1960

Occurrence of mineralized ground water in Southern St. Louis and Jefferson Counties, Missouri

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5200 A4

OCCURRENCE OF MINERALIZED GROUND WATER

IN SOUTHERN ST. LOUIS AND JEFFERSON COUNTIES, MISSOURI

BY

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A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE, GEOLOGY MAJOR

Rolla, Missouri

1960

Approved by

(advisor)

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ACKNOWLEDGMENT

The author is indebted to Dr. Thomas R. Beveridge, State Geologist, Missouri Geological Survey and Water Resources, and to Mr. James C. Maxwell, Assistant Professor of Geology, Missouri School of Mines and Metallurgy, for their suggestions, aid and guidance during the course of the investigation.

Professor Maxwell was the adviser in charge of the work involved in the investigation and constructively criticized the text and figures therein. Dr. T. R. Beveridge suggested the problem and permitted the writer to use facilities of the Missouri Geological Survey in the procurement of water well data and field maps and for the final drafting of figures in this report. Field expenses were paid by the Missouri Geological Survey.

The paper is dedicated to water well drillers who saved samples for the Survey and gave other pertinent data during personal interviews.

ABSTRACT

Mineralized ground water occurs at some localities in southeastern St. Louis and northern Jefferson Counties, Missouri. This water is usually undesirable and is detrimental to development of ground water resources.

Water well records in the offices of the Missouri Geological Survey and Water Resources provided data for a study of structure, lithology and occurrence of ground water. Water well drillers and property owners were interviewed to obtain additional information concerning drilling problems and quality of water.

Geologic cross-sections, subsurface contour maps and isochlorinity maps aided the study of lithology, structure and areal distribution of mineralized ground water. Relationship is suggested between occurrence of mineralized water and lithology and structure. Relatively impermeable lithologies which act as barriers to the movement of ground water, and structural depressions which act as traps, retard the flushing of mineralized water by fresh meteoric water.

Localities where mineralized water occurs with respect to two ground water zones are shown on geologic cross-sections and subsurface contour maps of the principal water bearing formations, the Keokuk-Burlington and the Kimmswick.

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INTRODUCTION

Mineralized ground water is detrimental to development of ground water resources for most industrial and domestic purposes. High concentration of salts in water corrodes metals and is therefore damaging to machinery. Many industries require relatively pure water. Dissolved salts, in high concentration, are harmful to people. Owners of swimming pools and commercial bath houses, however, may profit from the concentration of salts in ground water. Structural and lithologic factors which control ground water movement in carbonate rocks are not well known. The present study, therefore, was designed to determine the location, extent, and controlling geologic factors of mineralized water in southeastern St. Louis and northern Jefferson Counties.

In this report water with a concentration of more than two hundred and fifty parts per million of the chloride ion, more than two hundred and fifty parts per million of the sulphate ion, or more than one thousand parts per million total dissolved solids is considered to be mineralized (Public Health Reports)[1]. These criteria are mutually related in ground water encountered in the area.

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[1]All references are in bibliography.

