including a rock (geohydrologic) unit in a particular group were:

1. Areas of outcrop - units outcrop mainly in one physiographic province

2. Stratigraphic sequence - rocks in contact with each other

3. Hydraulic continuity - units are areally extensive and likely to exhibit similar hydraulic characteristics

4. Availability of data in computer storage - units known to have some ground-water quality data in computer files

Ground water in Kentucky is generally fresh near the outcrop of the rocks comprising the aquifer. Slightly saline to briny water occurs at variable depths beneath the freshwater. Preparation of trilinear diagrams revealed three principal geochemical processes which may occur in the aquifers of Kentucky: (1) mixing of freshwater and saline water in an interface zone; (2) dedolomitization of the Silurian, Devonian, and Mississippian carbonate rocks; (3) exchange of sodium for calcium in the freshwater sections of many of the sandstone-shale aquifers.

Many deficiencies and a few errors were found in the Survey's data files. The principal deficiencies were:

1. Very few post-1970 analyses of ground water include measurements of all major cations and anions, and few analyses include field measurements of pH and alkalinity.

2. The chemistry of the freshwater-saline water interface zone is inadequately defined throughout much of the State.

3. There are no analyses of stable isotopes and dissolved gases in ground water.

4. There are fewer than 10 analyses of most trace metals, radionuclides, and man-made organic chemicals, which may be present as trace environmental contaminants.

5. No data on bacteria in ground water have been collected from any aquifer in the State.

INTRODUCTION

Ground water was used by more than 375,000 people in Kentucky in 1980. Industries of the State used more than 133 million gallons of ground water daily. The continued use of ground water is dependent, in part, on the quality of this resource, which is measured by chemical analysis of water from wells and springs. Many historical ground-water quality data have been stored in computer files of the U.S. Geological Survey. A compilation of the available data through 1979 is given in Faust and others (1980). These historical data may be used to describe the geochemical processes occurring in Kentucky's aquifers. The data may also be compared with present or future conditions to measure changes in ground-water quality.

This report presents an evaluation of ground-water quality data from Kentucky using data stored in computer files of the Survey through September 30, 1981. A limited number of analyses of ground water or springs are in the files of the Kentucky Natural Resources and Environmental Protection Cabinet, Water Quality Division (formerly Kentucky Department of Health). However, these data are not computer accessible and were not used in this evaluation. Due to limitations of time and money, data in computer files of other Federal agencies were not evaluated for this report.

The primary objectives of the study were to examine the computer files of the Survey and (1) determine if the data needed to describe the ground-water quality of Kentucky are available, (2) identify errors and deficiencies in the data from Kentucky, and (3) to the extent possible, use the available data to describe the ground-water quality of Kentucky by major geohydrologic units.

HYDROGEOLOGIC SETTING

Precipitation is the major source of ground water in Kentucky. Mean annual precipitation ranges from about 40 inches in the north to about 52 inches in the southeast and south-central parts of the State. Mean annual runoff ranges from about 15 in/yr in the northeast to about 24 in/yr in the southeast. Statewide, the mean annual runoff is about 18 in/yr (Bell, 1963, p. 354). Some of the precipitation infiltrates to the water table. Water which does not run off or recharge the ground-water system is lost through evaporation and transpiration from plants. Once the water enters the ground-water system, its quality is affected, in part, by the types of rocks and minerals it contacts. Rocks underlying the State have been divided into geologic units based on faunal and lithologic characteristics. The principal geologic systems of Kentucky are shown in figure 1. Productive ground-water systems (aquifers) occur in one or more geologic units, depending on rock type and areal extent of the unit(s).

Physiography

The six main physiographic regions of Kentucky (fig. 2) have been described by McFarlan (1943) based on their distinctive geology and land forms.

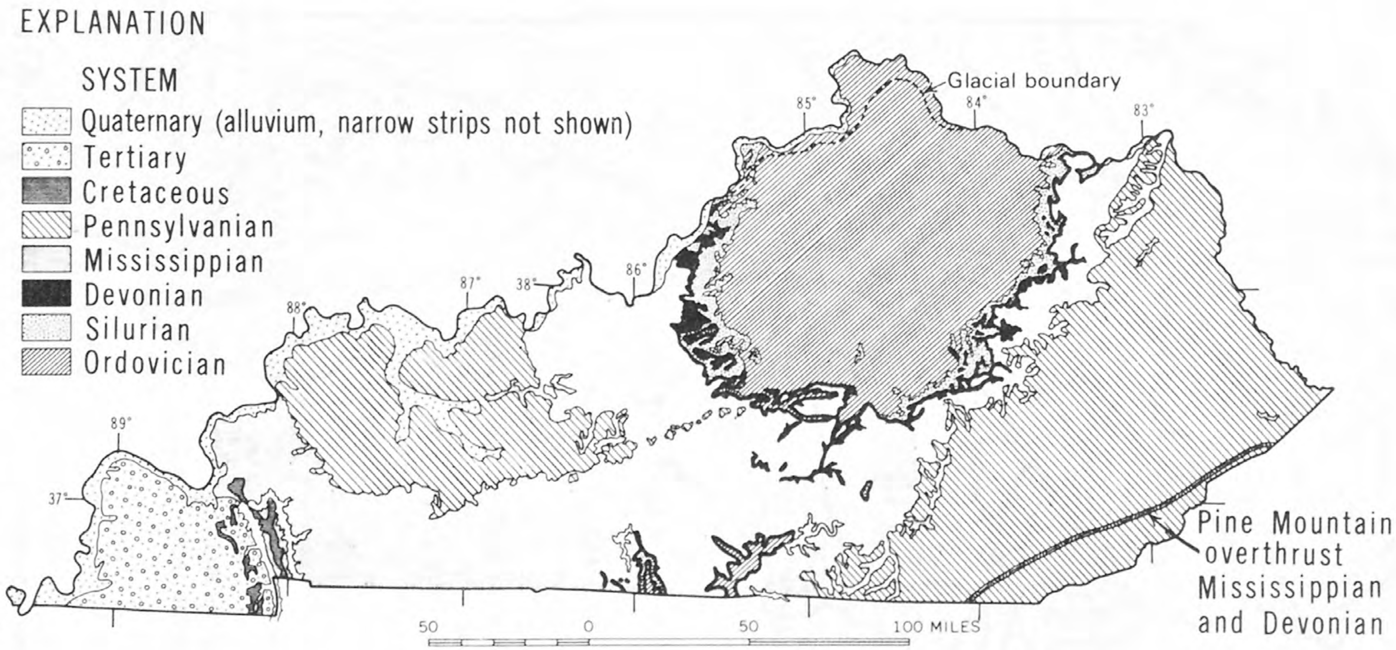

Figure 1.-- Generalized geologic map of Kentucky.

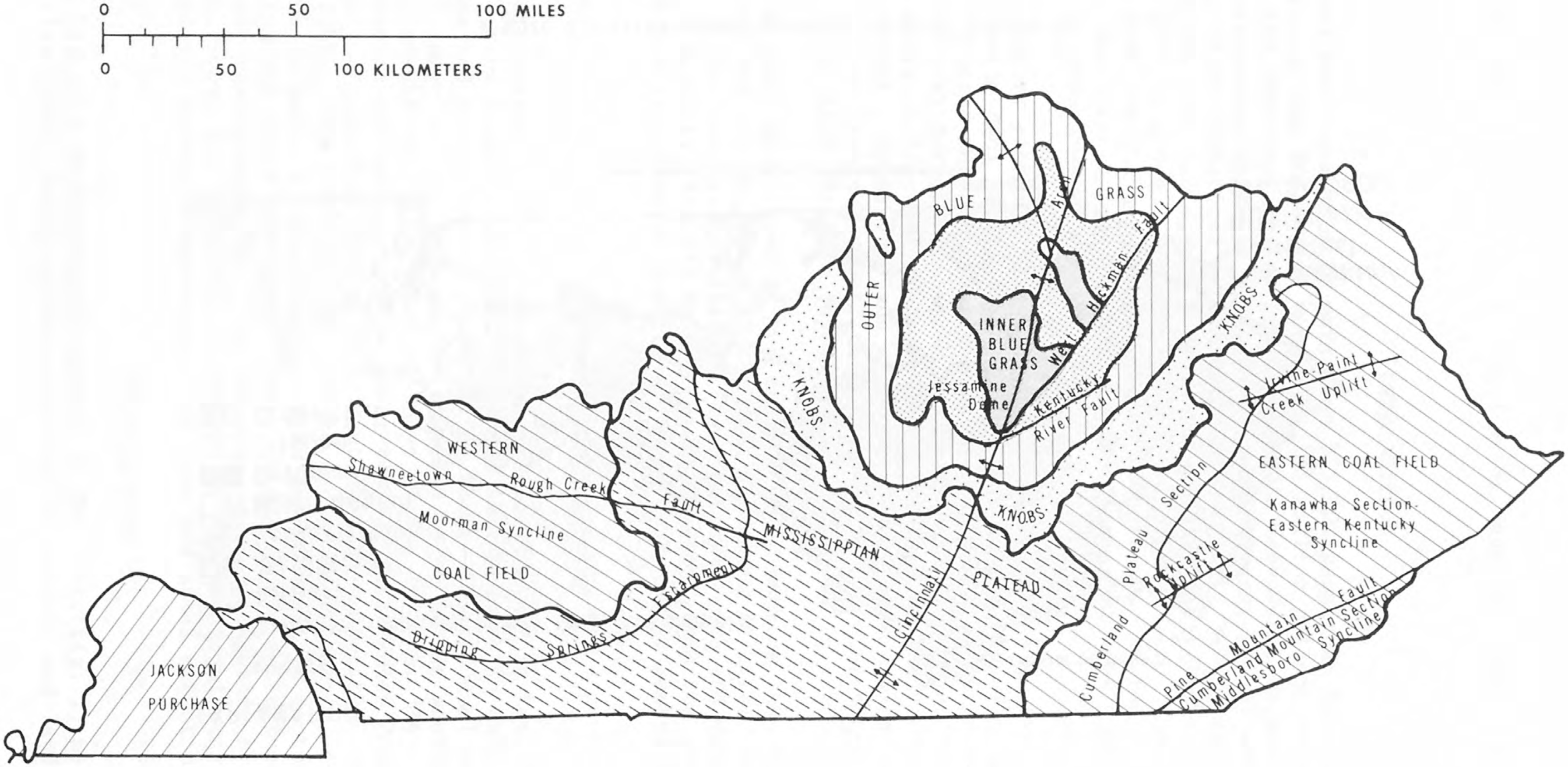

Figure 2.-- Physiographic regions and major structural features of Kentucky (modified from Hopkins, 1966).

Blue Grass Region

The Blue Grass region in the north-central part of the State is a gently rolling upland ranging in altitude above sea level from less than 800 feet in the northwest to about 1,000 feet in the southwest. Major streams have entrenched valleys to depths of 200 to 500 feet below the rolling upland. The Region is underlain by limestone and shale of Ordovician age and is divided into the Inner and Outer Blue Grass. The Inner Blue Grass, a central area of about 800 mi^2, is underlain by limestone and thin beds of shale. The land surface of the Inner Blue Grass is typical karst; sinkholes, caverns, and springs are fairly common and most of the drainage is subsurface. The Outer Blue Grass varies from about 5 to 30 miles in width and is underlain by shale and interbedded limestone. Although the Outer Blue Grass is typically an area of gently rolling hills, it is dissected and rugged near the major streams. Small sinkholes are fairly common but extensive subsurface drainage is uncommon.

Knobs Region

The Knobs region is a crescent-shaped area of conical or flat-topped hills that surrounds the Blue Grass region. This narrow band of hills is generally less than 10 miles wide and is underlain mostly by shale and some sandstone and limestone of Silurian to Early Pennsylvanian age. The hills are erosional remnants of the Mississippian Plateau on the south and west, and the Eastern Coal Field region on the east. Individual knobs, separated by broad, relatively flat stream valleys, rise as high as 750 feet above the surrounding lowlands. Some knobs have a caprock of sandstone or limestone.

Mississippian Plateau Region

The Mississippian Plateau region is a U-shaped area that surrounds the Western Coal Field in Kentucky. This Region extends from the Ohio River on the north, south to the Tennessee-Kentucky State line, and northwest to the Ohio River. Underlain by shale, sandstone, and massive limestone of Mississippian to Early Pennsylvanian age, the Region is separated into two major plateau areas by the Dripping Springs Escarpment. The plateau north (in places, northwest or west) of the escarpment is underlain by relatively thin alternating beds of limestone, shale, and sandstone of Late Mississippian to Early Pennsylvanian age. The topography is smooth to gently rolling except near the edge of the escarpment where the land surface is more rugged and karst features are common. Several famous caverns are located in the northern plateau near the escarpment. The plateau south (in places, southeast or east) of the escarpment is a level to gently rolling plain underlain by thick beds of relatively pure limestone of Mississippian age. Sinkholes, subsurface drainage, and other karst features are common and local relief is less than 200 feet.

Eastern Coal Field Region

The Eastern Coal Field region includes all the mountainous part of eastern Kentucky. Most of the Region is underlain by sandstone, siltstone, shale, and coal of Pennsylvanian age. Shale, limestone, and sandstone of Devonian to Mississippian age crop out along the western border and in a narrow belt on the north slope of Pine Mountain.

The topography of the Eastern Coal Field region differs in character from place to place and can be divided into three sections (Fenneman, 1946). The western third of this Region is a broad upland of moderate relief that is intricately dissected along its western border. The central and northern part of the Eastern Coal Field region is characterized by narrow, crooked valleys and narrow steep-sided ridges. The local relief increases from about 300 feet in the north near the Ohio River, to about 2,500 feet in the south near the Virginia-Kentucky State line. The southeastern section consists of two parallel ridges, Pine Mountain and Cumberland Mountain, ranging from about 2,100 to more than 3,500 feet in altitude. The area between the ridges is highly dissected, hilly, and rugged, with relief in excess of 2,500 feet.

Western Coal Field Region

The Western Coal Field region is a rolling upland 400 to 500 feet in altitude and underlain by sandstone, shale, siltstone, and coal of Pennsylvanian age. Structurally, it is a large syncline representing the southern part of the Illinois-Indiana-Kentucky basin of the Eastern Interior basin (Eardley, 1951, p. 32). The southern and western borders of the Region are marked by a range of rugged hills as much as 835 feet in altitude. Another line of hills extends across the central part of the Western Coal Field. The Green and Tradewater Rivers and their larger tributaries traverse the Region through extensive alluviated valleys of low relief. Alluvial terraces and flood plains on the Kentucky side of the Ohio River form the north and northwest boundaries of the Region. In places, these flood plains are as much as 10 miles wide.

Jackson Purchase Region

The Jackson Purchase region, the westernmost part of Kentucky, is bounded on the east by the Tennessee River, the north by the Ohio River, the west by the Mississippi River, and the south by the State of Tennessee. The topography of the Region is markedly different from other parts of Kentucky because the Jackson Purchase lies in the Mississippi Embayment, a coastal plain region underlain by unconsolidated sediments of Cretaceous and Tertiary age. Limestones and shales ranging in age from Mississippian in the east through Ordovician in the southwest underlie the Cretaceous sediments. The land surface is relatively flat with low, rolling hills and shallow, wide valleys. The altitude ranges from about 640 feet in the uplands near the Tennessee-Kentucky State line to about 270 feet in the flood plain of the Mississippi River, near the southwestern corner of Kentucky.

Geology and the Freshwater Flow System

The principal water-bearing formations (or units) in Kentucky are listed by retrieval group in table 1. These units range in age from Cambrian to Quaternary, are highly variable in water-yielding capacity, and, typically, are not areally extensive. Some of the names of rock units listed in table 1 are obsolete or driller's terminology, having been adopted to identify water samples before modern geologic mapping was completed in Kentucky. The Survey is gradually removing these obsolete or invalid formation names from its computer files. A generalized correlation chart of selected formations is given in figure 3. Detailed descriptions of the geologic units may be obtained from McFarlan (1943), Freeman (1951), Rice and others (1979), and Davis and others (1973). A map showing the geology of Kentucky has recently been prepared by McDowell and others (1981). The general hydrology of the different physiographic regions of Kentucky has been described by Palmquist and Hall (1961), Maxwell and Devaul (1962), Price and others (1962), Brown and Lambert (1963), and Davis and others (1973).

Table 1.-- Aquifer names and geologic unit codes used for retrieval of ground-water quality data from Kentucky.
(The stratigraphic names in this table are from many sources and do not necessarily follow U.S. Geological Survey usage.)

Retrieval Group	Aquifer name or geologic unit	WATSTORE Code
1 (Cambrian and Ordovician age rocks)	Chepultepec Dolomite and Rose Run Sandstone	364CPRR
	Newala-Longview Dolomite	364NLGV
	St. Peter Sandstone	364STPR
	Knox Dolomite	367KNOX
	Ordovician, Lower	367ODVCL
	Ordovician-Cambrian systems	367OVCB
	Copper Ridge Dolomite	371CPRG
2 (Middle and Late Ordovician age rocks)	Cumberland Formation (Richmond Group)	361CMBD
	Eden Group (Million Shale)	361EDEN
	Garrard Sand	361GRRD
	Leipers Limestone	361LPRS
	Ordovician, Upper	361ODVCU
	Cynthiana Formation (Granville)	364CNTN
	Lexington Limestone	364LXNG
	Stones River (Black River) Group	364SRVR
	Trenton Limestone	364TRNN
	Tyrone Limestone	364TYRN

Table 1.(cont'd)-- Aquifer names and geologic unit codes used for retrieval of ground-water quality data from Kentucky.

Retrieval Group	Aquifer name or geologic unit	WATSTORE Code
3 (Silurian and Devonian age rocks)	Devonian System	340DVNN
	Devonian, Upper	341DVNNU
	Knob Lick and Hardin Sandstones	341KBLH
	New Albany Shale	341NALB
	Boyle Limestone	344BOYL
	Clear Creek Limestone	344CLCK
	Dutch Creek Sandstone	344DCCK
	Devonian, Middle	344DVNNM
	Sellersburg and Jeffersonville Limestones equivalents (Onondaga Limestone)	344SBJV
	Silurian System	350SLRN
	Brownsport Formation	354BRPR
	Bisher Limestone	354BSHR
	Crab Orchard Formation	354CBOC
	Clinton Formation	354CLNN
	Laurel Dolomite and Osgood Formation	354LOGD
	Louisville Limestone and Lego Limestone Member of Wayne Formation (Big Six Sandstone)	354LVLG
	Louisville Limestone and Laurel Dolomite	354LVLL
	Osgood Formation and Brassfield Dolomite	354OGBF
	Salina Formation	354SLIN
	Silurian, Middle	354SLRNM
	Lockport Dolomite	355LCKP
	Niagaran Series	355NIGR
	Brassfield Limestone (Dolomite)	357BFLD
	Silurian, Lower	357SLRNL

Table 1.(cont'd)-- Aquifer names and geologic unit codes used for retrieval of ground-water quality data from Kentucky.

Retrieval Group	Aquifer name or geologic unit	WATSTORE Code
4 (Mississippian age rocks)	Levias Limestone Member of Ste. Genevieve Limestone	333LVIS
	McClosky Sand	333MCCK
	Meramecian Series	333MRMC
	Ste. Genevieve - St. Louis Limestones undifferentiated	333SGSL
	Ste. Genevieve Limestone	333SGVV
	Salem Limestone	333SLEM
	St. Louis and Salem Limestones undifferentiated	333SLSM
	Salem and Warsaw Formations	333SMWR
	St. Louis Limestone	333STLS
	Warsaw Limestone	333WRSW
	Fort Payne Formation	337FRPN
	Mississippian-Devonian System	337MPDV
	Mississippian, Lower	337MSSPL
5 (Late Mississippian age rocks)	Newman Limestone (Big Lime of eastern Kentucky)	330NWMN
	Aux Vases Sandstone	332AXVS
	Beech Creek Limestone Member of Golconda Formation	332BCCK
	Buffalo Wallow Formation	332BFLW
	Big Clifty Limestone Member of Golconda Formation	332BGCF
	Bethel Sandstone	332BTHL
	Beaver Bend Limestone	332BVBD
	Beaver Bend Limestone and Mooretown (Bethel) Formation	332BVBM
	Beaver Bend and Paoli Limestones	332BVBP
	Clore Limestone	332CLOR
	Cypress Sandstone (Elwren Sandstone)	332CPRS
	Chesterian Series	332CSTR
	Degonia Sandstone	332DGON
	Golonda Formation (Big Lime of western Kentucky)	332GLCD
	Glen Dean Limestone	332GLND
	Girkin Formation	332GRKN
	Hardinsburg Sandstone (Jones Sand)	332HDBG
	Haney Limestone Member of Golonda Formation	332HNEY
	Kinkaid Limestone	332KNKD
	Leitchfield Formation	332LCFD
	Menard Limestone	332MNRD
	Maxon Sandstone	332MXON
	Paint Creek Shale (Limestone)	332PCRK

Table 1.(cont'd)-- Aquifer names and geologic unit codes used for retrieval of ground-water quality data from Kentucky.