St. Louis-Jefferson Counties Area

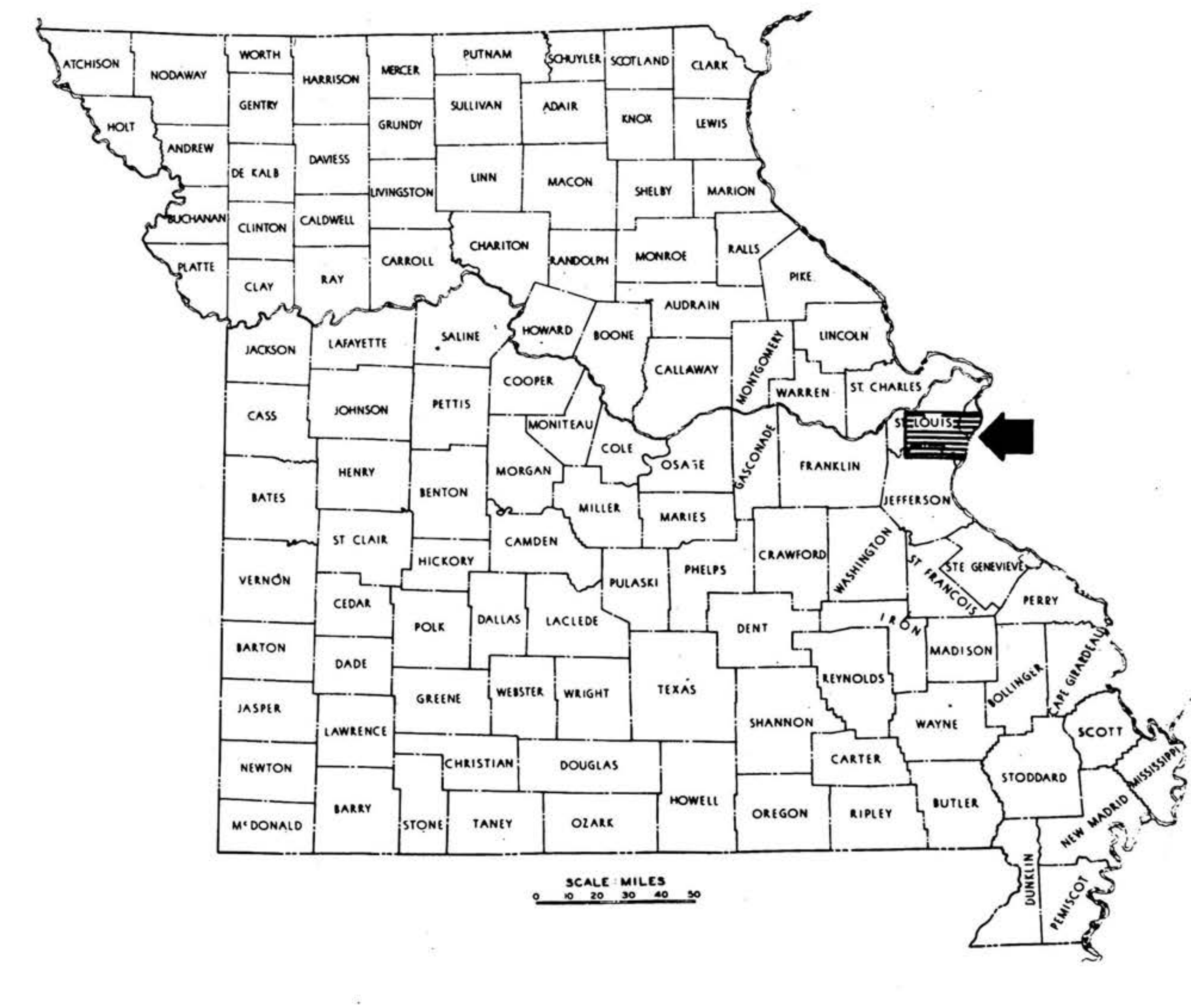
The area discussed here is bound on the east by the Mississippi River, which is the Missouri-Illinois state line. The opposite border is the western limit of Range 4 East, longitude approximately $90^{\circ}37'$W. The southern limit of Township 43 North, latitude approximately $38^{\circ}25'$N., bounds the area to the south; and the northern limit of Township 45 North, latitude approximately $38^{\circ}41'$N., is the other limit of the area. The restricted area, designated herein as the St. Louis-Jefferson Counties area, is shown in Figure 1.

Geologically, the area is located on the northeastern bank of the Ozark dome. The formations in the area are of Paleozoic age. The formations which outcrop in St. Louis and Jefferson Counties are shown in Figure 2.

The climate is sub-humid, with approximately thirty inches of precipitation per year. Infiltration capacity of the soil is high in most of the area, and upland flooding is not frequent. Vegetation is dense where not destroyed by man, and truck farming is an important industry.

The major element of topography is an eroded upland which slopes gently eastward between elevations of approximately seven hundred and five hundred and fifty feet. This upland has been dissected by small valleys so that the present surface is gently rolling. The largest stream is

LOCATION OF ST. LOUIS–JEFFERSON COUNTIES AREA



AREA COVERED BY THIS THESIS

FIGURE 1

COLUMNAR SECTION

SYSTEM	SYMBOL	NAME	
Quaternary	Q		
Pennsylvanian	Cp	Pleasanton Henrietta Cherokee	Gp. Gp. Gp.
Mississippian	Cm	Ste. Genevieve thru Sulphur Springs	Fm. Fm.
	O	Maquoketa thru Plattin	Fm. Fm.
	Osp	Joachim St. Peter Everton	Fm. Fm. Fm.
Ordovician			
	Ojc	Powell Cotter Jefferson City	Fm. Fm. Fm.
	Or	Roubidoux	Fm.
	Og	Gasconade	Fm.
Cambrian	Cpe	Eminence Potosi	Fm. Fm.

Figure 2. Geologic map of St. Louis and Jefferson Counties, showing principal highways and area discussed in this report (from Geological Map of Missouri, 1939).

the Meramec River, which traverses the south-central part of the area. The Missouri River lies just north of the northwestern corner, and the Mississippi River borders the area on the east. Bottom land makes up about ten per cent of the surface area. Karst topography has developed in the southeastern part of St. Louis County, and sinks occur in the northeastern and north central parts of the area covered by this thesis.

The northeastern part of the area is densely populated; southern St. Louis and many suburban communities are included. Federal, State and County roads traverse the area, density of roads decreasing with distance from St. Louis. Industrial sites are numerous in the northeastern part of the area but have not been established in the southwestern portion. Concentration of residences also decreases toward the southwest.

The project was based mainly upon a study of water well logs, supplemented by a review of available literature. In addition, drillers and owners of wells were interviewed; well water was analysed; contour maps were drawn to show subsurface structure and relative chlorinity; and geological cross-sections were prepared.

Outline of Project

Field work, during the summer of 1959 and on weekends in the fall, included personal interviews with water well drillers and owners, sampling of water from wells and examination of outcrops. Numerous well locations and elevations were checked in the field and with topographic maps. Water samples were collected from wells and were later analysed by Mabel Phillips, chemist of the Missouri Geological Survey.

Locations of wells, and well symbols which represent ground water zones in which the wells were completed, are shown in Figure 3. Names of ground water zones are those of the major water producing formations within the respective zones.

Subsurface contour maps were constructed in order to aid study of local structural features. The upper limits of the Keokuk-Burlington, Kimmswick and St. Peter formations were data for subsurface contours. Figure 3 also shows the location of five geologic cross-sections which illustrate the relation of mineralized water to lithology and structure.

Chloride ion concentrations of water from wells were plotted on maps with respect to the geographic locations of the wells and with respect to the ground water zones producing water to the wells. Isochlorinity lines were drawn to illustrate areas of high or low ground water chlorinity within the Keokuk-Burlington and Kimmswick ground water zones.

Through the study of subsurface contour maps and geologic cross-sections, the author was able to determine relationship between lithology and structure and the occurrence of mineralized water. Superimposition of isochlorinity maps on subsurface maps indicate that, in general, the areas of high mineralization are located in structural lows. Formation lithologies and associated mineralized water, seen in the cross-sections, indicate that, at least in part, lithology controls the migration of ground water and hence the occurrence of mineralized water.

CHAPTER II

PREVIOUS INVESTIGATIONS

Early studies of the geology of St. Louis and Jefferson Counties were of a general nature. Papers published prior to Shepard's paper in 1907 dealt with gross features rather than detailed studies of structure and stratigraphy. More recent work has emphasized local structural features and lithology of formations. Ground water investigations by geologists have been made under the auspices of the United States Geological Survey and the State Geological Surveys of Missouri and Illinois.

E. M. Shepard (1907) discussed the underground waters of Missouri and their relation to stratigraphy and structure. He included a section on the St. Louis basin which underlies St. Louis, St. Charles, the northern portion of Jefferson and the northeastern portion of Franklin Counties. The structure was described generally as the east limb of an anticlinal ridge the crest of which extends from Plattin, Jefferson County, through Pacific, in the northeast corner of Franklin County, northwestward and continues into Warren County. Shepard stated that the strata dip uniformly to the northeast for some distance into Illinois. The anticlinal fold slightly interrupts the generally northeasterly dip from the Ozarks which is characteristic of all sedimentary strata below the Pennsylvanian series. Included in Shepard's paper are cross-sections which extend through the St. Louis area. Mention is made of the quantity and quality of water in deep artesian water wells in St. Louis County. A portion of the description of the Belcher well, as given by Litton, presents pertinent data as to the depths at which mineralization was encountered.