Retrieval Group	Aquifer name or geologic unit	WATSTORE Code
5(cont'd)	Palestine Sandstone	332PLSN
	Paoli Limestone	332POLI
	Reelsville Limestone	332RLVL
	Renault Formation (Limestone)	332RNLT
	Ravencliff Sandstone	332RVCF
	Surficial deposits of slumped material	332SDSM
	Sample Sandstone	332SMPL
	Tar Springs Sandstone	332TSPG
	Vienna Limestone	332VINN
	Waltersburg Sandstone	332WLBG
6 (Early and Middle Pennsylvanian age rocks)	Caseyville Formation	324CSVL
	Lee Formation	327LEE
7 (Middle and Late Pennsylvanian age rocks)	Henshaw Formation	321HNSH
	Henshaw and Lisman Formations undifferentiated	321HSLM
	Lisman Formation	321LSMN
	Breathitt Formation	324BRTT
	Carbondale Formation	324CBDL
	Carbondale and Tradewater Formations undifferentiated	324TDCV
	Tradewater - Caseyville Formations, undifferentiated	324TDCV
	Tradewater Formation (Anvil Rock Sandstone)	324TRDR
8 (Late Cretaceous age rocks)	McNairy Formation	211MCNR
9 (Tertiary age rocks)	Claiborne and Wilcox Formations (Groups) undifferentiated	124CBWX
	Claiborne Group	124CLBR
	Eocene Series	124EOCN
	Jackson Group	124JCKS
	Wilcox Formation (Group)	124WLCX

Table 1.(cont'd)-- Aquifer names and geologic unit codes used for retrieval of ground-water quality data from Kentucky.

Retrieval Group	Aquifer name or geologic unit	WATSTORE Code
10 (Quaternary alluvium)	Holocene alluvium	111ALVM
	Alluvium along Mississippi River and Ohio River tributary streams	111AMOT
	Colluvium	111CLVM
	Holocene series	111HLCN
	Ohio River deposits, lower terrace	112ORLT
	Ohio River deposits, upper terrace	112ORUT
	Outwash	112OTSH

Figure 3.-- Generalized correlation chart of selected geologic formations used for retrieval of ground-water quality data. Rock types are shown where many geologic formations are combined.

SYSTEM	RETRIEVAL GROUP	WESTERN KENTUCKY	CENTRAL KENTUCKY	EASTERN KENTUCKY
QUATERNARY	10	Alluvium and outwash deposits	Alluvium and outwash deposits	Alluvium and outwash deposits
TERTIARY	9	Claiborne Group	**	**
CRETACEOUS	8	McNairy Formation	**	**
PENNSYLVANIAN	7	Sturgis Formation Carbondale Formation Tradewater Formation	**	Breathitt Formation **
	6	Caseyville Formation	**	Lee Formation
MISSISSIPPIAN	5	Rocks of Chesterian age	Pennington Formation Newman Limestone (upper part)	Pennington Formation Newman Limestone (upper part)
	4	Ste. Genevieve Limestone St. Louis Limestone Fort Payne Formation	Members of Newman Limestone (upper part) **	Newman Limestone Fort Payne Formation
DEVONIAN	3	Chattanooga Shale	New Albany Shale	Ohio Shale
SILURIAN		Limestones, dolomites, and shales	Limestones, dolomites, and shales	Limestones, dolomites, and shales
ORDOVICIAN	2	(No data)	Shales and limestones Lexington Limestone	(No data)
CAMBRIAN	1	(No data)	St. Peter Sandstone Knox Dolomite	St. Peter Sandstone Knox Dolomite

** -- No equivalent formation(s) in this area.

In general, the ground-water flow system in Kentucky is a thin veneer of freshwater circulating over a deep reservoir of highly mineralized (and possibly immobile) water. The Survey has assigned terms (Robinove and others, 1958) for highly mineralized waters as follows:

	Dissolved solids (milligrams per liter)
Slightly saline	1,000-3,000
Moderately saline	3,000-10,000
Very saline	10,000-35,000
Briny	>35,000

Hopkins (1966) has mapped the fresh-saline water interface in Kentucky. The map shows that the depth to water with 1,000 mg/L (milligrams per liter) dissolved solids varies from 25 to about 350 feet below land surface in the Blue Grass and Mississippian Plateau regions. Hopkins states "the greatest depths of freshwater are in the Jackson Purchase, Western Coal Field, and Eastern Coal Field regions where the interface ranges from 200 to more than 2,000 feet below land surface." As explained by Hopkins (1966), "the interface is not a plane but a zone of varying thickness...(and) chemical change within this zone is gradational rather than abrupt." Shallow ground water above the interface zone is likely to have less than 500 mg/L dissolved solids and be either sodium bicarbonate or calcium magnesium bicarbonate type throughout the State. Below the interface zone the less mineralized water usually is a sodium bicarbonate chloride type. The brines which occur at greater depths are usually sodium chloride type.

The head distribution and depth of freshwater flow in Kentucky is controlled by three main factors: (1) geologic structures, (2) composition of the bedrock, and (3) surface and subsurface drainage patterns. The major geologic structures of Kentucky are shown on figure 2. The major positive structural feature shown in figure 2 is the Cincinnati arch, which exposes some of the oldest rocks in the State in the Inner Blue Grass region. Younger rocks dip west and east from the Cincinnati arch toward the Western and Eastern Coal Fields. The coal fields lie in synclinal basins that are cut by major east- to northeast-trending fault systems. The significance of the geologic structures is that the flexures give regional dip to the rocks, bring different rock units to the surface, and provide a general direction to ground-water flow along bedding planes. The flexures and faults also enhance the vertical movement of ground water through secondary porosity and permeability which develops when competent rocks break rather than bend.

The composition of the bedrock controls the distribution and depth of freshwater flow by affecting the ease of ground-water movement. Where present near land surface, dense fractured limestones (and dolomites) dissolve, developing high vertical and horizontal permeability. Thus, in the Mississippian Plateau and Blue Grass regions where carbonate rocks are abundant, subsurface drainage, caves, and other karst features are common. The amount of dissolution of the carbonate rocks decreases with depth due to saturation of the ground water with the principal rock minerals, calcite and dolomite. At depths of more than a few hundred feet, the vertical fractures are not being enlarged by solution; downward ground-water flow is more difficult; and saltwater (possibly connate) remains in the rocks. In areas where sandstones and shales are present near land surface, the development of secondary permeability is slight; but the primary permeability, especially in unconsolidated sandy units, is relatively high. In the Eastern and Western Coal regions, and commonly in the Jackson Purchase region, freshwater can be found in sandy units more than 750 feet below land surface.

Surface and subsurface drainage patterns are themselves controlled to some degree by geologic structures and the composition of the bedrock. In the limestone areas of Kentucky, where karst features are extensive, major streams are the drains for the regional ground-water system. Under the prevailing water-table conditions, high heads are not developed and the hydraulic pressure required for deep, vertical movement of freshwater is not present. Where regionally extensive aquifers are confined in the downdip direction, high heads can be maintained for greater distances from recharge areas. In the Eastern and Western Coal regions, and the Jackson Purchase region, downdip confinement of water-bearing sand units maintains high heads downgradient from the recharge areas. These heads are sufficient to drive the deep circulation of freshwater found in these three Regions.

METHODS FOR SUMMARIZING DATA

Description of the Data File

This study evaluates ground-water quality data from Kentucky, using only data stored in the WATSTORE system of the Survey (U.S. Geological Survey, 1974). Historical data collected prior to September 30, 1981, were used. Data from 2,362 wells and springs were reviewed; these wells and springs had a total of 10,578 chemical analyses on file.

Combining Geologic Formations into Retrieval Groups

There are 159 geohydrologic units currently in use to identify ground-water quality data from Kentucky. In order to present a generalized view of the ground-water quality of the State, 110 of the principal water-bearing geologic formations were combined into 10 retrieval groups (table 1). The main criteria for combining formations to form the retrieval groups were the following:

1. Areas of outcrop - units crop out mainly in one physiographic province

2. Stratigraphic sequence - rocks in contact with each other

3. Hydraulic continuity - units are areally extensive and likely to exhibit similar hydraulic characteristics

4. Availability of data in computer storage - units known to have some ground-water quality data in computer files

Hereafter in this report, these retrieval groups will be designated Group _n_, where _n_ = 1, 2, 3, ... 10.

A Survey computer program called QWSYMAP (Hutchison, 1975, vol. 3, ch. IV) was used to make maps of the dissolved-solids concentration of water samples from each retrieval group. This computer program produces contour maps which consist of closed curves connecting points of equal dissolved-solids concentration. The computer-generated maps were edited and revised by hand to produce the figures cited in the following discussion of each group.

Group 1 - Cambrian and Ordovician Formations

Rocks of Group 1 are not exposed in Kentucky. The principal water-bearing units are the Knox Dolomite and the St. Peter Sandstone. These rocks are nearest the surface below the Blue Grass region. The St. Peter Sandstone is included in Group 1 because drillers and others have commonly listed permeable zones in the Knox as St. Peter. The Knox has been the target for oil and gas wells throughout most of the State, and analyses from these test wells indicate the water generally is very saline. A map of the dissolved-solids concentration of water samples from Group 1 is given in plate 1.

Group 2 - Upper Ordovician Formations

Some of the younger Ordovician limestones and shales are exposed in the Blue Grass region. Springs and karst topography commonly occur in the Inner Blue Grass region, but are less common in the Outer Blue Grass region. The Ordovician limestones supply drinking water in the Blue Grass region, but downdip, the water is saline. On the flanks of the Cincinnati arch, where Group 2 rocks underlie the Devonian black shale, the water is very saline. A map of the dissolved-solids concentration of water from Group 2 is shown in plate 2.

Group 3 - Silurian and Devonian Formations

The rocks of Group 3, the Silurian dolomites, limestones, and shales, and the black shale and thin limestones of Devonian age, do not yield large amounts of water. These rocks crop out in the Knobs region, but they yield saline water only a short distance downdip. Along the western edge of the Mississippian Plateau and in the eastern Jackson Purchase area, freshwater is present in Group 3 rocks for many miles downgradient. This group is absent in the Blue Grass region and, south of the Blue Grass region, only the Devonian black shale is found on the crest of the Cincinnati arch. The older Devonian formations, if ever present, have been removed from the crest of the arch and the black shale rests directly on Ordovician rocks (pl. 3). Water in rocks below the Devonian black shale is very saline in all of the central and eastern part of Kentucky, and in some places contains oil or gas. A map of dissolved-solids concentration of water from Group 3 is shown in plate 3.

Group 4 - Mississippian Formations

Group 4 contains the Fort Payne Formation and overlying rocks of Meramecian age. The Meramecian rocks are the limestone beds which contain extensive subsurface drainages in the Mississippian Plateau region. The Fort Payne Formation in the western and central part of the State is included because of hydrologic continuity with the overlying Meramecian carbonate sequence. Rocks in Group 4 are overlain by the less permeable Chesterian rocks; Group 4 rocks overlie the nearly impermeable Devonian black shale. Water in the rocks of Group 4 is fresh throughout most of the Mississippian Plateau region, but becomes very saline in the subsurface in the Eastern and Western Coal Field regions. A map of dissolved-solids concentration of water from Group 4 is shown in plate 4.

Group 5 - Upper Mississippian Formations

The principal water-bearing rocks of Late Mississippian age are the Chesterian rocks and the upper part of the Newman Limestone. The Chesterian rocks are alternating sandstones, shales, and limestones, which may hold freshwater at shallow depths in outcrop areas but will not produce large amounts of ground water. Beneath the Western Coal Field these rocks produce brines, and locally oil and gas. Chesterian rocks of the Eastern Coal Field are equivalent to the Pennington Formation and the upper part of the Newman Limestone (fig. 3). A sandstone in the Pennington, called Maxon sandstone by drillers, is the source of numerous oil or gas wells, and generally contains brine. Similarly, the Newman Limestone is a source for oil or gas wells; therefore, analyses of water from the Newman are included with Chesterian rocks. A map of dissolved-solids concentration of water from Group 5 is shown in plate 5.

Group 6 - Lower and Middle Pennsylvanian Formations

The principal water-bearing units in Group 6 are the Caseyville and Lee Formations. The Caseyville Formation in the Western Coal Field and the Lee Formation in the Eastern Coal Field are not in vertical or horizontal contact, but they exhibit similar hydrologic characteristics in the two coal field areas. There are more sandstones in the Caseyville than in the overlying Pennsylvanian formations and, as presently defined (Rice and others, 1979, p. F16), the Lee Formation is almost all sandstone. Although these sandstones are not regionally extensive, the two formations are herein treated as continuous hydrologic units, because they are traceable for miles in some areas (Davis and others, 1974). Both units generally contain freshwater near outcrop areas, but both contain highly mineralized brine at depth. A 1,000-foot deep, freshwater, paleo-aquifer in the Caseyville that is unrelated to the post-glaciation freshwater flow system has been described by Davis and others (1974). A map of dissolved-solids concentration of water from Group 6 is shown in plate 6.

Group 7 - Middle and Upper Pennsylvanian Formations

The principal water-bearing units in Group 7 are the Middle and Upper Pennsylvanian deposits in the Western Coal Field. Group 7 includes the shale, siltstone, sandstone, limestone, and coal beds of the Sturgis (table 1 uses obsolete names: Henshaw and Lisman), Carbondale, and Tradewater Formations. In the Eastern Coal Field, lithologically and stratigraphically similar deposits in the Breathitt Formation are included in Group 7. The base of Group 7 rocks in the Western Coal Field is arbitrarily placed at the base of the 1b (Bell) coal (Rice and others, 1979, p. F22), although, in some areas, the basal Tradewater Formation cannot be distinguished by lithology from the underlying Caseyville Formation (Group 6). Discontinuous sandstone aquifers are present throughout the Western Coal Field region and may locally be in hydraulic continuity with the underlying Caseyville Formation.

In the Eastern Coal Field, the base of Group 7 is the top of the underlying coarse-grained sandstones of the Lee Formation. Locally, beds of the Lee (Group 6) intertongue with beds of the Breathitt Formation. Most of the freshwater circulation is shallow in the Eastern Coal Field region and available ground water occurs only in fracture porosity. In this region, the Middle and Upper Pennsylvanian rocks (Group 7) have been separated from the Lower and Middle Pennsylvanian rocks (Group 6) for two reasons: (1) rocks of Middle and Upper Pennsylvanian are recharged locally, they generally contain freshwater, and are the source of ground water in most of the area, and (2) traditionally, the deeper Pennsylvanian sandstones in oil-field drilling areas are called Caseyville or Lee Formation (or less precise equivalent terms by drillers). Deep water samples from oil test wells are commonly brines, and the analyses have been assigned to the Lee or Caseyville for computer storage. A map of dissolved-solids concentration of water from Group 7 is shown in plate 7.

Group 8 - McNairy Formation

The McNairy Formation consists of unconsolidated sand and clay of Late Cretaceous age. The unit crops out in the eastern and northern parts of the Jackson Purchase region and underlies the entire Region downdip from the outcrop area. The Porters Creek Clay of Tertiary age overlies the McNairy and is an effective barrier to both downward and upward exchange of water between the McNairy and the overlying Tertiary sands (Group 9). A map of the dissolved-solids concentration of water from Group 8 is shown in figure 4.

Group 9 - Tertiary Formations

The principal aquifers in the Tertiary deposits of Kentucky are in the Claiborne Group. The Claiborne consists of unconsolidated sand and clay of Eocene age. The Claiborne sediments overlie the Wilcox Formation or the Porters Creek Clay and are present in about 80 percent of the Jackson Purchase region. Circulation of ground water in the Claiborne sands is laterally extensive, but downward percolation is retarded at the contact between the Claiborne and the Porters Creek Clay or clays of the Wilcox. Except for local areas of perched water, Claiborne sediments appear to act as one unit of hydrologic circulation (Davis and others, 1973). The water in the Claiborne is generally fresh; a map of the dissolved-solids concentration of water from Group 9 is shown in figure 5.

Group 10 - Quaternary Alluvium

The Quaternary sand and gravel deposits in the alluvial valleys of the Ohio River yield large amounts of water for industrial, public supply, and irrigation wells. The sands and gravels are hydraulically connected with the river, and heavy pumping of wells near the river can induce recharge from the stream. The alluvium in the valleys of other major rivers in Kentucky is generally composed of clay, silt, and sand; these fine-grained alluvial deposits generally do not yield large quantities of water to wells. The water in the alluvium is generally fresh, although contamination by oil-field brines, industrial, or municipal wastes may have locally affected the ground-water quality (Hopkins, 1963; Davis, 1980). A map of dissolved-solids concentration of water from Group 10 deposits along part of the Ohio River is shown in figure 6.

Statistical Approach

This review of available ground-water quality data from Kentucky involved (1) summarizing, by retrieval group, major dissolved constituents and physical properties measured in ground-water samples, (2) graphical analysis (quadrilinear diagrams) of principal ions by retrieval group, and (3) summarizing, from the entire data file, analyses of trace elements, radionuclides, and man-made organic chemicals. Procedures of the Statistical Analysis System (Helwig and Council, 1979) were utilized to summarize and graph the data. The statistical parameters selected to characterize the major dissolved constituents and physical properties were the maximum, minimum, median, and the 75 percent and 25 percent quartiles. The retrieval group summaries are listed in table 2. Frequency bar graphs of dissolved solids, chloride, sulfate, and hardness, by retrieval group, are shown in figures 7-16. The intervals selected for the frequency bar charts were chosen on the basis of drinking water standards (U.S. Environmental

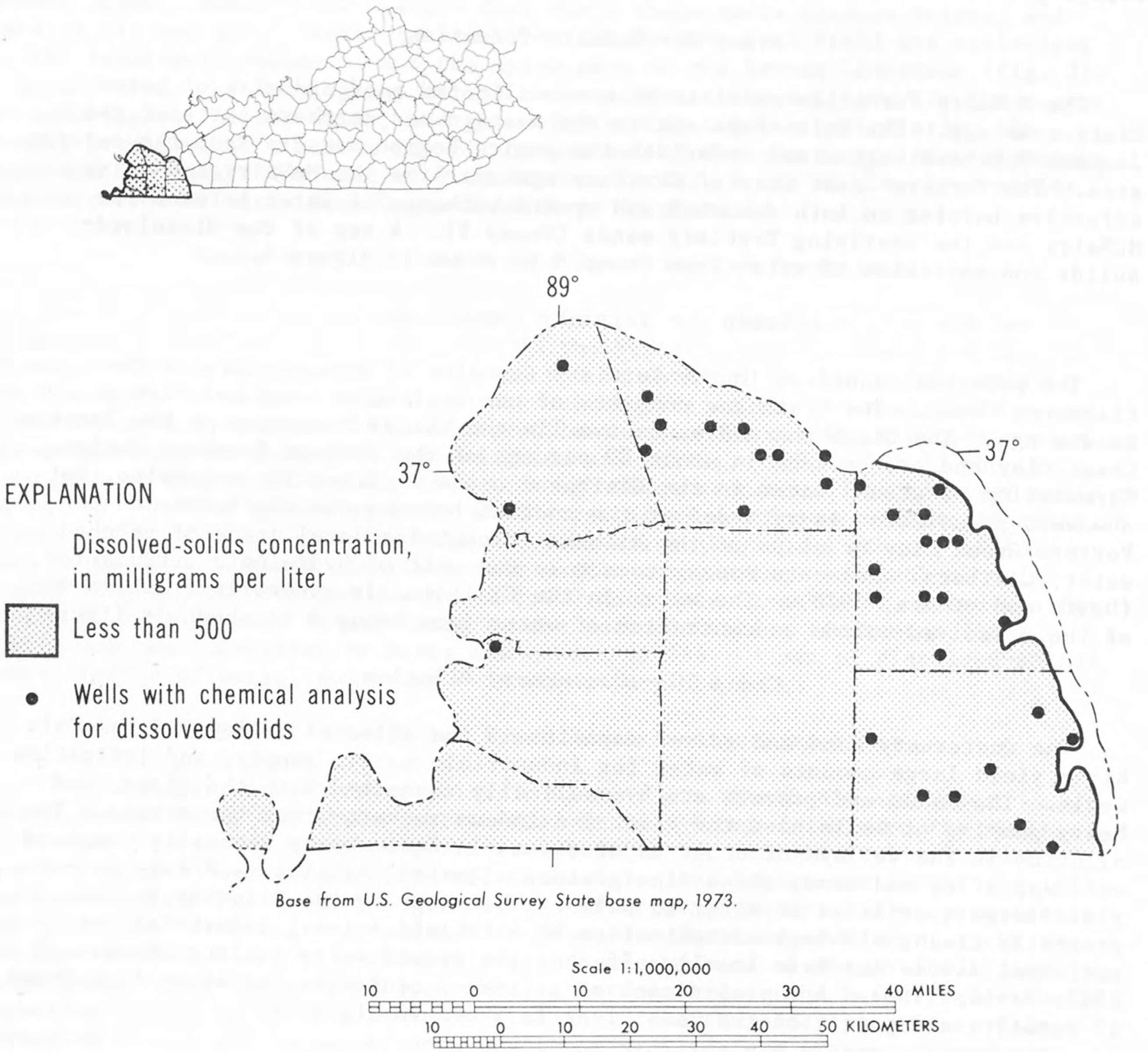

Figure 4.-- Dissolved-solids concentration in ground water from McNairy Formation in Kentucky.