Under the joint auspices of the United States Geological Survey and the State Geological Survey of Illinois, N. M. Fenneman (1911) reported on the geology and mineral resources of the St. Louis Quadrangle, which is a rectangle 31 miles long from east to west and 17½ miles north to south. The area is divided into two nearly equal parts by the Mississippi River, with the city of St. Louis near its center. Topography, stratigraphy, structure, geologic history, economic geology and water resources of the area were discussed in the paper. It included a geologic map, photographs of outcropping formations, surface structural features and two generalized cross-sections. The cross-sections show a general northeasterly dip and low northwest-southeast trending folds.

Some breccias of the St. Louis formation in the St. Louis, Missouri, region were studied in 1925 by Grawe. His study pointed out that local solution caverns within the St. Louis formation are now filled with breccia which resulted from collapse of the roofs of the caverns. Photographs showing brecciated zones in the St. Louis formation were included in the paper.

Charles D. Gleason (1935) presented a preliminary and generalized summary of the ground water resources of St. Louis County. He discussed stratigraphy and structure of formations and the chemical composition of well water. Descriptions of the water-producing formations and the mode of occurrence of the water were presented. Five water provinces were established on the basis of the formations in which mineralization of the ground water had been encountered in water wells. Included in the report were a geologic and water province map of St. Louis County, two cross-sections showing Gleason's interpretation of the stratigraphy and structure of the area, and the compilation of quantity and quality of water from wells completed in the several water-producing formations.

The geology of the Manchester Quadrangle in St. Louis County was studied by Bousfield (1949) who discussed the stratigraphy, general structure and topography of the area. The lithologies of the outcropping formations were described and numerous field check points were given. Bousfield stated that a major unconformity separates the Upper Ordovician formation, the Maquoketa, from the Mississippian beds above it. The limestones of Mississippian age grade into or are conformable to each other.

The general aspects of fresh and sulpho-saline water in the limestones of Mississippian and Ordovician age above the St. Peter sandstone in St. Louis City and County were discussed by John G. Grohskopf (1959). According to Grohskopf, the mineralization of the water in the limestones may be governed, at least in part, by the presence or absence of impervious shales which overlie the limestones and which may prevent migration of fresh water. He stated that in the eastern and northeastern part of the area and away from the outcrop mineralized water may be expected in the St. Peter formation.

Veesaert (1952), conducted a field study of parts of Creve Coeur and Chesterfield Quadrangles, in St. Louis County, to determine lithologic bases for establishing contacts between Mississippian formations. The lithologies of these and Pennsylvanian formations in the area were described in his report.

The geology of the Kirkwood Quadrangle in St. Louis County was discussed in an unpublished master's thesis by Baldwin (1953). He included stratigraphy, structure and references to mineralized water wells in the area.

Earl McCracken (1956), discussed the stratigraphy and structure of north St. Louis County in a review of oil development in the region. Using the top of the Warsaw formation as the datum, a structural map was drawn. Deep wells in the vicinity seemed to substantiate the idea that structure in the Warsaw is continuous with depth into the St. Peter and Kimmswick formations. The Kimmswick is the oil bearing formation in the area.

Gypsum and anhydrite deposits in Illinois were reported by Saxby and Lamar (1957) in a paper prepared specifically to provide information for the possible future economic development of these evaporites. The two minerals occur in the St. Louis limestone formation of Mississippian age and are restricted to the southern half of Illinois, part of which borders the area covered in this thesis. The general geology of the gypsum and anhydrite was discussed, and their areal distribution is shown on small scale maps.

Recent work relative to geology of this area has been done by private companies which are interested in quarrying limestone or river gravel. Water well drillers are active in much of the area and well cuttings collected by the drillers are being analysed and recorded by the Missouri Geological Survey.

CHAPTER III

GEOLOGY OF THE AREA

The geology of south St. Louis and north Jefferson Counties is relatively simple. Middle and Upper Ordovician formations crop out in the southwest part of the area; surface rocks in the northeast are of Mississippian and Pennsylvanian ages. Most of the outcropping formations are of Mississippian age and are chiefly limestone. Pennsylvanian shales and limestones cover much of the northern half of St. Louis County and occur chiefly at the higher elevations in the northern part of the area covered in this thesis. Figure 2 is a geologic map of St. Louis and Jefferson Counties. A monocline dipping gently to the northeast is the general structural feature. However, this is modified by low anticlines, low synclines, and local domes and basins.