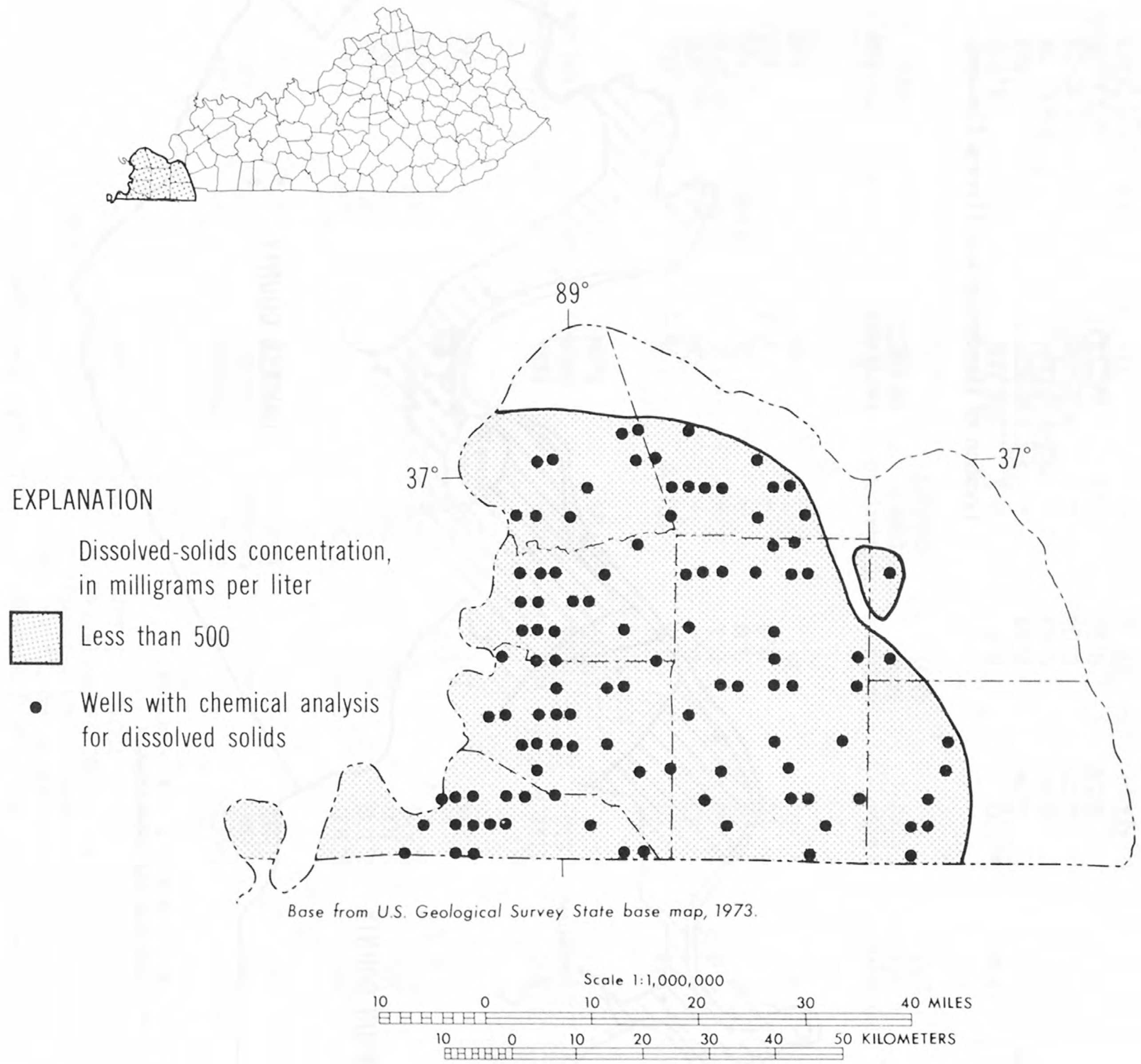

Figure 5.-- Dissolved-solids concentration in ground water from Tertiary formations in Kentucky.

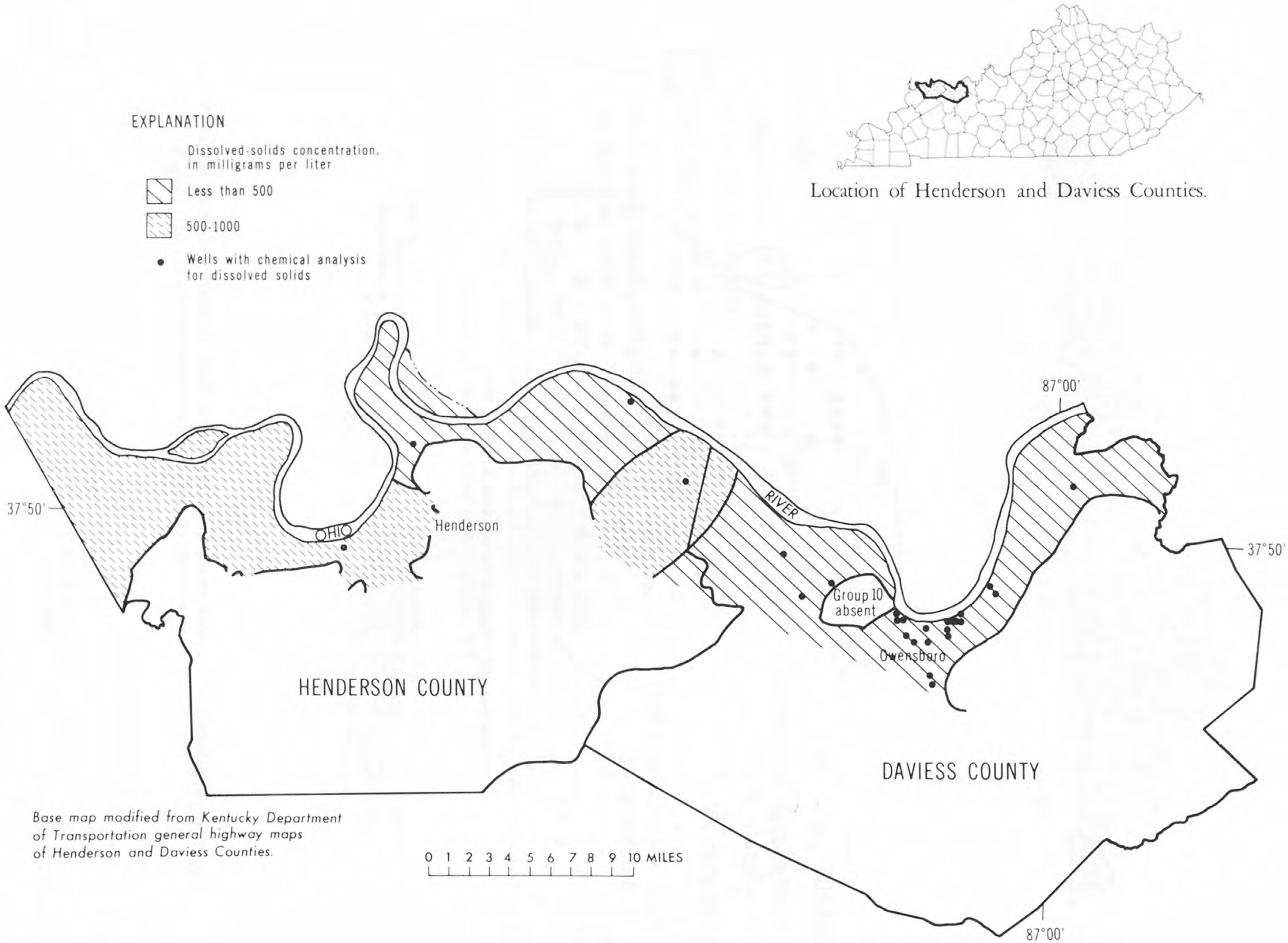

Figure 6.-- Dissolved-solids concentration in ground water from the Quaternary alluvium along the Ohio River.

Table 2.--Summary of selected ground-water quality data from Kentucky
Temperature: Temperature of water, in degrees Celcius. Specific conductance: In micromhos per centimeter at 25°C (units are milligrams per liter except as indicated). Dissolved solids: Residue on evaporation at 180°C. Color: In units relative to platinum-cobalt standard.

Group 1	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity as $CaCO_3$	Sulfate (SO_4)
Maximum	48,000	19,900	56,100	9,950	2,310	108	919	3,600
75 percentile	2,800	886	11,100	327	396	0.0	320	1,400
Median	720	300	5,100	150	290	0.0	248	484
25 percentile	196	123	2,560	76	122	0.0	144	173
Minimum	2.8	0.1	1.5	0.5	0.0	0.0	0.0	0
Number of samples	193	193	194	187	190	180	122	196

	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Nitrate (NO_3)	Phosphate (PO_4)	Temperature	Specific conductance	Dissolved solids
Maximum	198,000	17	56	7.8	0.09	38.5	205,000	390,000
75 percentile	25,100	3.0	13	0.4	-	24	58,100	43,300
Median	8,700	1.8	10	0.1	-	21	25,000	17,200
25 percentile	3,790	1.0	8	0.0	-	16	13,100	7,320
Minimum	8	0.0	0	0.0	-	4.5	222	136
Number of samples	202	179	167	59	1	49	193	190

	Color	Hydrogen sulfide (H_2S)	Iron (Fe)	Manganese (Mn)	Dissolved organic carbon	Hardness as $CaCO_3$	Iodide (I)	Bromide (Br)
Maximum	400	304	4,300	8.9	2.5	182,000	639	1,370
75 percentile	7	-	2.50	0.65	-	11,630	5.0	144
Median	5	-	0.21	0.13	-	3,100	1.5	38
25 percentile	2	-	0.05	0.04	-	1,080	0.54	21
Minimum	0	-	0.00	0.00	0.1	22	0	0.4
Number of samples	60	1	121	73	2	193	113	113

Table 2.--Summary of selected ground-water quality data from Kentucky--Continued

Group 2	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity as $CaCO_3$	Sulfate (SO_4)
Maximum	72,100	4,520	53,600	1,290	1,840	43	742	3,300
75 percentile	129	48	780	18	304	0.0	242	75
Median	89	16	24	3.3	253	0.0	199	41
25 percentile	69	7.8	6.8	1.6	196	0.0	161	24
Minimum	2.7	1.8	1.0	0.3	0.0	0.0	0.0	0
Number of samples	343	343	339	334	565	524	154	577

	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Nitrate (NO_3)	Phosphate (PO_4)	Temperature	Specific conductance	Dissolved solids
Maximum	141,000	19	55	110	14	27	16,300	246,000
75 percentile	163	0.8	10	17	2.10	14.5	1,280	2,570
Median	22	0.3	8	9.6	1.10	13.3	606	392
25 percentile	8	0.2	7	1.4	.42	12	466	296
Minimum	0	0.0	1.1	0.0	.03	6.7	202	114
Number of samples	581	537	311	492	9	390	584	345

	Color	Hydrogen sulfide (H_2S)	Iron (Fe)	Manganese (Mn)	Dissolved organic carbon	Hardness as $CaCO_3$	Iodide (I)	Bromide (Br)
Maximum	37	27	640	59	6.5	187,000	28	394
75 percentile	4	-	0.69	0.12	5.6	380	5.3	148
Median	3	0.2	0.23	0.04	2.6	270	3.4	78
25 percentile	1	-	0.09	0.00	2.1	219	1.6	30
Minimum	0	0	0.00	0.00	2.0	14	0.0	1.4
Number of samples	255	3	514	281	4	575	69	68

Table 2.--Summary of selected ground-water quality data from Kentucky--Continued

Group 3	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity as $CaCO_3$	Sulfate (SO_4)
Maximum	63,000	14,500	67,700	4,200	4,500	84	1,170	3,280
75 percentile	4,350	1,600	27,700	264	481	0.0	453	517
Median	653	284	5,500	61	286	0.0	244	172
25 percentile	117	43	37	3.5	122	0.0	76	19
Minimum	2.8	1.2	0.9	0.2	0.0	0.0	0	0
Number of samples	260	259	266	252	533	424	100	537

	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Nitrate (NO_3)	Phosphate (PO_4)	Temperature	Specific conductance	Dissolved solids
Maximum	205,000	9.0	54	64	1.47	26.5	1,140,000	388,000
75 percentile	10,000	1.0	18	3.2	0.80	15.6	40,300	99,200
Median	54	0.2	12	0.5	0.29	14.4	1,590	16,500
25 percentile	10	0.1	8	0.1	0.06	13.3	475	1,060
Minimum	0	0.0	0.7	0.0	0.03	7.2	38	99
Number of samples	544	419	204	384	8	353	499	266

	Color	Hydrogen sulfide (H_2S)	Iron (Fe)	Manganese (Mn)	Dissolved organic carbon	Hardness as $CaCO_3$	Iodide (I)	Bromide (Br)
Maximum	110	61	1,800	75	3.4	160,000	27	1,500
75 percentile	4	0.9	7.25	2.88	-	1,980	8.9	247
Median	2	0.2	0.99	0.94	-	645	4.7	129
25 percentile	1	0	0.17	0.07	-	212	2.5	49
Minimum	0	0	0.00	0.00	1.9	9	0	0
Number of samples	103	10	453	184	2	531	151	152

Table 2.--Summary of selected ground-water quality data from Kentucky--Continued

Group 4	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity as $CaCO_3$	Sulfate (SO_4)
Maximum	21,000	2,140	42,100	460	1,140	133	420	42,500
75 percentile	96	32	25	2.9	252	0.0	220	50
Median	67	12	5	1.2	196	0.0	171	12
25 percentile	49	6.1	2.4	0.8	144	0.0	118	6
Minimum	2.1	0.6	0.5	0.0	0.0	0.0	0.0	0
Number of samples	601	602	483	464	1,741	1,598	793	2,289

	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Nitrate (NO_3)	Phosphate (PO_4)	Temperature	Specific conductance	Dissolved solids
Maximum	85,000	7.4	208	490	0.92	30	151,000	143,000
75 percentile	15	0.4	12	8	.24	15	609	470
Median	5	0.2	10	4.3	.12	14	407	288
25 percentile	3	0.1	8	1.9	.05	13.3	293	213
Minimum	0	0.0	0.5	0.0	0.00	2.5	2.5	27
Number of samples	1,934	1,698	450	1,612	58	1,596	2,380	862

	Color	Hydrogen sulfide (H_2S)	Iron (Fe)	Manganese (Mn)	Dissolved organic carbon	Hardness as $CaCO_3$	Iodide (I)	Bromide (Br)
Maximum	160	160	630	69	7.2	56,000	20	1,180
75 percentile	5	48	0.30	0.74	4.7	288	12	125
Median	3	8	0.12	0.02	2.2	195	7.4	78
25 percentile	1	0.3	0.05	0.00	1.2	140	3.6	21
Minimum	0	0	0.00	0.00	0.5	1	0.0	0.1
Number of samples	278	13	1,629	462	6	1,864	51	52

Table 2.--Summary of selected ground-water quality data from Kentucky--Continued

Group 5	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity as $CaCO_3$	Sulfate (SO_4)
Maximum	72,200	3,600	49,300	3,530	3,600	118	2,950	7,460
75 percentile	1,970	626	19,800	83	248	0.0	195	122
Median	287	156	6,480	26	106	0.0	73	12
25 percentile	31	3.5	4.3	0.9	54	0.0	47	4
Minimum	3.6	0.2	0.6	0.2	0.0	0.0	0.0	0
Number of samples	183	186	188	182	357	352	109	405

	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Nitrate (NO_3)	Phosphate (PO_4)	Temperature	Specific conductance	Dissolved solids
Maximum	138,000	19	79	54	0.03	31.7	157,000	288,000
75 percentile	10,800	0.9	14	1.4	-	14.9	13,700	61,600
Median	6	0.1	10	0.5	-	13.3	427	18,000
25 percentile	2	0.1	9	0.2	-	12.1	146	240
Minimum	0	0.0	0.7	0.0	-	7	32.1	24
Number of samples	382	357	148	257	1	236	408	203

	Color	Hydrogen sulfide (H_2S)	Iron (Fe)	Manganese (Mn)	Dissolved organic carbon	Hardness as $CaCO_3$	Iodide (I)	Bromide (Br)
Maximum	40	-	7,100	82	2.9	182,000	15	576
75 percentile	5	-	0.62	1.01	-	1,500	6.6	130
Median	3	-	0.10	0.11	-	127	4.6	81
25 percentile	1	-	0.04	0.01	-	59	3.2	36
Minimum	0	-	0.00	0.00	0.5	4	0.03	0.0
Number of samples	63	0	327	130	2	368	107	107

Table 2.--Summary of selected ground-water quality data from Kentucky--Continued

Group 6	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity as $CaCO_3$	Sulfate (SO_4)
Maximum	16,000	2,600	50,000	510	1,290	114	692	4,600
75 percentile	25	9.4	248	4.7	177	0.0	95	69
Median	13	4.7	30	2.2	52	0.0	41	20
25 percentile	4.0	1.3	5.9	1.2	10	0.0	8	6
Minimum	0.5	0	0.2	0.1	0.0	0.0	0.0	0
Number of samples	180	185	185	176	512	503	262	532

	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Nitrate (NO_3)	Phosphate (PO_4)	Temperature	Specific conductance	Dissolved solids
Maximum	110,000	17	150	167	0.74	25	16,300	197,000
75 percentile	54	0.6	22	1.5	0.38	16.8	522	538
Median	13	0.2	13	0.4	0.26	15	335	252
25 percentile	3	0.1	10	0.1	0.06	13.9	130	82
Minimum	0	0.0	4.5	0.0	0.03	1.4	7.2	16
Number of samples	350	266	404	252	16	270	537	203

	Color	Hydrogen sulfide (H_2S)	Iron (Fe)	Manganese (Mn)	Dissolved organic carbon	Hardness as $CaCO_3$	Iodide (I)	Bromide (Br)
Maximum	250	0	93	18	6.5	51,000	22	1,190
75 percentile	5	0	2.12	1.30	4.5	120	3.2	177
Median	3	0	0.58	0.53	2.0	74	1.7	93
25 percentile	2	0	0.20	0.09	0.8	24	1.7	20
Minimum	0	0	0.00	0.00	0.4	1	0.0	0.0
Number of samples	142	4	502	402	5	533	18	18

Table 2.--Summary of selected ground-water quality data from Kentucky--Continued

Group 7	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity as $CaCO_3$	Sulfate (SO_4)
Maximum	456	234	909	33	1,170	133	800	2,750
75 percentile	55	19	153	3.8	255	0.0	193	51
Median	30	9.2	61	2.4	160	0.0	148	17
25 percentile	16	4.5	22	1.4	68	0.0	93	5
Minimum	1.4	0.2	0.6	0.3	0.0	0.0	0.0	0
Number of samples	108	107	107	98	450	400	74	447

	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Nitrate (NO_3)	Phosphate (PO_4)	Temperature	Specific conductance	Dissolved solids
Maximum	3,900	78	60	220	-	25.6	10,700	3,230
75 percentile	32	0.3	19	2.8	-	15.6	683	671
Median	9	0.2	14	0.9	-	14	380	354
25 percentile	4	0.1	11	0.2	-	12.8	215	214
Minimum	1	0.0	2	0.0	-	4	17	16
Number of samples	580	430	103	440	0	450	447	83

	Color	Hydrogen sulfide (H_2S)	Iron (Fe)	Manganese (Mn)	Dissolved organic carbon	Hardness as $CaCO_3$	Iodide (I)	Bromide (Br)
Maximum	15	-	157	12	-	2,190	-	-
75 percentile	5	-	3.50	0.28	-	172	-	-
Median	3	-	0.76	0.04	-	98	-	-
25 percentile	2	-	0.26	0.00	-	52	-	-
Minimum	0	-	0.00	0.00	-	3	-	-
Number of samples	98	0	443	97	0	448	0	0

Table 2.--Summary of selected ground-water quality data from Kentucky--Continued

Group 8	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity as $CaCO_3$	Sulfate (SO_4)
Maximum	57	13	85	12	220	87	184	1,430
75 percentile	33	8.0	18	4.5	102	0.0	75	17
Median	16	4.1	3.9	0.9	52	0.0	26	10
25 percentile	7.2	2.3	2.8	0.5	26	0.0	21	4
Minimum	1.4	0.1	1.0	0.1	0.0	0.0	7	0
Number of samples	69	68	65	64	174	169	20	178

	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Nitrate (NO_3)	Phosphate (PO_4)	Temperature	Specific conductance	Dissolved solids
Maximum	98	3.3	87	103	0.03	21.7	2,150	299
75 percentile	14	0.2	15	2.7	-	16.5	287	191
Median	4	0.1	12	0.5	-	15.6	143	90
25 percentile	2	0.1	10	0.1	-	14.4	78	60
Minimum	0	0.0	4.5	0.0	-	1.6	20	20
Number of samples	178	177	70	176	1	91	177	60

	Color	Hydrogen sulfide (H_2S)	Iron (Fe)	Manganese (Mn)	Dissolved organic carbon	Hardness as $CaCO_3$	Iodide (I)	Bromide (Br)
Maximum	30	-	28	1.00	0.8	952	-	-
75 percentile	5	-	1.40	0.11	-	88	-	-
Median	3	-	0.42	0.02	-	48	-	-
25 percentile	2	-	0.15	0.01	-	26	-	-
Minimum	0	-	0.00	0.00	0.3	1	-	-
Number of samples	64	0	178	61	2	177	0	0

Table 2.--Summary of selected ground-water quality data from Kentucky--Continued

Group 9	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity as $CaCO_3$	Sulfate (SO_4)
Maximum	640	326	15,000	73	644	14	353	274
75 percentile	15	5.4	16	1.0	76	0.0	74	6
Median	7.2	2.7	9.7	0.6	44	0.0	25	2
25 percentile	3.3	1.4	5.9	0.4	25	0.0	19	1
Minimum	0.5	0.3	2.0	0	0.0	0.0	11	0
Number of samples	164	164	164	161	466	454	37	469

	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Nitrate (NO_3)	Phosphate (PO_4)	Temperature	Specific conductance	Dissolved solids
Maximum	25,000	2.0	59	439	0.03	20	56,200	43,500
75 percentile	12	0.1	18	9.6	-	16.1	220	147
Median	6	0.1	15	2.9	-	15	120	83
25 percentile	3	0.0	12	0.5	-	14.4	75	56
Minimum	0	0.0	7	0.0	-	9.4	23	24
Number of samples	469	450	168	467	1	219	468	191

	Color	Hydrogen sulfide (H_2S)	Iron (Fe)	Manganese (Mn)	Dissolved organic carbon	Hardness as $CaCO_3$	Iodide (I)	Bromide (Br)
Maximum	35	-	120	20.0	1.3	2,700	5.5	70
75 percentile	5	-	0.66	0.80	-	56	-	-
Median	2	-	0.19	0.20	-	30	-	-
25 percentile	1	-	0.08	0.00	-	16	-	-
Minimum	0	-	0.00	0.00	-	1	4.0	48
Number of samples	159	0	461	159	1	469	2	2

Table 2.--Summary of selected ground-water quality data from Kentucky--Continued

Group 10	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity as $CaCO_3$	Sulfate (SO_4)
Maximum	2,460	1,850	6,260	100	742	30	566	2,490
75 percentile	160	46	24	3.4	429	0.0	363	191
Median	100	30	16	2.3	328	0.0	290	67
25 percentile	66	19	8.2	1.3	208	0.0	207	29
Minimum	1.9	0.7	2.1	0.2	0.0	0.0	0.0	0
Number of samples	481	492	451	450	1,189	747	268	1,361

	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Nitrate (NO_3)	Phosphate (PO_4)	Temperature	Specific conductance	Dissolved solids
Maximum	32,600	73	170	209	1.23	27.8	64,800	48,700
75 percentile	39	0.2	19	6.3	0.34	15.8	1,130	820
Median	18	0.1	17	1.0	0.06	15	692	466
25 percentile	7	0.1	14	0.2	0.03	14	483	315
Minimum	0	0.0	1.6	0.0	0.03	4	36	24
Number of samples	1,323	852	471	1,194	31	1,141	1,111	439

	Color	Hydrogen sulfide (H_2S)	Iron (Fe)	Manganese (Mn)	Dissolved organic carbon	Hardness as $CaCO_3$	Iodide (I)	Bromide (Br)
Maximum	5,000	0	9,660	540	5.3	13,800	0.7	61
75 percentile	5	0	3.60	1.30	1.6	540	-	-
Median	3	0	0.99	0.35	0.9	350	0.0	-
25 percentile	1	0	0.23	0.10	0.4	238	-	-
Minimum	0	0	0.00	0.00	0.0	4	0.0	-
Number of samples	399	11	1,297	480	31	1,374	3	1

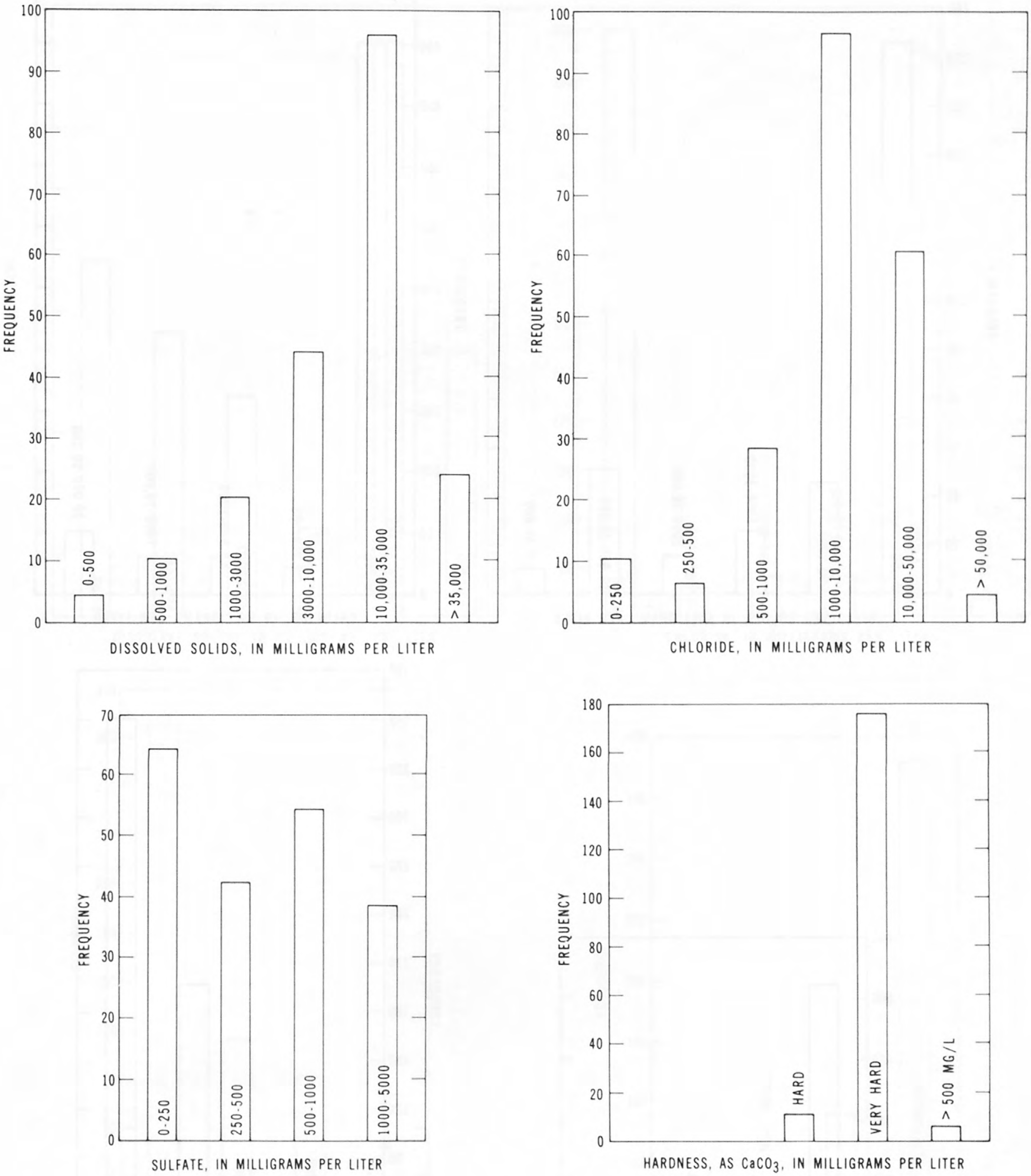

Figure 7.-- Frequency bar chart of selected Group 1 data.

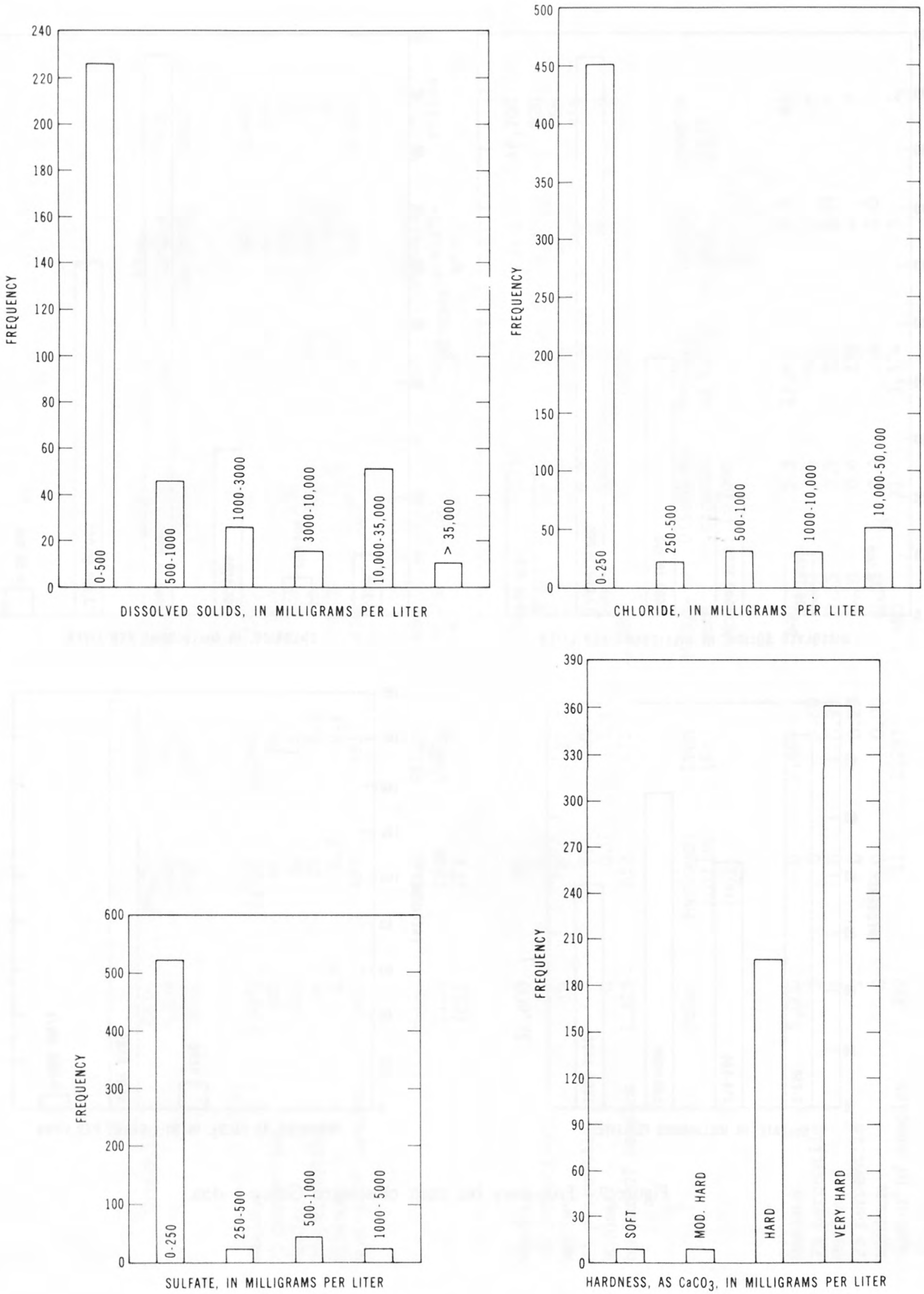

Figure 8.-- Frequency bar chart of selected Group 2 data.

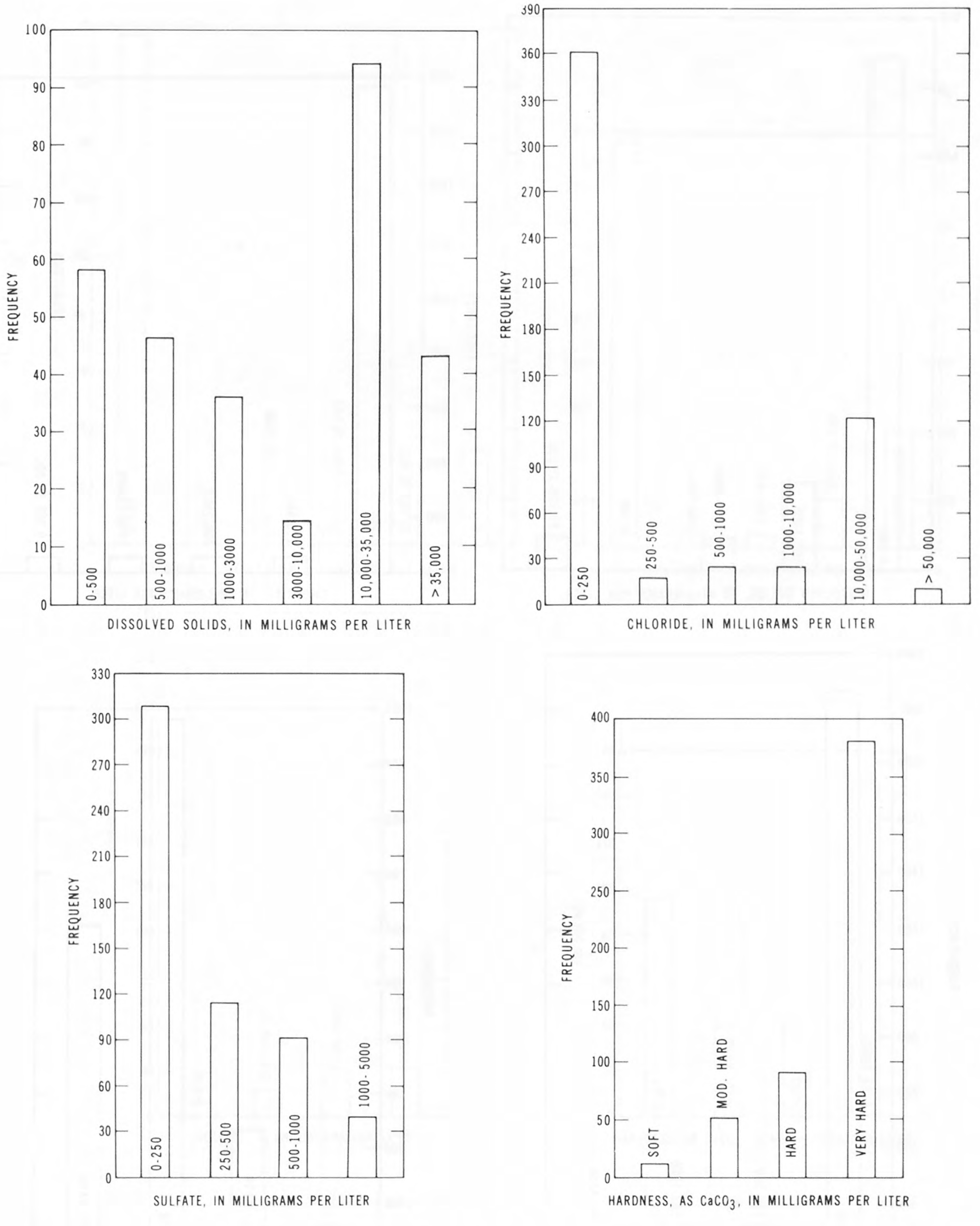

Figure 9.-- Frequency bar chart of selected Group 3 data.

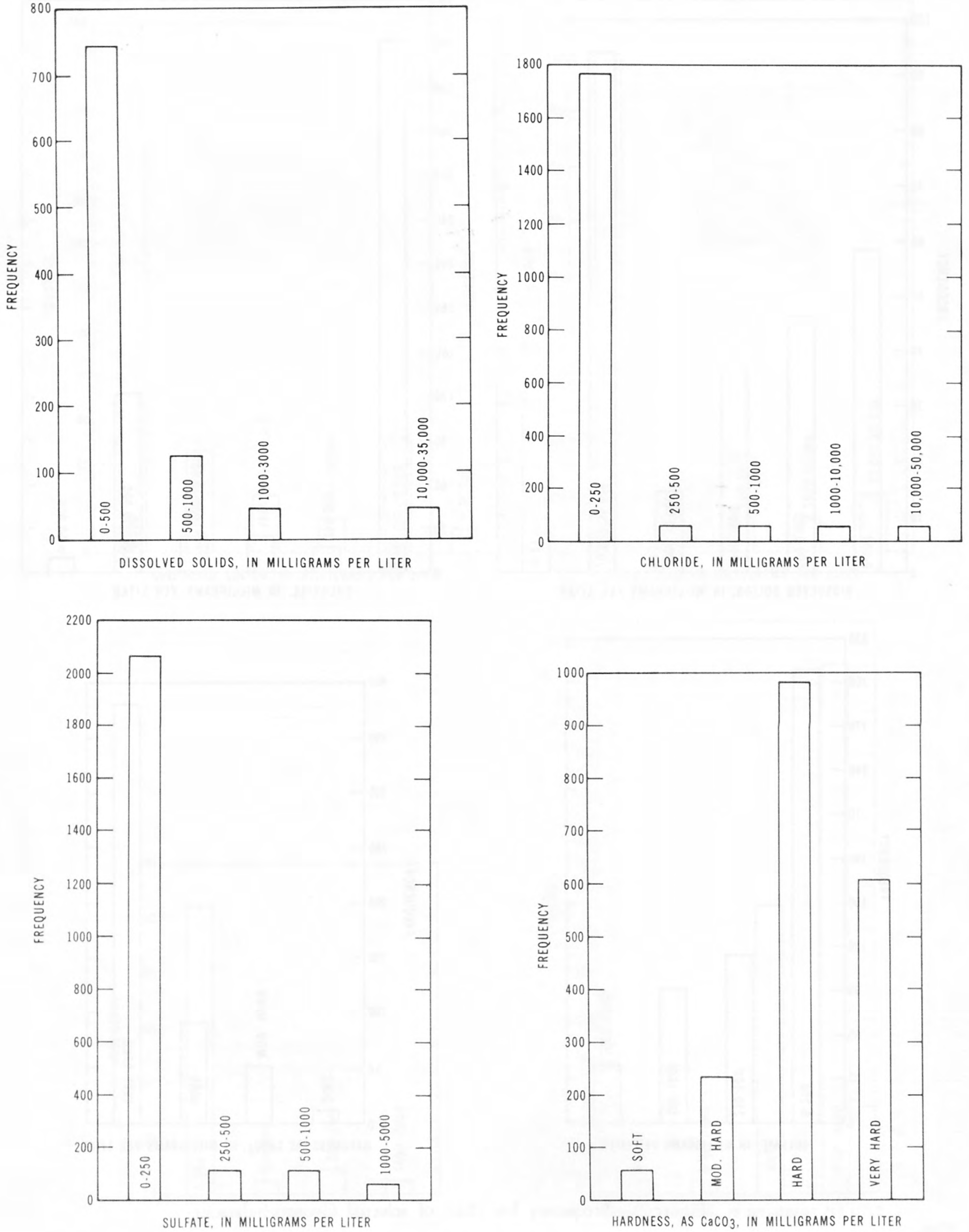

Figure 10.-- Frequency bar chart of selected Group 4 data.

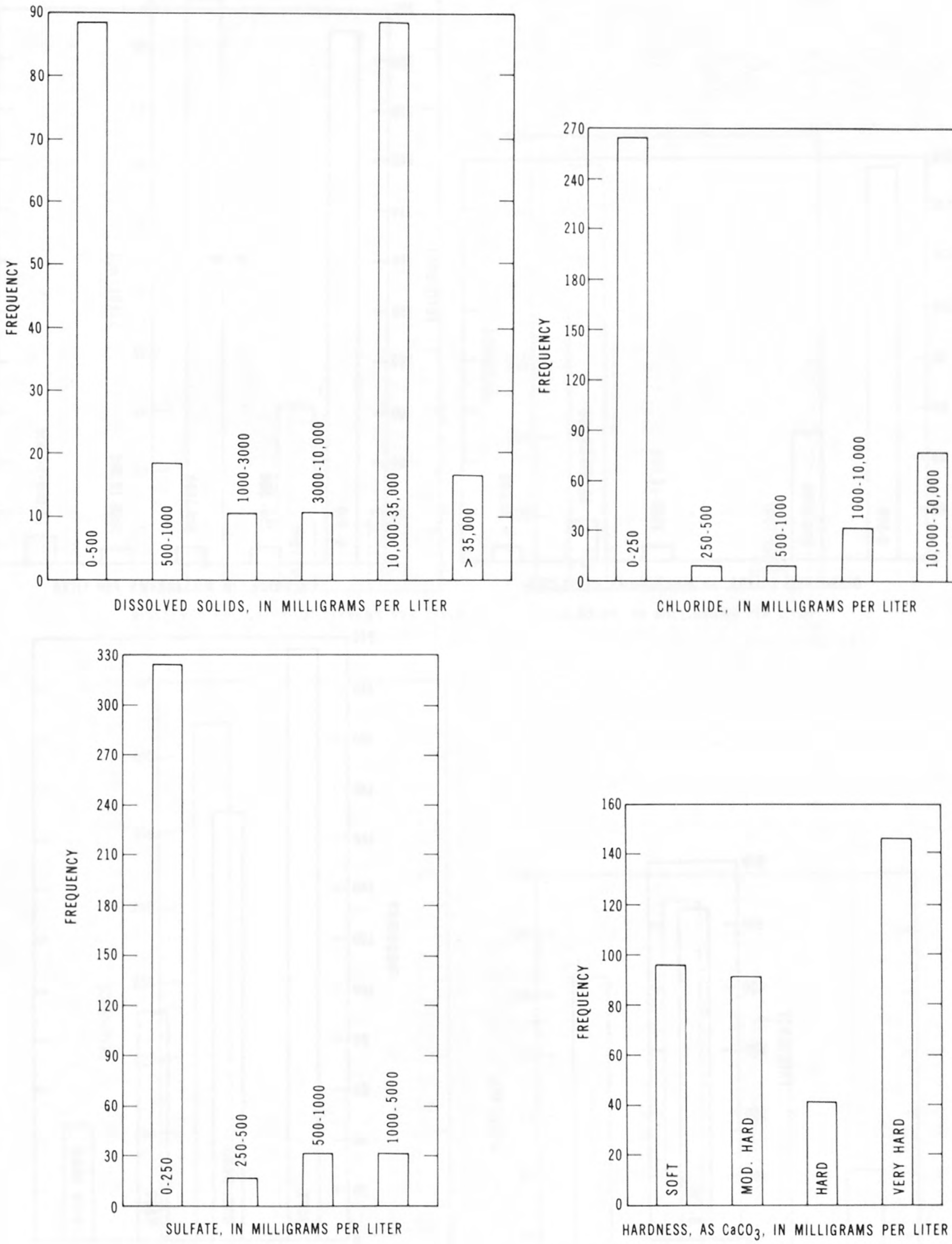

Figure 11.-- Frequency bar chart of selected Group 5 data.