Subsurface geology, discussed in this report, is based on water well records on file in the offices of Missouri Geological Survey. Only one unconformity is indicated by the water well data, although more may be present. The Mississippian strata overlie the Ordovician formations at a very slight angle.

Stratigraphy

The formations considered in this paper are shown in the generalized stratigraphic section, Figure 4. A few wells have penetrated formations older than the St. Peter, and many wells have been drilled through the Pennsylvanian shales, but only the strata between these limits are pertinent to the present work.

The St. Peter formation of Middle Ordovician age is a quartz sandstone and is the oldest outcropping rock in the area. It can be seen in the field only in the southwestern part of the area. The thickness of this sandstone ranges from 80 to 150 feet, increasing northeastward.

A gray to tan dolomite and dolomitic limestone with a few shale seams in its upper and middle parts lies above the St. Peter. This is the Joachim formation, which ranges in thickness from 100 to 125 feet.

The Plattin formation, which ranges from 100 to 125 feet in thickness, lies above the Joachim and is a somewhat cherty gray to white limestone. Overlying the Plattin is the Decorah formation, which is dense gray limestone at the base and a shale or a shaly limestone in the upper part. The thickness of the Decorah ranges from 25 to 35 feet.

The youngest Middle Ordovician formation in the area is the Kimmswick, which is a cherty gray to white crystalline and massive-bedded limestone. The Kimmswick ranges from 75 to 120 feet in thickness.

The Upper Ordovician part of the section is represented by the Maquoketa formation, which is chiefly a gray shale. It is cherty in a few locations and very calcareous in its lower portion in other locations, especially in the northeast. In the extreme northeastern part of the area, this formation is made up of 30 feet of limestone at its base overlain by 110 feet of gray shale. The Maquoketa wedges out toward the southwest, suggesting the possibility of an unconformity above it.

A light gray, crystalline dolomite, the Edgewood formation of Silurian age, occurs above the Maquoketa formation in the extreme northeast and abruptly pinches out to the southwest. The maximum thickness of this dolomite encountered in the area is 75 feet. Overlying the dolomite is a black shale of undetermined age. Its maximum thickness is 28 feet; it rapidly pinches out to the southwest.

The Sulphur Springs formation, which is the oldest Mississippian formation in the section, occurs with a maximum thickness of 30 feet in the southwest and pinches out to the northeast. The lithology of the formation grades northeastwardly from quartz sandstone at the outcrops in the southwestern part of the study area to sandy and shaly limestone where it pinches out.

The Chouteau formation, a gray dense limestone of Mississippian age, overlies the Ordovician Maquoketa and

Mississippian Sulphur Springs formations, as shown in cross-section A-A', Figure 6. It also overlies the shale and dolomite of Silurian age and the Sulphur Springs formation, as shown in cross-section E-E', Figure 10. This suggests the presence of an angular unconformity between the Ordovician and Silurian formations and Mississippian Chouteau formation. The Chouteau formation ranges in thickness from zero to 35 feet.

Overlying the Chouteau formation is the Fern Glen limestone. It is red to gray-green, sometimes shaly in the upper part, and a little cherty. It ranges in thickness from 15 to 45 feet. Where the Chouteau pinches out, the Fern Glen overlies the Maquoketa and Sulphur Springs formations.

A thick section of very cherty limestone, the Keokuk-Burlington formation, overlies the Fern Glen. This limestone is gray-white, coarsely crystalline and massive-bedded, and ranges from 200 to 260 feet in thickness.

A lithologically heterogeneous formation, the Warsaw, occurs above the thick section of cherty limestone. Its thickness ranges from 60 to 100 feet. The formation is mostly soft, gray shale, but grades into cherty shale, cherty limestone, calcareous shale and shaly limestone.

The Spergen formation, a tan, crystalline, oolitic limestone with some chert and dolomite, ranges in thickness from 130 to 180 feet. This limestone overlies the Warsaw and is sometimes difficult to separate from the latter by lithology alone, since the Spergen contains some local lenses of shaly limestone and calcareous shale.