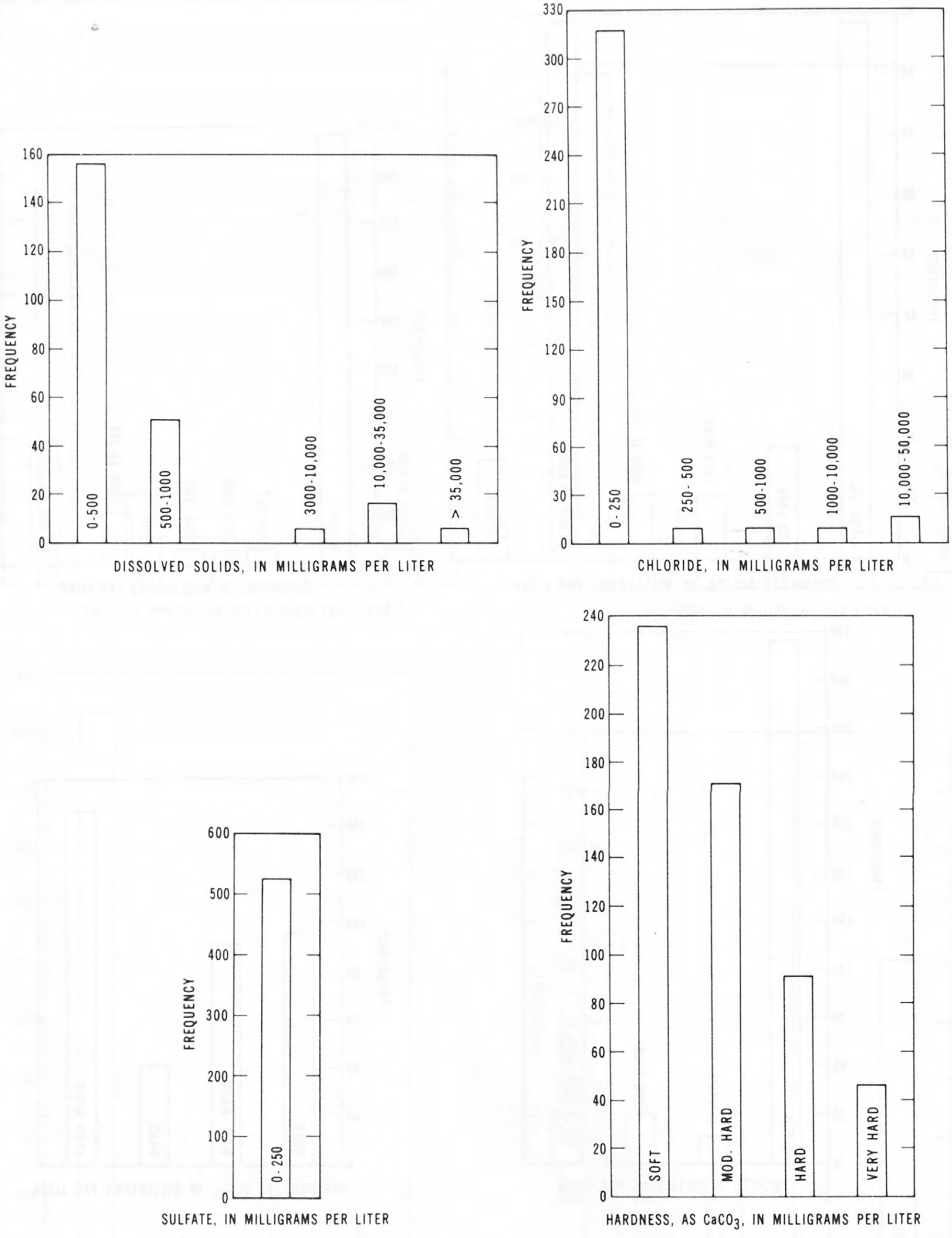

Figure 12.-- Frequency bar chart of selected Group 6 data.

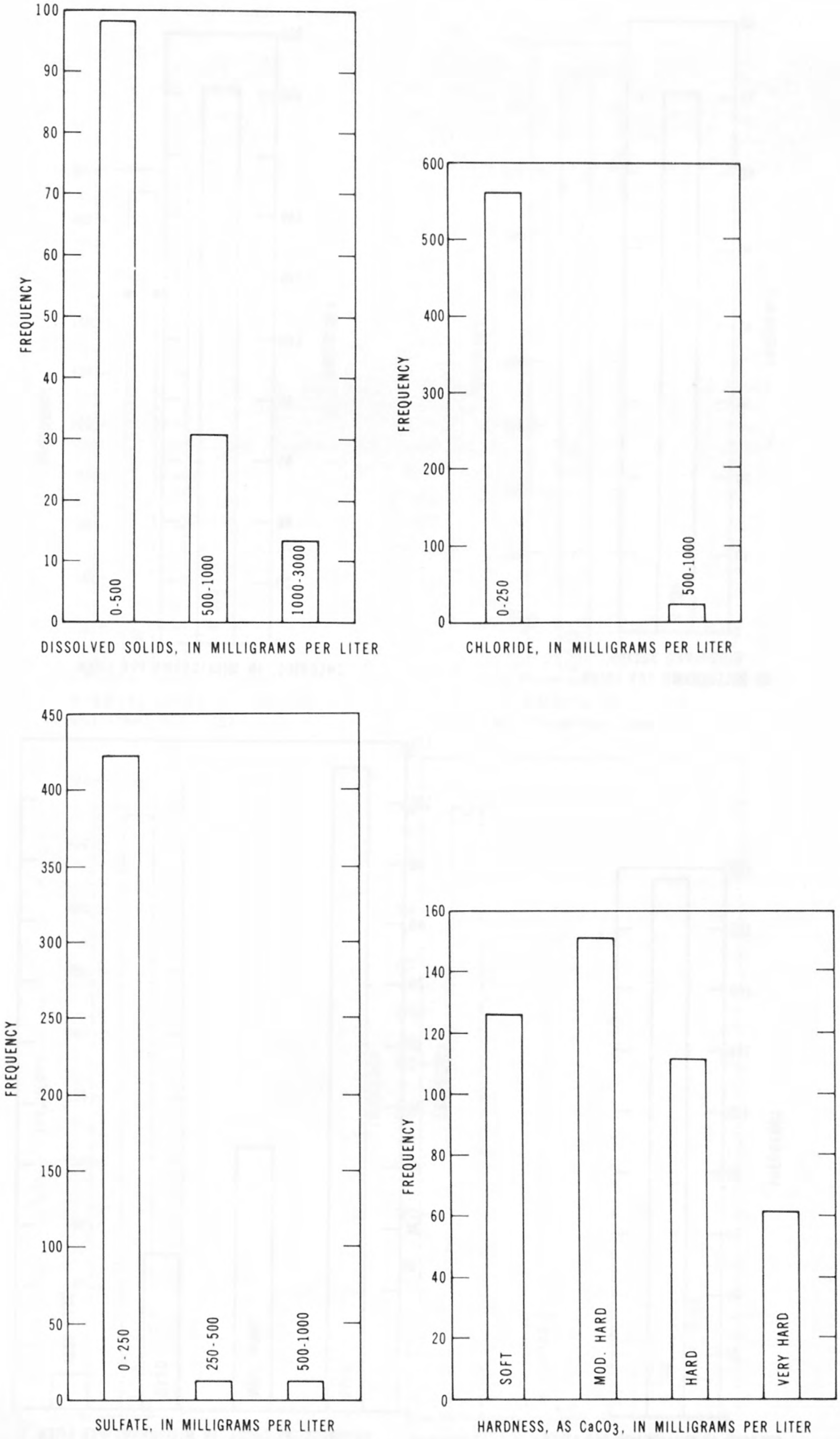

Figure 13.-- Frequency bar chart of selected Group 7 data.

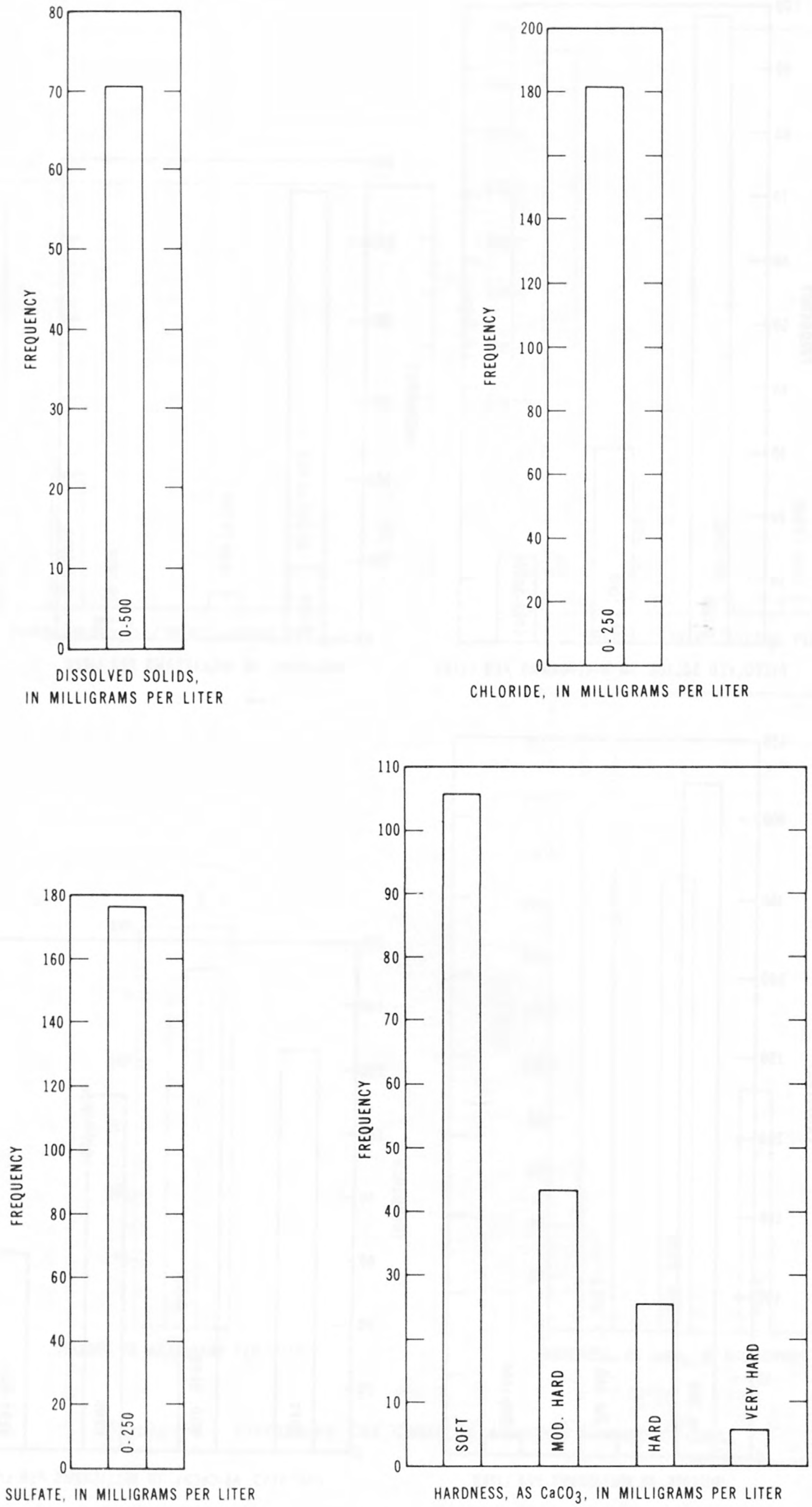

Figure 14.-- Frequency bar chart of selected Group 8 data.

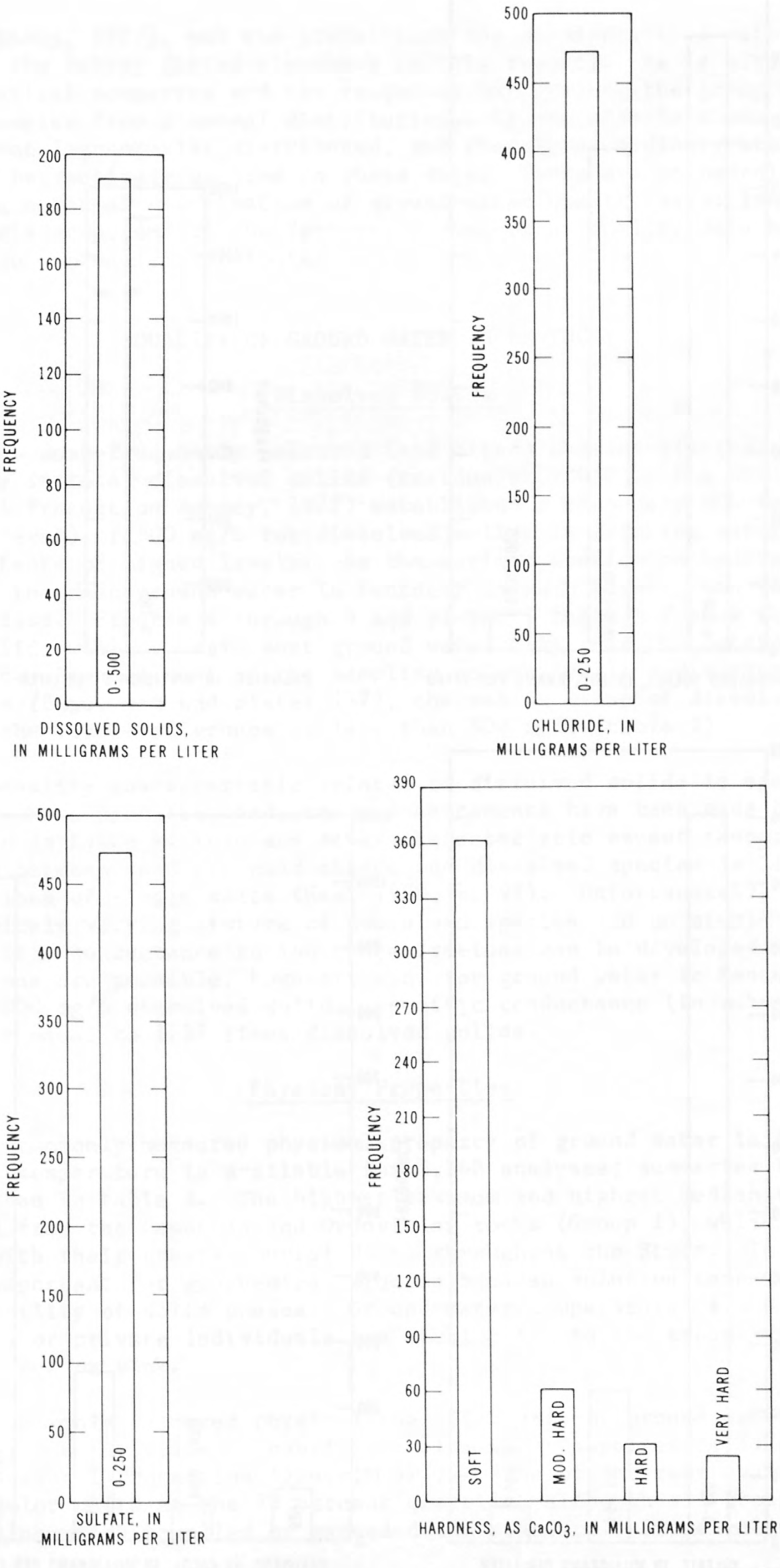

Figure 15.-- Frequency bar chart of selected Group 9 data.

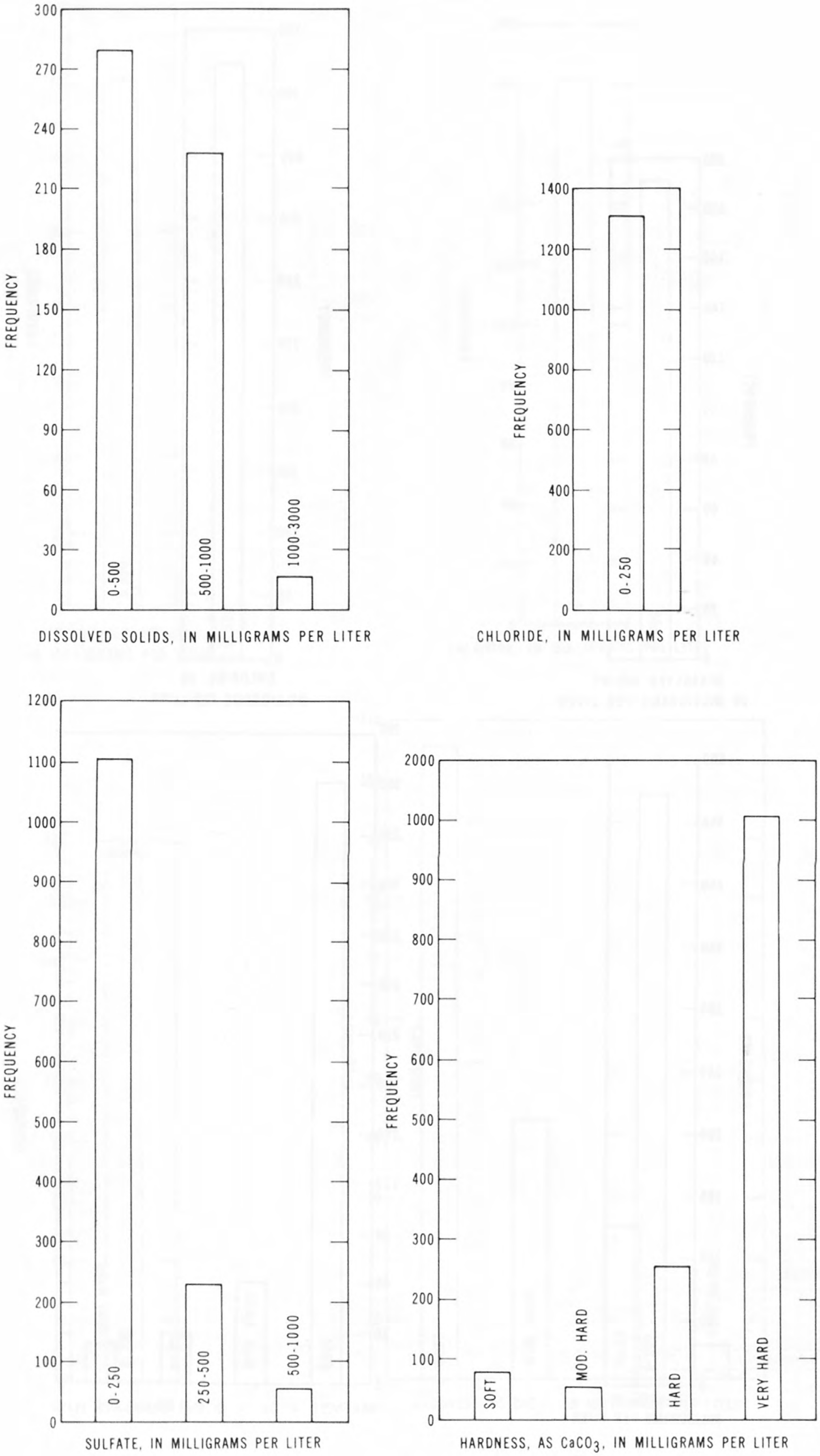

Figure 16.-- Frequency bar chart of selected Group 10 data.

Protection Agency, 1977), and the classifications of mineralized water and hardness used by the Survey (sited elsewhere in this report). As is clearly shown by the statistical summaries and the frequency bar graphs, the group data are not random samples from a normal distribution. It can also be shown that the samples are not log-normally distributed, and therefore, ordinary statistical tests cannot be routinely applied to these data. There are no hydrologic reasons for expecting a normal distribution of ground-water quality data; indeed one would be mildly surprised if the Kentucky ground-water quality data had been normally or log-normally distributed.

QUALITY OF GROUND WATER IN KENTUCKY

Dissolved Solids

One of the most frequently measured (and cited) characteristics of ground-water quality is total dissolved solids (residue at 180°C). The EPA (U.S. Environmental Protection Agency, 1977) established a secondary MCL (maximum contaminant level) of 500 mg/L for dissolved solids in drinking water, based on aesthetic effects of higher levels. As the earlier section on hydrogeology has pointed out, the deep ground water in Kentucky is much higher than 500 mg/L in dissolved solids. Figures 4 through 6 and plates 1 through 7 show that low dissolved solids will occur in most ground water only near the outcrop area of the rock unit. Because most of the sampling points (wells and springs) were in outcrop areas (figs. 4-6 and plates 1-7), the median value of dissolved solids for most of the retrieval groups is less than 500 mg/L (table 2).

A water-quality characteristic related to dissolved solids is specific conductance. More specific conductance measurements have been made on ground-water samples in Kentucky than any other characteristic except temperature. The relation between specific conductance and dissolved species is linear for dilute solutions of single salts (Hem, 1970, p. 97). Unfortunately, ground water is a widely varying mixture of dissolved species and no simple relationship of specific conductance to ion concentrations can be developed. Some gross generalizations are possible, however, and, for ground water in Kentucky with less than 5,000 mg/L dissolved solids, specific conductance (in μmhos/cm) is approximately equal to 1.37 times dissolved solids.

Physical Properties

The most commonly measured physical property of ground water is temperature. In Kentucky, temperature is available for 5,368 analyses; summaries by retrieval group are given in table 2. The highest maximum and highest median temperatures are reported from the Cambrian and Ordovician rocks (Group 1), which is consistent with their greater burial depth throughout the State. Temperature values are important for geochemical studies because solution temperature affects solubility of solid phases. Ground-water temperature is also important when industry or private individuals are seeking to use the ground-water system as a heat source or sink.

Another commonly measured physical characteristic of ground water is color. The secondary MCL for color in public drinking water supplies is 15 color units (U.S. Environmental Protection Agency, 1977). None of the retrieval groups exceeds 15 color units at the 75 percent quartile, although all groups contained a maximum value which equalled or exceeded the standard. Since color may be indicative of dissolved organic materials, as well as iron or manganese, organic chemical analysis of highly colored ground-water samples would be a prudent precautionary action.

Major Ions

The major ions occurring in ground water are the ions of calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), bicarbonate (HCO_3^{-}), sulfate (SO_4^{2-}), and chloride (Cl^{-}). Of these ions only chloride is considered non-reactive in the ground-water environment. The frequency bar charts of both dissolved-solids and chloride data (figs. 7a, b to 16a, b) show a bimodal population for most of the retrieval groups. For 7 of the 10 groups, the most data were available on water samples with dissolved-solids concentrations of less than 500 mg/L and chloride concentrations of less than 250 mg/L. The secondary MCL for chloride is 250 mg/L (U.S. Environmental Protection Agency, 1977), based on objectional taste at higher levels. The data in table 2 show that only Groups 1, 3, and 5 have the 75 percent quartile of chloride greater than 250 mg/L; and only Group 1 has a median value of chloride greater than 500 mg/L. The bimodality of the dissolved-solids and chloride data is in large part a reflection of the bias introduced by the types of wells available for collecting ground-water samples. Historically, most of the ground-water quality data in Kentucky has come from analysis of samples of domestic and public supply wells which were completed in formations containing good (fresh) water. In some parts of the State, oil tests and brine survey wells were drilled and subsequently made available for water sampling. Due to lack of economic incentive or potential use, very few wells have been completed in the mixing zone between the shallow freshwater-flow system and the underlying sluggish (immobile?) brines. After consideration of the preceding maps, charts, and statistics on dissolved-solids and chloride data, it should be evident that the great abundance of freshwater analyses in Kentucky is more the result of an abundance of freshwater wells, than an abundance of freshwater aquifers.

The frequency bar charts of sulfate in each retrieval group (figs. 7c-16c) do not show a bimodal distribution; rather they show a fairly uniform decrease in frequency of observations as concentrations increase. Referring to table 2, none of the groups had a 75 percent quartile of sulfate greater than 5,000 mg/L; and only Groups 4 and 5 had maximums of greater than 5,000 mg/L sulfate. The reason for this is that sulfate, unlike chloride, is reactive (nonconservative) in the ground-water environment. By calculation, 5,000 mg/L of sulfate is the solubility limit of gypsum ($CaSO_4 \cdot 2H_2O$) in ground water which has ionic strength of 0.17 and contains about 435 mg/L Ca^{2+}. At higher concentrations of Ca^{2+}, the precipitation of gypsum will keep the concentration of sulfate lower. Conversely, the presence of gypsum in the aquifer will tend to keep the sulfate concentration high, because gypsum can easily dissolve, as well as precipitate. The high sulfate maximums given in table 2 for Groups 4 and 5 are from brines which originated from contact with alkali-earth-depleted evaporite beds.

These examples of sulfate data from Kentucky are illustrative of the general problem of describing the occurrence of reactive species in different, areally extensive aquifers: the reactive species are present (or not present) due to chemical-physical properties of the aquifer system(s) which have evolved over long distances and over a long period of time. Consequently, without consideration of geohydrologic and geochemical principles, statistical analysis of ground-water chemical analyses will provide very little understanding of the "quality" of the ground-water resource.

The frequency bar charts of hardness in each retrieval group (figs. 7d-16d) illustrate one possibly useful statistical summary of ground-water quality data. When the question to be answered is whether the ground water of an area is suitable for a particular use or not, statistical summaries are a good approach. The criteria for measuring suitability are not necessarily related to the physical and chemical processes acting in the aquifer. The criteria used by the Survey (Hem, 1970, p. 225) to classify water on the basis of total hardness (in mg/L of $CaCO_3$) are:

0-60	soft
61-120	moderately hard
121-180	hard
more than 180	very hard

Water that is very hard may be unsuitable for many industrial purposes. For domestic use, there is a higher level of tolerance, apparently through decreased consumer sensitivity after continual use. The statistical summaries of hardness given in table 2 show that more than 75 percent of the available analyses from Groups 1, 2, 3, and 10 were in the very hard range. From these data and the preceding discussion of sampling point locations, it seems reasonable to state that there is a high probability of getting very hard water from any well that produces water from aquifers in Groups 1, 2, 3, or 10.

An alternative way to describe ground-water quality of an area is to use trilinear diagrams (Piper 1944; Hem, 1970, p. 264-270). The trilinear diagram has been used with the concept of hydrochemical facies (Back, 1966) to describe not only regional aquifer systems, but also to discuss the evolution of ground-water chemistry in certain rock types (Cushing and others, 1973, p. 9-10; Hanshaw and Back, 1979; Freeze and Cherry, 1979, p. 238-254). The central part of a trilinear diagram is shown in figures 17-26, and is hereafter referred to as a quadrilinear diagram. Each data point on the quadrilinear diagram represents one (or more) complete analysis; that is, the analysis contains measurements of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, CO_3^{2-}, SO_4^{2-}, and Cl^{-}. Further, the total positive ions had to be equal (plus or minus a few percent) to the total negative ions. A summary of the analyses used for the quadrilinear diagrams is given in table 3.

The quadrilinear diagrams show most of the important features of the evolution of major ion ground-water quality in Kentucky. Figures 17-22, and to a lesser extent figures 25 and 26, show the saline and brine subset of the ground-water quality data base. The freshwater data are most clearly evident in figures 18-21, 24, and 26. An indication of mixing between fresh and saline water is indicated in figures 17-21, although only a few analyses are available to define the intermediates between the two end-member compositions. As seen in figures 18-20, 22, 24, and 25, an increase in Na + K, while maintaining relatively high proportions of $HCO_3 + CO_3$, may be interpreted as exchange of Na^{+} for Ca^{2+} (Foster, 1950). A relative increase in Na + K over Ca + Mg could also be related to increases in HCO_3 created during oil and gas maturation. The increased bicarbonate would cause calcite ($CaCO_3$) precipitation, thus lowering the relative amount of Ca + Mg in solution. This alternative predicts calcite growths in the aquifer voids, a phenomena which could be checked by petrographic examination of drill cuttings. Determination of hydrocarbon diagenesis and concurrent calcite precipitation in the aquifers is, however, beyond the scope of this report.

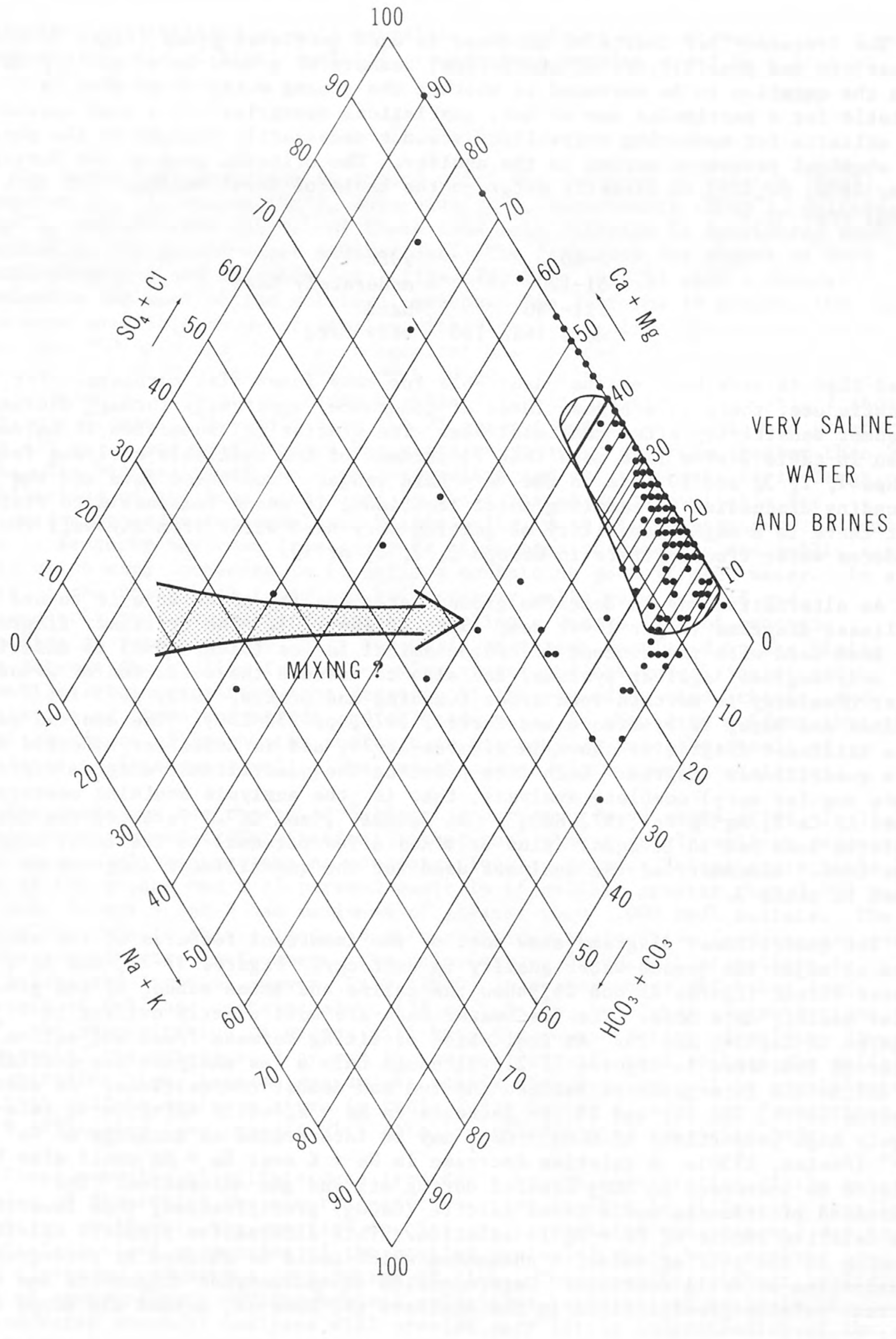

Figure 17.-- Analyses of ground water from Group 1.

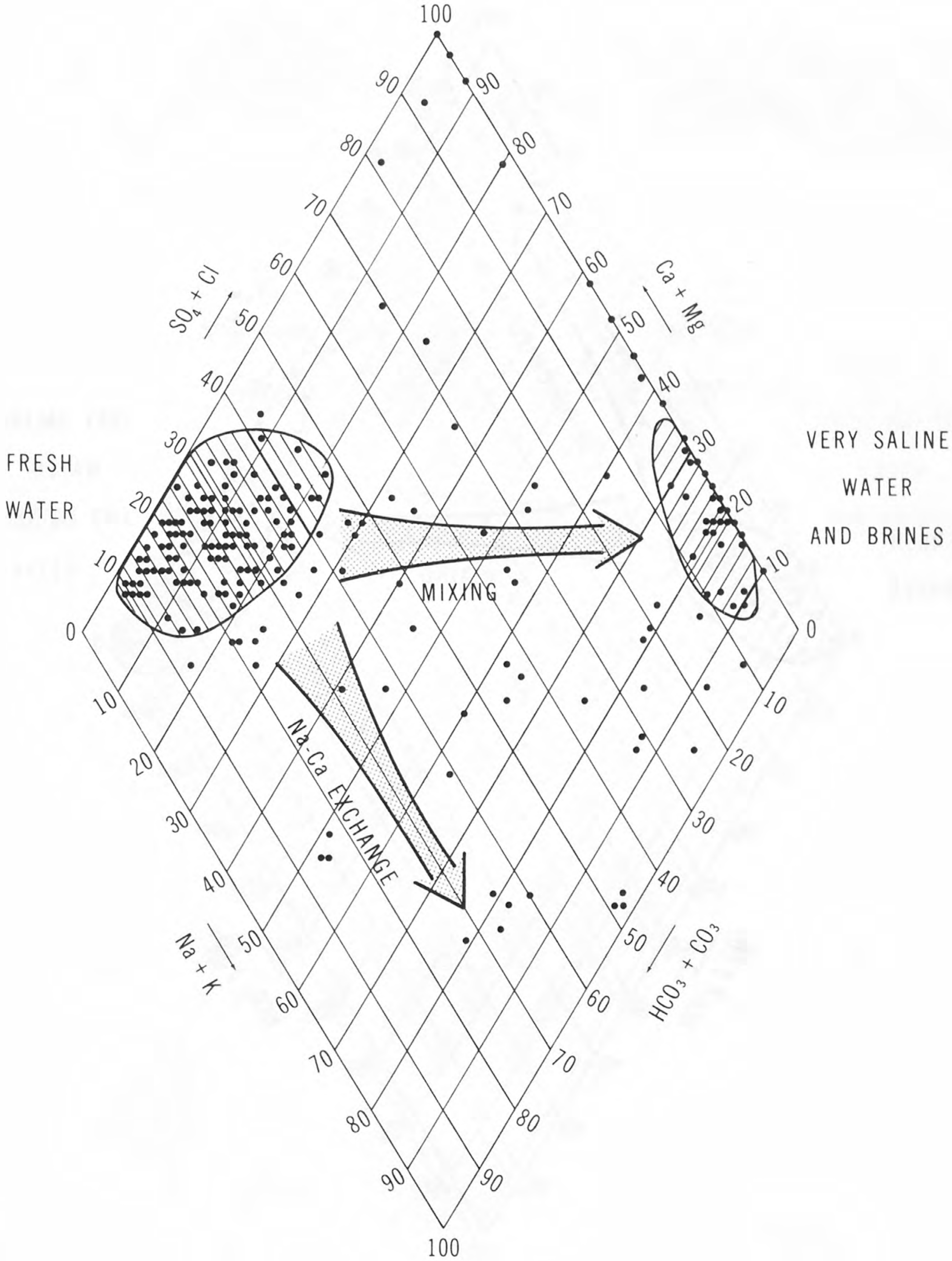

Figure 18.-- Analyses of ground water from Group 2.

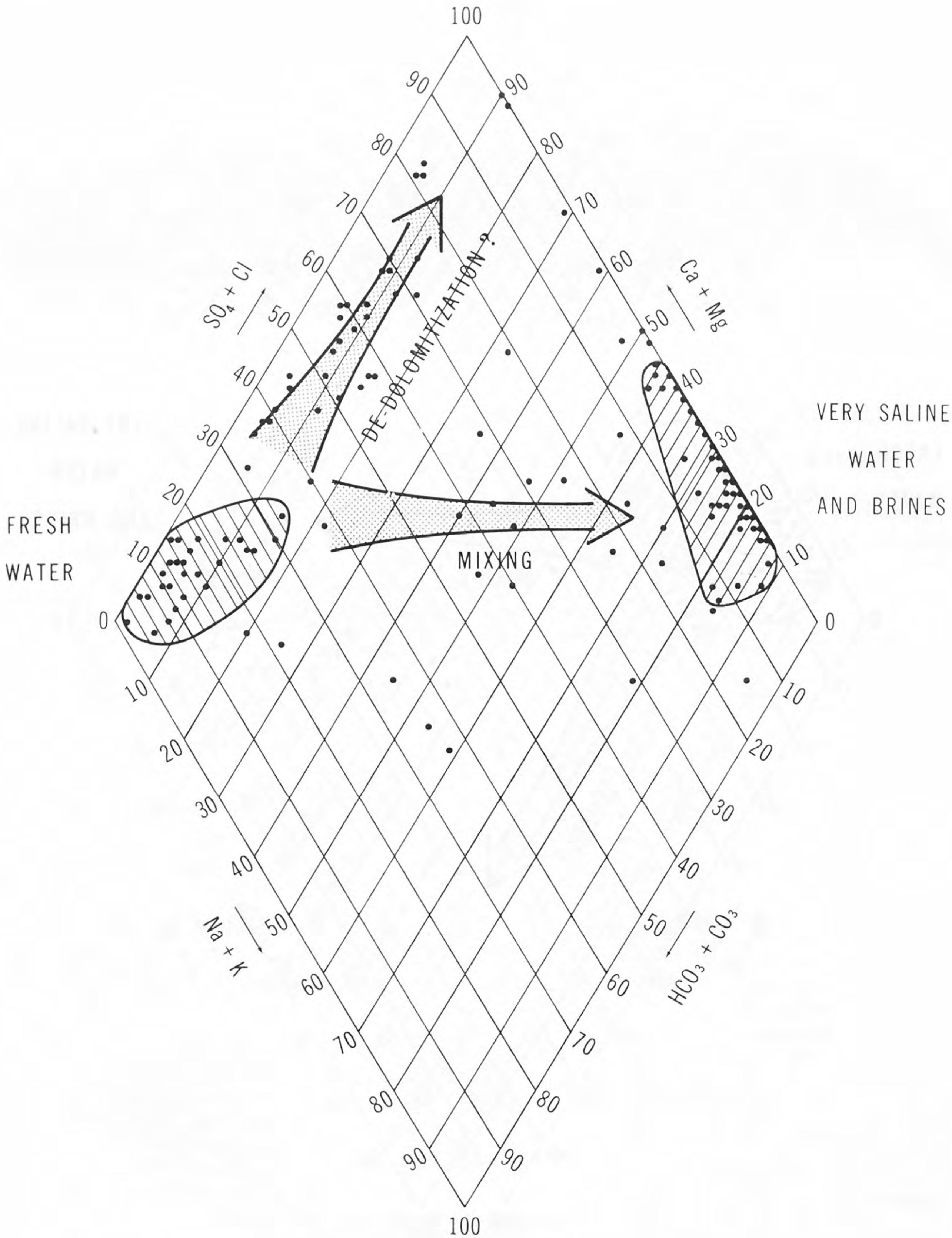

Figure 19 .-- Analyses of ground water from Group 3 .

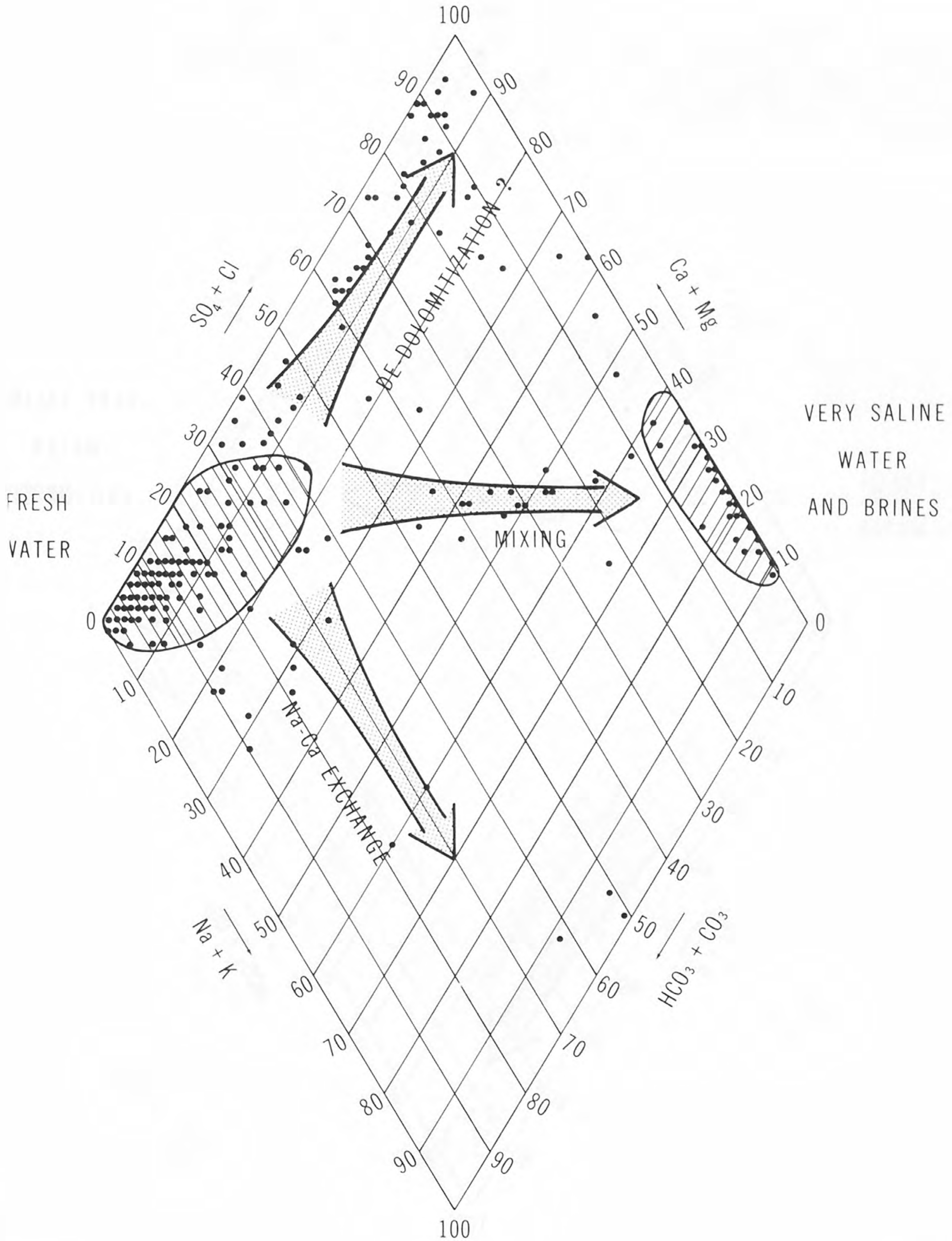

Figure 20.-- Analyses of ground water from Group 4.