The St. Louis formation occurs above the Spergen and is composed of limestone and some dolomite, both of which contain a little chert. The texture of the limestone ranges from dense to lithographic in the lower part to coarsely crystalline in the upper part. Slightly shaly and sandy areas occur locally in the central part of the area. The St. Louis formation varies from 100 to 170 feet in thickness.

In the eastern part of the thesis area the St. Louis formation is overlain by the Ste. Genevieve formation, a gray-white, crystalline and slightly cherty limestone. The thickness of this formation ranges from 20 to 70 feet.

Pennsylvanian shales with some limestones occur above the Mississippian formations in the northern part of the area. The thickness of the strata of this age increases northward and with increase in elevation of the surface. The upper limit of the Pennsylvanian strata is the present erosional surface.

Regional Structure

Structural features in the St. Louis-Jefferson Counties area are more evident when studied over a large area, since the maximum dip of the formations is only two degrees. Such a slight deviation from the horizontal might seem insignificant in many cases, but when fluid traps are under consideration the slightest reversal of dip may be of importance.

In his paper on the occurrence of ground water in St. Louis County, Gleason (1935) defined the major structure as a northeast dipping monocline with low parallel folds trending northwest-southeast. McCracken (1956) described a dome with 25 to 75 feet of closure within one square mile in north St. Louis County. Deep well data suggest that the structure of this dome is vertically continuous into, and possibly through, the Ordovician section.

Figure 11 of the present thesis is a subsurface contour map of the top of the Keokuk-Burlington formation. This surface has a general northwest-southeast strike and northeast dip; significant modifications of this trend occur locally. The subsurface contour map of the top of the Kimmswick formation, Figure 12, suggests that the above mentioned general attitude of the Mississippian Keokuk formation is generally continuous with depth into the Ordovician formations.

Local Structure

Most of the local structural depressions in the Keokuk-Burlington formation, as shown in Figure 11, are not continuous into the Kimmswick formation. This lack of vertical continuity plus local thickening of the Warsaw formation, which overlies the Keokuk-Burlington formations, suggests that the structural depressions are sink structures. Such structures may have resulted from the differential solution of the lower part of the Keokuk-Burlington formation and intraformational collapse. Grawe (1923) described similar but smaller intraformational collapse in the St. Louis formation in St. Louis County.

The most significant modifications of the general northeastward dip are the local highs shown in the southeastern corner of T. 45N., R. 4E.; south central T. 45N., R. 5E.; and local lows shown in the northwestern corner T. 45N., R. 4E.; northwestern corner T. 44N., R. 5E.; south central T. 44N., R. 5E.; and northwestern corner T. 43N., R. 6E. Gentle folds which trend nearly perpendicular to the monoclinal strike, occur in the eastern half T. 45N., R. 4E.; central part of T. 44N., R. 5E.; east central T. 43N., R. 6E. See Figures 11 and 12.

The monoclinal dip is somewhat greater in the southeastern part of the area than elsewhere; the beds are nearly horizontal in the northwestern portion. The geographic locations of five geologic cross-sections are shown in Figure 3. Cross-section B-B', Figure 7, illustrates the near absence of dip and folding. Maximum monoclinal dip and modifying folding is shown in cross-section E-E', Figure 10, which shows the southeastern portion of the area under investigation. The vertical scale of the geologic cross-sections is largely exaggerated with respect to the horizontal scale.

Deviation from perfect vertical structural continuity between Mississippian and Ordovician formations is due in part to a northeastward increase in thickness of the Upper Ordovician formation in the area, the Maquoketa, and the onlap of a Silurian formation from the northeast. Variations of thickness of the Upper Ordovician formation and lower Mississippian formations, as shown in cross-section E-E', suggest a period of erosion and sporadic deposition between the two ages.

Joints, solution channels and open bedding planes occur in all the formations to varying degrees. The most highly jointed formations are the limestones with cherty beds. Solution channels occur mostly in limestones, although some are encountered in dolomites and along bedding planes of calcareous shales. Solution channels are common along formational contacts.