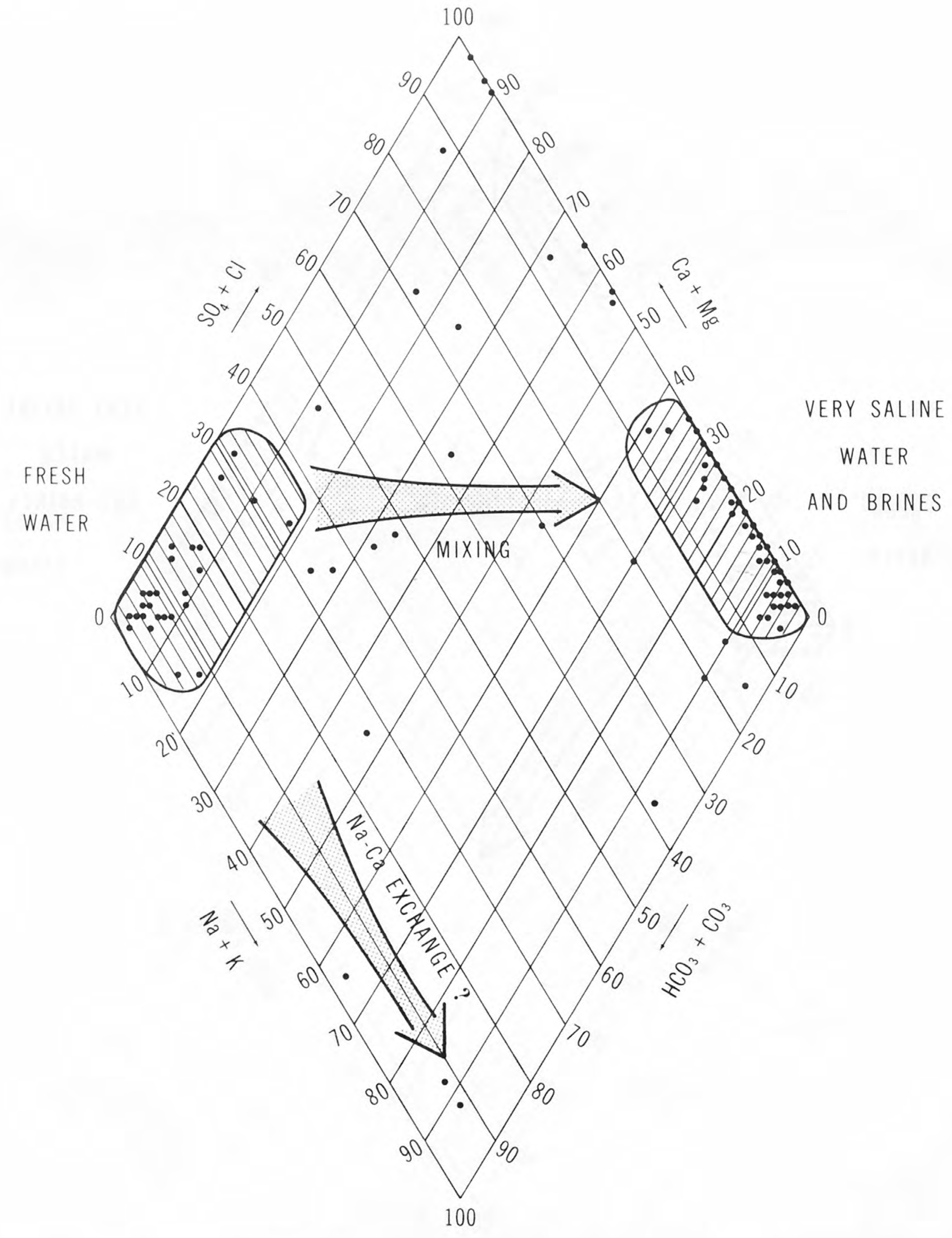

Figure 21.-- Analyses of ground water from Group 5.

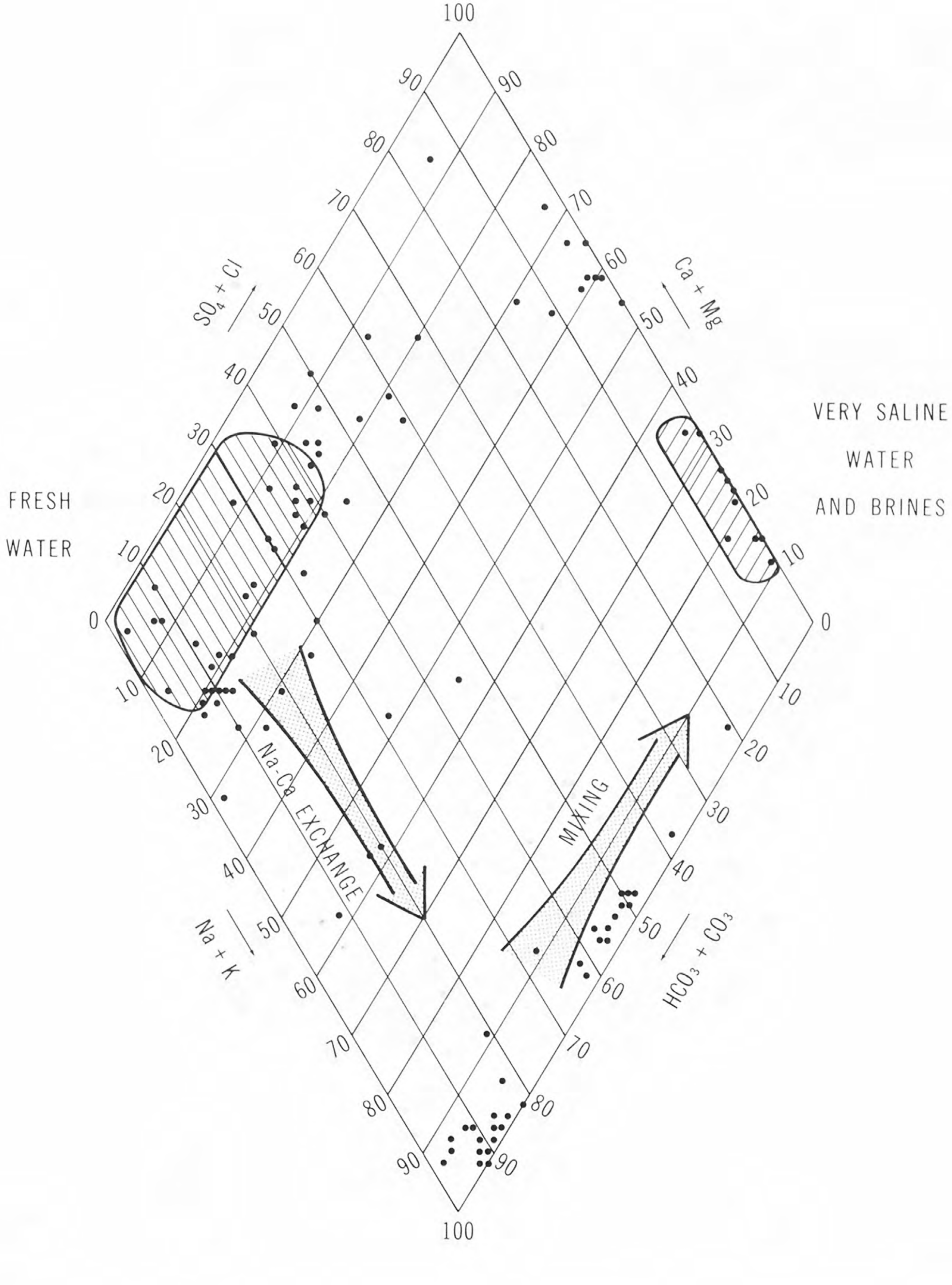

Figure 22 .-- Analyses of ground water from Group 6 .

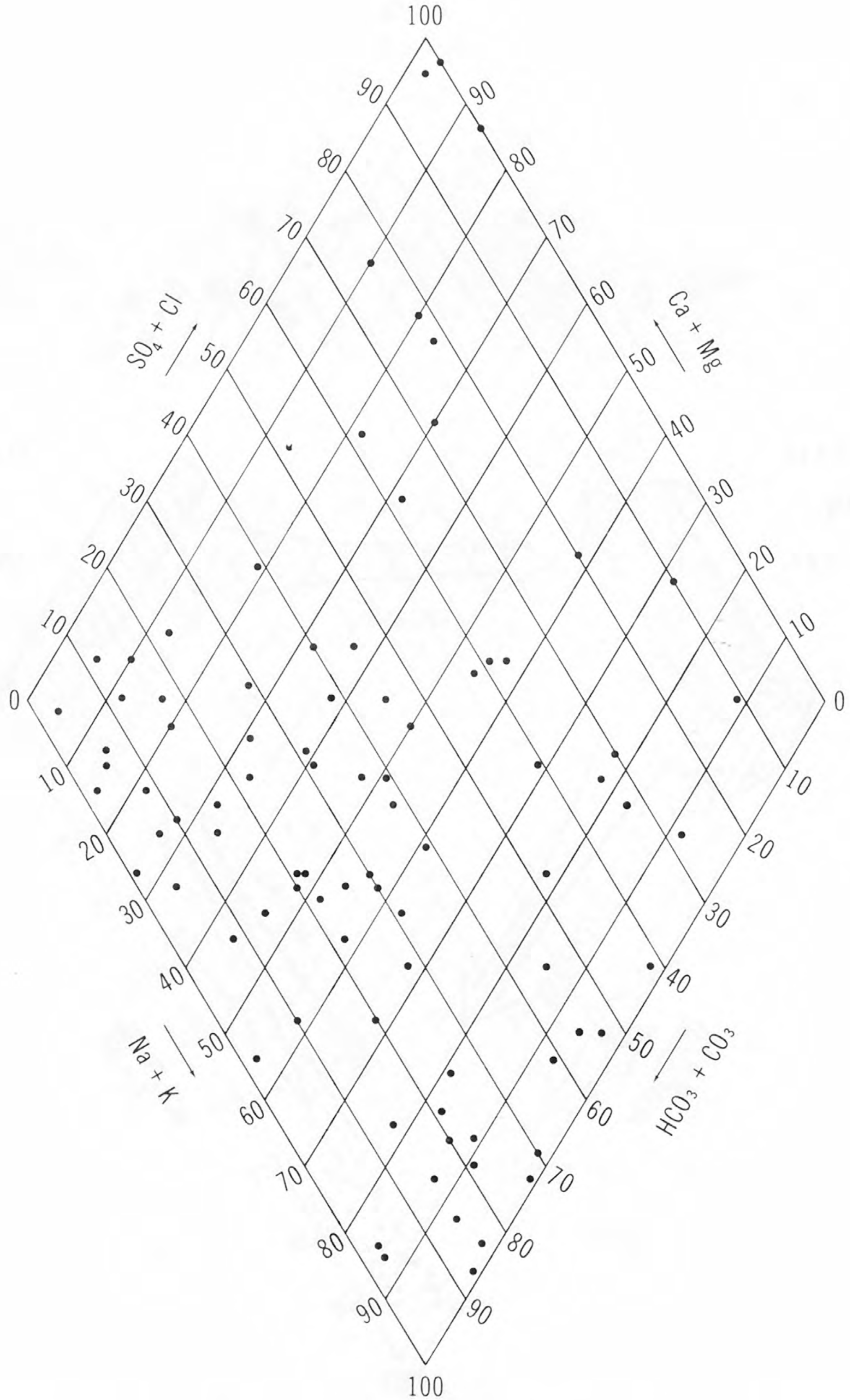

Figure 23 .-- Analyses of ground water from Group 7 .

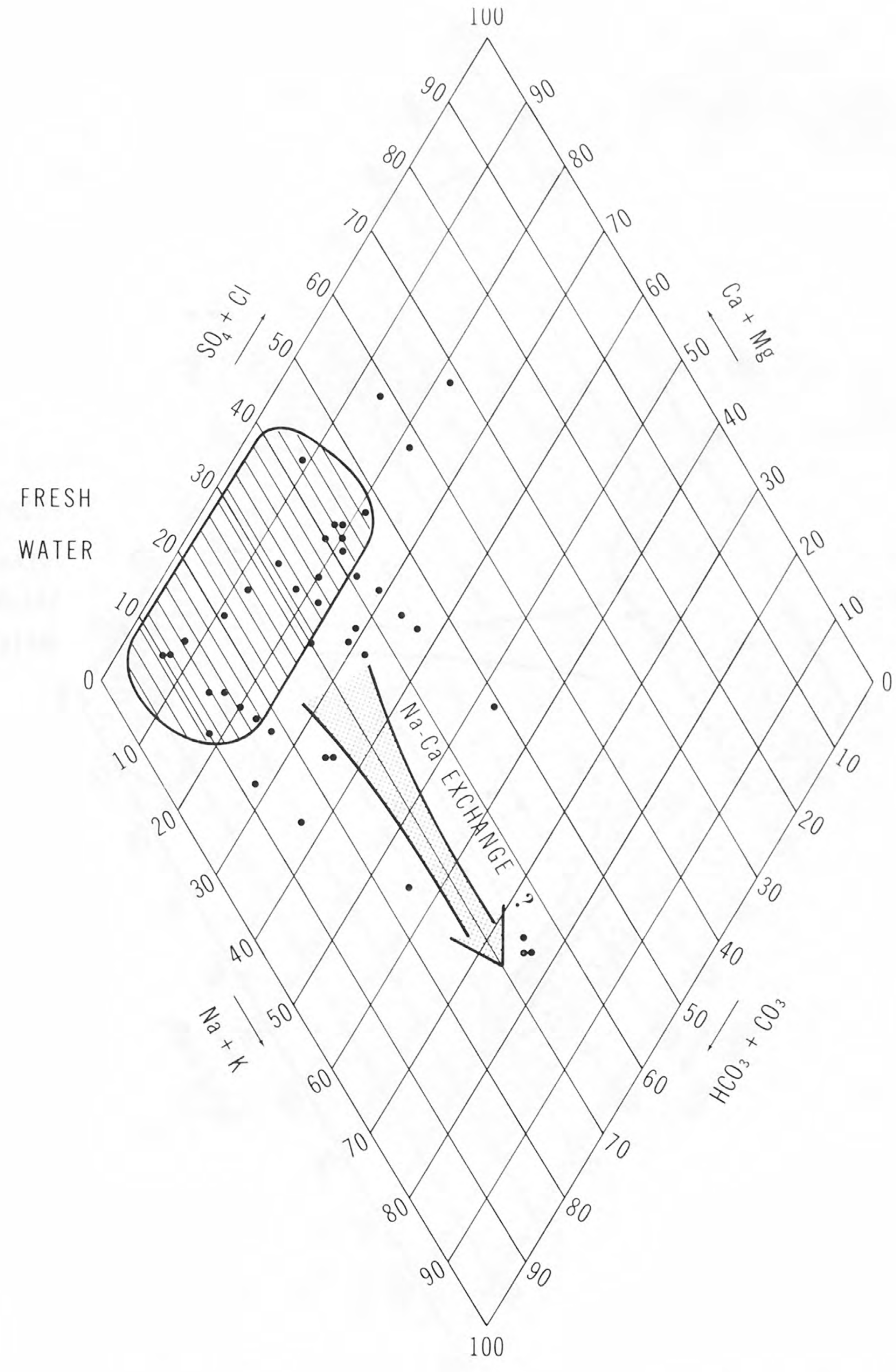

Figure 24 .-- Analyses of ground water from Group 8 .

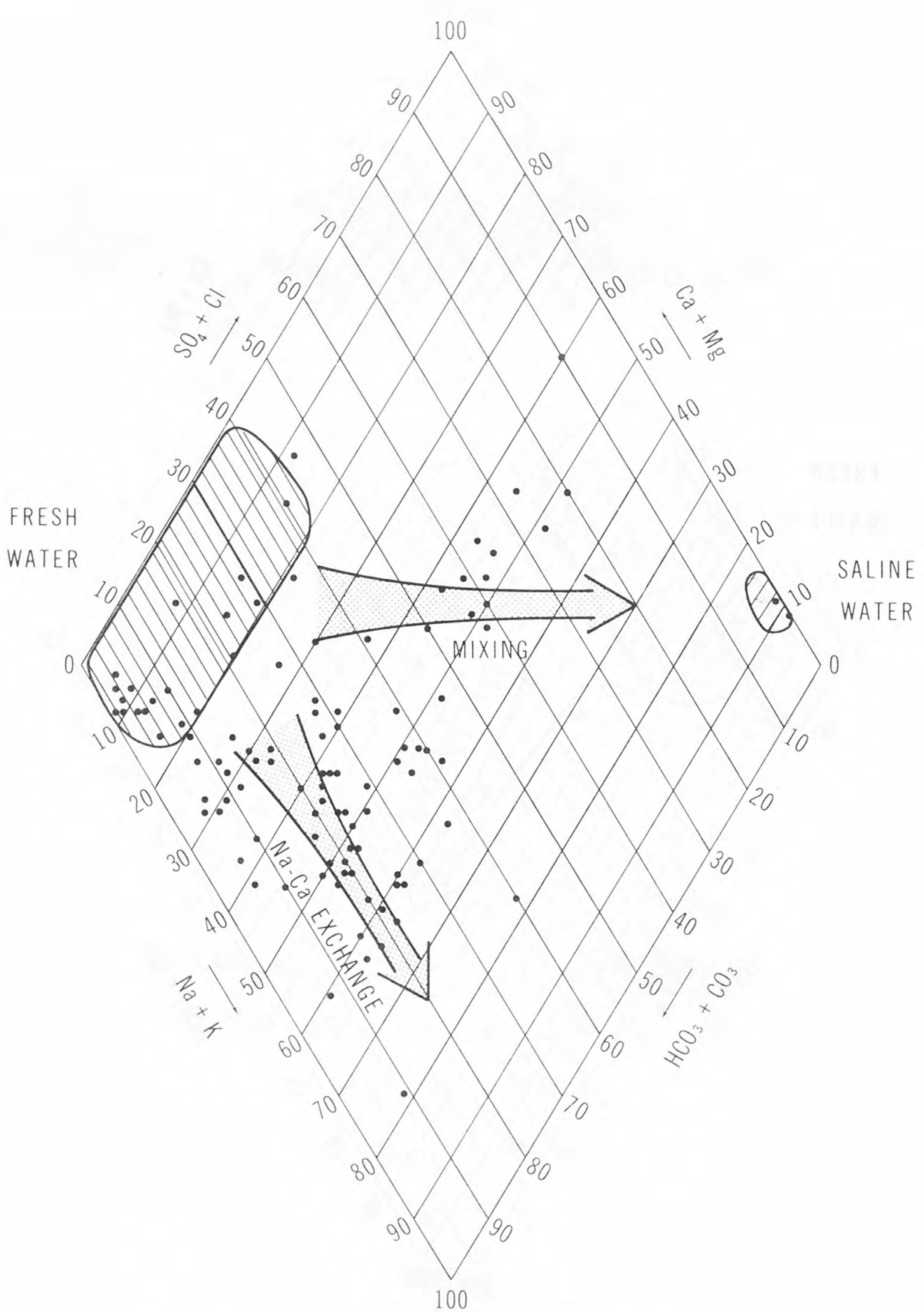

Figure 25 .-- Analyses of ground water from Group 9 .