CHAPTER IV

DRILLING AND SAMPLING

Essentially all of the water well drilling done in the St. Louis-Jefferson Counties area has been and is being done by the cable tool method. Drillers in the area have cooperated with the Missouri Geological Survey by saving cuttings and water samples from many of the wells. The cuttings are studied in detail and recorded on graphic logs by Survey geologists. Water samples are analysed by Survey chemists for the determination of concentration of dissolved and suspended solids. The well logs are used to further geological knowledge of the area and to provide permanent records for the well drillers so that they may base future contracts on these compiled data.

The cable tool drilling method employs the impact of a bit suspended on a steel drilling cable, which is reciprocated in a vertical motion. The cuttings produced by bit action are removed from the hole at five foot intervals by withdrawing the bit and bailing out. These cuttings are sampled by the driller, placed in sample bags supplied by the Missouri Geological Survey, and shipped to the Survey for study and correlation with samples from other wells. Time and labor are expended by the driller in the sampling, bagging and shipping necessary to provide adequate samples for geological study.

Bailing at five foot intervals is not always convenient for the drillers. Bailing intervals vary with lithology being penetrated, and the driller must sometimes bail more frequently to obtain the standard five foot interval desired by the Survey than is required for efficient drilling. The standard sampling interval was established by the Survey to provide a working basis for recording lithology and other pertinent data on printed forms.

During the summer and fall months of 1959, the author interviewed water well owners and well drillers who have drilled wells in the thesis area. Interviews with drillers have shown that a variety of opinions on sampling exists. There are as many opinions as there are well drillers. Each driller is an independent businessman competing in an area in which water well drilling is highly competitive.

Each driller knows that well records on file with the Survey are available to the public and that he is free to study them to gain knowledge of ground water conditions in an area. Also available on the logs are data concerning methods of well completion employed by other drillers. Casing records, production of water, quality of water and other pertinent information are also recorded on the logs; knowledge of such information is very significant in bidding on future contracts.

Drillers who have worked in an area for a number of years may feel confident that they have complete knowledge of ground water conditions therein. They have developed methods of casing out soft shales which occur at certain levels or mineralized water which occurs in some formations in some localities. Plugging off mineralized water and retaining fresh water in wells has been done successfully by some drillers and has been attempted unsuccessfully by others.

Some independent water well drillers feel reluctant to supply very important information pertaining to their business to a government agency which will in turn make it available to the drillers' competitors.

Drillers who provide data pertaining to the geologic and hydrologic properties of formations encountered while drilling realize the significance of compiling such data. Knowledge of Missouri's subsurface geology and ground water resources expands with each sample sent in by drillers. Correlation of wells with each other provides the details necessary for better understanding of lithofacies changes within formations as well as for interpretation of local and regional structure. The more information from wells the Survey has the more efficiently it can perform its services of advising property owners with regard to procurement of potable water supplies and water well drillers with regard to successful completion of wells.

Much information is contributed by the drillers to the Survey, but some is withheld and not recorded. Some data on file at the Missouri Geological Survey, at no fault of the Survey, do not correspond to data acquired through personal interviews with well drillers and well owners. Usually, such discrepancies are of little significance, but sometimes they are of great significance. One such discrepancy is that of successful production of fresh water from beneath a formation which produces mineralized water, whereas the log on record states only that two strings of casing were used and that the water was fresh.

Personal interviews with water well drillers regarding sampling and providing the Survey with well information helped the author to appreciate the drillers' views. The drillers desire cooperation with the Survey; however, they must compete with each other. Knowledge of and experience in methods of obtaining potable water supplies in newly developed areas or in areas in which impotable water has been encountered give a driller distinct economic advantage if other drillers are unacquainted with the methods. Once the methods are known to the driller's competitors, his bargaining power for contract bids is lessened.

Appreciation of the high competition in water well drilling in the St. Louis-Jefferson Counties area provided the author an understanding of reasons why information on well logs is not complete as it otherwise might be. However, data secured from water well records, along with information secured through personal interviews with well drillers and owners, served as an adequate basis for understanding many of the problems involved in the occurrence of mineralized water in the thesis area.

CHAPTER V

QUALITY OF GROUND WATER

Many well water analyses were made by Missouri Geological Survey chemists prior to the present investigation. They were recorded with other well data on strip logs on file with the Survey. During the summer of 1959, the author acquired samples of water from sixty-five water wells in the St. Louis-Jefferson Counties area. The samples were analysed by Mabel Phillips, Survey chemist, for concentrations of total dissolved solids, the chloride ion and the sulphate ion. Results of analyses showed concentration of salts to be much less than that in sea water. In some cases the concentration of salts is high enough to make the water unusable for industrial and domestic purposes.