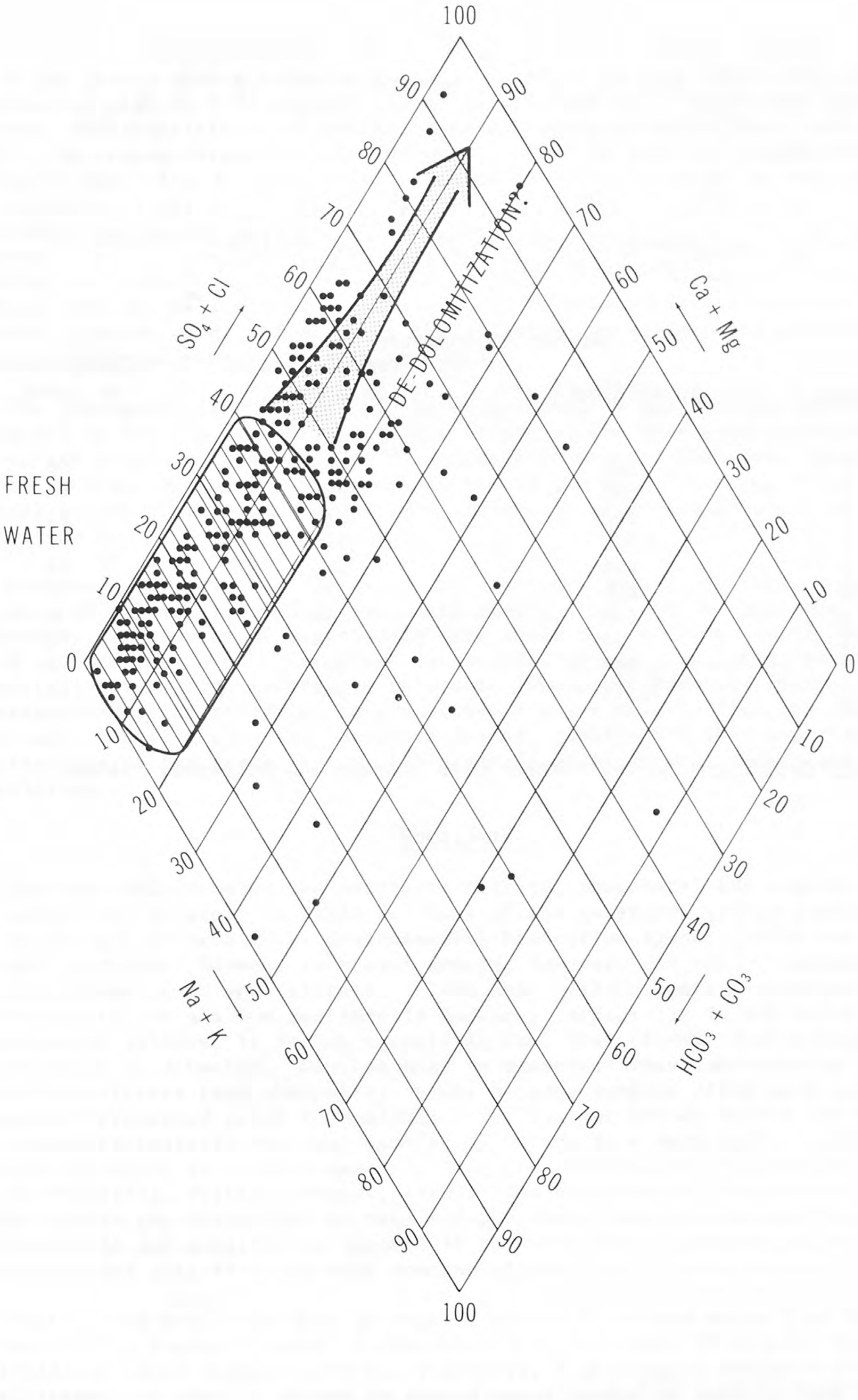

Figure 26 .-- Analyses of ground water from Group 10.

Table 3. -- Summary of analyses used for quadrilinear diagrams of ground-water quality in Kentucky.

Group	Number of analyses In WATSTORE[1]	Complete and balanced	Dated 1970 or later
1	202	180	56
2	550	287	46
3	546	235	91
4	2,366	314	91
5	418	162	61
6	600	130	45
7	585	89	0
8	178	44	5
9	469	107	6
10	1,371	368	114

1 -- U.S. Geological Survey's Water Data Storage and Retrieval System

A few groups show a relative increase in $SO_4 + Cl$ over $HCO_3 + CO_3$, while maintaining high Ca + Mg content (figs. 19, 20, and 26). This trend may indicate dedolomitization of the aquifers by gypsum solution (Back and others, 1983). As gypsum dissolves, the increase in Ca^{2+} in solution causes calcite precipitation. The decrease in bicarbonate in solution caused by calcite precipitation leads to dissolution of dolomite. This interpretation seems reasonable for Groups 3 and 4, which contain dolomitic rocks. As for Group 10, however, the alluvium in the river valleys is unlikely to contain dolomite. The alluvial aquifers receive ground water from underlying (dolomitic?) rocks, as well as from rainfall and adjacent streams. To some extent, therefore, the chemical content of ground water in the alluvium may reflect the dedolomitization process within adjacent carbonate aquifers.

The interpretation of figure 23 is complicated by the diverse nature of the sediments in Group 7, the discontinuous nature of the sandstone aquifers in the group, and possible incorporation of analyses in Group 7 that more properly belong in Group 6. Given the uncertainties in the data for Group 7 and the general nature of this review, further evaluation of figure 23 would be unprofitable.

Further description of the major ion chemistry of and the interpretation of geochemical processes involving silicate minerals in Kentucky aquifers is limited by the paucity of modern data (see table 3). Prior to about 1970, few field measurements of the important parameters, pH and alkalinity, were made on a routine basis. Even fewer data on stable isotopes, dissolved gases, and oxidation-reduction potential in ground water are available from the Kentucky data base. Until these data voids are filled, qualitative (and quantitative) descriptions of the geochemistry of Kentucky's aquifers will remain mostly speculation.

Nutrients

The available data on the nutrients nitrate, phosphate, and organic carbon are summarized by group in table 2. None of the retrieval groups exceeded the MCL of 40 mg/L nitrate (U.S. Environmental Protection Agency, 1977) for the 75 percent quartile. Several retrieval groups, however, did report maximum values well in excess of 40 mg/L nitrate. Given that surface contaminants can easily reach many of the shallow aquifers in Kentucky, especially in the karst areas and alluvial valleys, it is not surprising that high nitrate levels might occasionally be detected. Caution must be exercised when interpreting historical nitrate (and phosphate) values because samples often were not "properly" preserved prior to analysis. The current Survey method for nitrate and phosphate analysis requires sample collection in a dark bottle, addition of mercuric chloride to 40 mg/L mercuric ion, and chilling to 4°C prior to analysis (R. J. Pickering, written commun., 1980). The magnitude of the errors introduced to the historical nitrate and phosphate data due to sampling procedures is not possible to quantify. For this reason comparison of historical and post-1980 nutrient concentrations is of limited value.

Most of the available data on organic carbon in ground water from Kentucky is post-1970. However, prior to September 30, 1981, only 55 samples had been analyzed for total organic carbon. Therefore, a meaningful analysis of time or areal trends, of organic carbon in ground water cannot be made in this report.

Trace Elements, Radionuclides, and Organic Chemicals

The data for the common trace metals iron and manganese were summarized in table 2 because of the large number of analyses available. Prior to about 1970, the recommended method for collection of ground-water samples of iron and manganese required filtering only if cloudiness was observed in the raw sample (Rainwater and Thatcher, 1960). Since 1970, Survey methods for collection of ground-water samples for iron and manganese analysis specify filtration and acidification to pH 2.0, to separate and stabilize the dissolved and suspended phases (Brown and others, 1970; Skougstad and others, 1979). Many of the pre-1970 iron and manganese data from Kentucky are stored under parameter codes which do not describe the phase (suspended-solid or dissolved) where the iron or manganese occurred in the original water sample. Since the majority of the iron and manganese data from Kentucky were collected prior to 1970, and colored or turbid samples were filtered at time of sampling, pre-1970 iron and manganese data are included with the post-1970 dissolved-iron and dissolved-manganese data.

There are secondary MCLs for iron and manganese of 0.3 and 0.05 mg/L, respectively (U.S. Environmental Protection Agency, 1977). The data of table 2 show that the median values of Groups 3, 6, 7, 8, and 10 exceed this recommendation for iron, and that the median values of Groups 1, 3, 5, 6, 9, and 10 exceed this recommendation for manganese. These two metals are an aesthetic irritant more than a health problem at higher concentrations. Dissolved iron and manganese can be easily removed from raw ground water by aeration and flocculation or filtration.

A search of the entire data file was made for analyses of trace elements, radionuclides, and man-made organic chemicals. The summary table 4 shows that only a few constituents have been measured more than 10 times and only two trace metals, aluminum and zinc, were measured more than 100 times. In an era of increasing public concern over trace quantities of pollutants in ground water, this lack of environmentally significant data must be viewed as a major deficiency in the Survey's ground-water quality data files for Kentucky.

Bacteria

The identification and enumeration of specific coliform bacteria may be used to indicate the degree of contamination of water from human or animal wastes. Knowledge of the presence of iron-oxidizing, sulfate-reducing or nitrate-reducing bacteria could be helpful in understanding the geochemistry of an aquifer. Prior to September 30, 1981, no analysis for the above-mentioned bacteria had been made in ground-water samples from Kentucky by the Survey.

DEFICIENCIES OF THE DATA FILES

The ground-water quality data file for Kentucky contains many deficiencies and some errors. The most serious deficiency is that most of the analyses are of temperature, specific conductance, and common inorganic chemicals; there are fewer than 10 analyses of many trace elements, bacteria, man-made organic chemicals, or radionuclides from any of the aquifers in Kentucky. Interpretation of the available data is further limited because: (1) the distribution and number of samples from each aquifer varies widely throughout the State; (2) there are erroneous geohydrologic unit codes assigned to some wells or samples;

Table 4. -- Summary of determinations of trace metals, radionuclides, and man-made organic chemicals in ground water from Kentucky. (Units are micrograms per liter except as indicated.)

Total and total recoverable: Water sample was not filtered prior to analysis.
Dissolved: Water sample passed through 0.45 micrometer filter prior to analysis.
Radium-226: Activity in picocuries per liter.
Gross beta: Activity in picocuries per liter as Strontium/Yttrium-90.

	Number of samples	Mean	Standard deviation	Minimum value	Maximum value
Trace metals					
Aluminum, dissolved	359	19,900	204,000	0.	3,170,000
Aluminum, total recoverable	19	1,200	4,330	0.	19,000
Arsenic, dissolved	8	1.12	0.354	1.	2.
Arsenic, total	8	2.87	2.80	1.	8.
Barium, dissolved	7	140.	73.7	50	250
Barium, total recoverable	27	48,300	132,000	0.	640,000
Beryllium, dissolved	7	3.36	4.53	0.7	10
Beryllium, total recoverable	4	5.50	5.19	1.	10
Bismuth, total	4	2.25	0.500	2.	3.
Boron, dissolved	8	4,850	12,600	0.	36,000
Boron, total recoverable	4	49.0	21.0	33	80
Cadmium, dissolved	18	1,280	5,420	0.	23,000
Cadmium, total recoverable	14	2.21	1.53	0.	5.
Chromium, dissolved	12	6.58	14.1	0.	50
Chromium, total recoverable	14	3.50	7.07	0.	20
Cobalt, dissolved	13	7.69	6.58	2.	22.
Cobalt, total recoverable	12	13.4	28.0	2.	100
Copper, dissolved	34	8.62	16.0	0.	85
Copper, total recoverable	15	56.3	152.	0.	580.
Gallium, total	4	0.500	0.577	0.	1.
Germanium, total	4	2.75	0.500	2.	3.
Lead, dissolved	25	16.2	39.9	0.	200
Lead, total recoverable	14	4.36	6.38	0.	20
Lithium, dissolved	47	907	2,120	0.	12,000
Lithium, total recoverable	31	972	4,650	0.	26,000
Mercury, dissolved	8	0.512	0.402	0.1	1.4

Table 4. (cont'd) -- Summary of determinations of trace metals, radionuclides, and man-made organic chemicals in ground water from Kentucky. (Units are micrograms per liter except as indicated.)

	Number of samples	Mean	Standard deviation	Minimum value	Maximum value
Mercury, total recoverable	7	0.500	0.0	0.5	0.5
Molybdenum, dissolved	7	7.43	4.39	1.	10
Molybdenum, total recoverable	4	3.00	1.41	2.	5.
Nickel, dissolved	6	11.3	25.3	0.	63
Nickel, total recoverable	6	2.83	1.47	0.	4.
Selenium, dissolved	6	2.67	1.97	1.	6.
Selenium, total	6	1.50	0.837	1.	3.
Silver, total recoverable	4	0.0	0.0	0.	0.
Strontium, dissolved	7	33,300	85,900	86	228,000
Strontium, total recoverable	35	191,000	343,000	0.	1,430,000
Tin, total recoverable	4	2.25	0.500	2.	3.
Titanium, total	4	64.0	69.2	6.	150
Vanadium, dissolved	5	6.00	0.00	6.	6.
Vanadium, total	4	2.50	0.577	2.	3.
Zinc, dissolved	117	4,030	17,200	0.	160,000
Zinc, total recoverable	20	4,020	16,900	0.3	76,000
Zirconium, total	4	4.00	0.816	3.	5.
Radionuclides					
Gross beta	5	126.	101	10	200
Radium$_{226}$, total	1	---	---	---	22
Radium$_{226}$, dissolved	5	2.56	4.10	0.1	9.8
Uranium, dissolved	6	0.800	0.756	0.1	2.1
Organic chemicals					
Aldrin, total	4	0.00	0.0	0.00	0.00
Chlordane, total	4	0.00	0.0	0.00	0.00
DDD, total	4	0.00	0.0	0.00	0.00
DDE, total	4	0.00	0.0	0.00	0.00
DDT, total	4	0.00	0.0	0.00	0.00
Diazinon, total	4	0.002	0.005	0.00	0.01
Dieldrin, total	4	0.002	0.005	0.00	0.01
Endrin, total	4	0.00	0.00	0.00	0.00
Ethion, total	4	0.00	0.00	0.00	0.00

Table 4. (cont'd) -- Summary of determinations of trace metals, radionuclides, and man-made organic chemicals in ground water from Kentucky.
(Units are micrograms per liter except as indicated.)

	Number of samples	Mean	Standard deviation	Minimum value	Maximum value
Heptachlor, total	4	0.00	0.00	0.00	0.00
Heptachlor epoxide, total	4	0.002	0.005	0.00	0.01
Lindane, total	4	0.00	0.00	0.00	0.00
Malathion, total	4	0.00	0.00	0.00	0.00
Methyl parathion, total	4	0.00	0.00	0.00	0.00
Methyl trithion, total	4	0.00	0.00	0.00	0.00
Methylene blue active substance (milligrams per liter)	68	0.062	0.120	0.	0.7
Polychlorinated naphthalenes, total	3	0.00	0.00	0.00	0.00
Parathion, total	4	0.00	0.00	0.00	0.00
PCB, total	4	0.00	0.00	0.00	0.00
Phenols, total	3	2.33	2.31	1.	5.
Silvex, total	4	0.00	0.00	0.00	0.00
Toxaphene, total	4	0.00	0.00	0.00	0.00
Trithion, total	4	0.00	0.00	0.00	0.00
2,4-D, total	4	0.00	0.00	0.00	0.00
2,4,5-T, total	4	0.00	0.00	0.00	0.00

(3) the map locations of the wells sampled have been found to be erroneous in a few cases. In addition, important information about the well is often missing or incomplete: for example, the geohydrologic unit code may be available, but total depth or depth to well-screen is missing; some wells are known to have multiple screen openings, but only the shallowest (deepest?) opening is recorded. Other related data, such as well use, type of casing, and type of pump may also be incomplete. Finally, ground-water quality data from local and State agencies have not been systematically reviewed and stored in a computer-accessible format.

The data file reviewed in this report contains analyses of water samples collected for many purposes. The bulk of the data was collected by the Survey to meet the objectives of local or subregional investigations of the quality and quantity of ground-water resources of the State. Many of these investigations restricted the analysis of ground-water samples to major inorganic constituents in order to hold down project costs. Sampling to meet individual project objectives may also affect interpretation of the data in another way. Occasionally, wells and springs were sampled during episodes of contamination to document type and amount of contamination. Other water samples from the well or spring may also have been collected prior to contamination, or after the contamination ceased. Thus, the data file contains analyses of water from some locations for both natural and contaminated conditions. The data file also contains over 500 analyses of highly mineralized water and brines. These data were originally collected from about 500 sites statewide to identify brines potentially suitable for economic development, or to describe water from oil test wells. These brine data are not representative of ground water that is part of the post-glacial, freshwater flow system.

The distribution of ground-water quality data in Kentucky is erratic: for Groups 2, 3, 4, and 10 more than 200 complete, balanced analyses are available to describe the general quality of the aquifers in each group. In contrast, for Group 8 only 44 analyses are complete and balanced. The areal distribution of samples (figs. 4-6 and plates 1-7) shows that the outcrop area of each retrieval group has been extensively sampled. Where the older formations are buried, sampling is limited or nonexistent. This data void limits our understanding of the geochemistry of the freshwater-saline water interface zone. The development of ground-water flow models is similarly hampered by imprecise location of the freshwater-saline water interface in many aquifers in Kentucky.

There are several reasons why the data file contains incorrect geohydrologic unit codes used to identify the source of water for a particular sample. The geohydrologic nomenclature used in WATSTORE was adopted before modern geologic mapping was completed in Kentucky. Thus, many of the geohydrologic unit names in the file are obsolete, or may represent different geologic units in different parts of the State. Also, translation of imprecise driller's descriptions into geohydrologic unit codes probably has introduced some errors. A third type of error might be made when assigning a geohydrologic unit to a well when only well depth was available. Often the location of a well was originally plotted on a county planimetric map, and later transferred to a modern topographic map. Occasionally, this transfer led to plotting inaccurate locations and, using the well depth as a guide, to assigning an incorrect geohydrologic unit to the well.

In addition to ground-water quality files, the Survey maintains the Ground Water Site Inventory File (Baker and Foulk, 1975). This file when used in conjunction with the WATSTORE water-quality data file would allow statistical evaluations of ground-water quality and well characteristics such as topography of well site, well depth, sampling depth, type of well, length of casing, yield of well, and many others. Unfortunately, the Ground Water Site Inventory File is incomplete for many Kentucky wells.

Chemical analyses of ground water or springs are known to be in the files of the Kentucky Natural Resources and Environmental Protection Cabinet, Water Quality Division (formerly Kentucky Department of Health). However, these data are not computer accessible and were not used in this evaluation. Due to limitations of time and money, data in computer files of other Federal agencies were not evaluated for this report.

This review was able to characterize the general ground-water quality of Kentucky using existing water-quality data from computer files of the Survey and previously published reports. During the life of the project, some obviously erroneous data were discovered in the computer files. Whenever possible these erroneous data were "flagged" for correction; infrequently, insufficient or missing records in office files required deletion of water-quality data from the computer file. The study determined the following serious deficiencies in the ground-water quality data:

1. Very few post-1970 analyses of ground water include measurements of all major cations and anions, and few analyses include field measurements of pH and alkalinity.

2. The chemistry of the freshwater-saline water interface zone is inadequately defined throughout much of the State.

3. There are no analyses of stable isotopes and dissolved gases in ground water.

4. There are fewer than 10 analyses of most trace metals, radionuclides, and man-made organic chemicals, which may be present as trace environmental contaminants.

5. No data on bacteria in ground water have been collected from any aquifer in the State.

SUMMARY AND CONCLUSIONS

Ground water was used by more than 375,000 people in Kentucky in 1980; industrial use was more than 133 million gallons per day for the same year. Continued use of ground water is dependent in large part on the chemical quality of the water. This report reviewed 10,578 chemical analyses from 2,362 wells and springs in Kentucky. These water-quality data are available in computer files of the Survey, and were collected prior to September 30, 1981. These data were examined for errors and deficiencies, statistically summarized, and used to describe the general water quality of the State.

Of the 159 geohydrologic units used to store ground-water quality data from Kentucky, 110 of the principal water-bearing geologic formations were combined into 10 retrieval groups. These retrieval groups were used for data summary preparation and general description of ground-water quality of the State. The major criteria used to group the rock units together were:

1. Areas of outcrop - units crop out mainly in one physiographic province

2. Stratigraphic sequence - rocks in contact with each other

3. Hydraulic continuity - units are areally extensive and likely to exhibit similar hydraulic characteristics

4. Availability data in computer storage - units known to have some ground-water quality data in computer files

The ground water of Kentucky is generally fresh near the outcrop of the rocks comprising the aquifer. Saline to briny water occurs at variable depths beneath the freshwater; in the Blue Grass and Mississippian Plateau regions, saline water may occur at depths of only 25 feet below land surface. In the Jackson Purchase region, freshwater commonly occurs more than 750 feet below land surface. Interpretation of the available data indicates the following geochemical processes may be occurring in Kentucky aquifers: (1) mixing of fresh, calcium-magnesium bicarbonate ground water with sodium-chloride brines in the interface zone between the post-glacial, freshwater flow system and a possibly immobile saltwater system; (2) within the freshwater system, dedolomitization in the Silurian, Devonian, and Mississippian carbonate rocks (a similar trend was noted in the trilinear plot of analyses from the Quaternary alluvium, which may reflect processes occurring in the underlying bedrock); (3) also within the freshwater system, exchange of Na^+ for Ca^{2+} within many of the sandstone-shale aquifers.

Many deficiencies and a few errors were found in the data files. The principal deficiencies in the ground-water quality data available from Kentucky were:

1. Very few post-1970 analyses of ground water included measurements of all major cations and anions, and few analyses include field measurements of pH and alkalinity.

2. The chemistry of the freshwater-saline water interface zone is inadequately defined throughout much of the State.

3. There are no analyses of stable isotopes and dissolved gases in ground water.

4. There are fewer than 10 analyses of most trace metals, radionuclides, and man-made organic chemicals, which may be present as trace environmental contaminants.

5. No data on bacteria in ground water have been collected from any aquifer in the State.

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