Data derived from previous analyses and those made during the summer of 1959 provided a basis for the study of distribution of mineralized ground water within the thesis area. Water which contains a concentration of total dissolved solids in excess of one thousand parts per million, the chloride ion in excess of two hundred and fifty parts per million or the sulphate ion in excess of two hundred and fifty parts per million is herein considered mineralized (Public Health Reports).

Location of water wells discussed in this study is shown in Figure 3. Symbols indicate wells in which mineralized water has been reported. Symbols indicate also the ground water zones in which the mineralized water occurs.

Chloride ion concentration is the most useful criterion for describing mineralized ground water in the area covered in this thesis. The other criteria, total dissolved solids and sulphate ion concentration, fluctuate directly with chloride ion concentration, but they are usually less easily detected in the field by taste and preliminary chemical analysis.

Isochlorinity maps, Figures 14 and 15, show lines of equal chloride ion concentration as determined from analyses of water samples from the Keokuk-Burlington and Kimmswick ground water zones. Areas of high chloride ion concentration in these zones are presented in the same manner as hills are shown by topographic contour lines. Isochlorinity intervals vary because of the wide range of chloride ion concentration in the area.

Casing technique and well completion ability vary with well driller. Contamination of one ground water zone by mineralized water from other zones is known to occur. The ground water in the formations is confined under a hydrostatic head which produces a static water level well above the level at which the water is encountered. E. E. Burt, well driller in Ballwin, Missouri, informed the author that he plugged off mineralized water below the St. Peter formation to reduce contamination of water in the St. Peter sandstone in an adjacent well. The plug was successful and the water in the St. Peter sandstone in the adjacent well became fresh, as it was before the deeper well was drilled. These two wells are located at Crowley's Bridgehead Inn on Highway 66 in the southwest part of St. Louis County.

Unless the driller reported the depth at which water was encountered and a sample of water was taken at that time for analysis, the quality of water at that horizon cannot be determined. Whenever the water is sampled after completion of the well, the analysis represents the concentration of dissolved solids of a mixture of water from all the water producing horizons penetrated and not cased or plugged off.

Wells from which no mineralized water was reported are here considered fresh water wells. Whenever reasonable doubt as to the accuracy of analysis or detection of mineralized water arose for a given well, the information pertaining to quality of water was omitted from tables and isochlorinity maps.

Error has been introduced into the interpretation of distribution of mineralized water in Keokuk-Burlington and Kimmswick water wells by the inadequate sampling. Too few water samples have been saved by drillers, and many of the samples which were saved and turned into the Survey were taken at the total depth level rather than at the level at which water was encountered.

In spite of the inaccuracies involved in the sampling of ground water in the area, the analyses provided valuable information regarding the location of mineralized water. When plotted on a map, the chloride ion concentration shows a reasonably consistent pattern.

Ground water in the area is not transitional from mineralized to fresh as one might expect. The boundary between fresh and mineralized water in a ground water zone is unusually abrupt. Figures 14 and 15 show that areas of high mineralization sometimes occur close to areas of low mineralization. This may be due to the factors which control the occurrence of mineralized water. Lithofacies changes within a formation may retain connate water after uplift. Structural features such as basins and synclines may act as traps for connate water and prevent flushing by meteoric water. Both lithofacies changes within a formation and structural features may cause abrupt boundaries between fresh and mineralized water.

CHAPTER VI

RELATION OF MINERALIZED WATER TO LITHOLOGY

Carbonate rocks make up the major portion of strata present in the area encompassed by this thesis. Nearly all ground water is derived from the St. Peter and overlying formations. The major water producing lithology is limestone with interbedded chert. Sandstones, where present in the area, yield abundant water supplies, but they make up a minor part of the geologic column. Shaly formations yield water only when they contain appreciable chert or when interbedded with sandstone or limestone.

The geologic formations of the St. Louis-Jefferson Counties area were grouped in this study into five ground water zones; the St. Louis-Spergen, Keokuk-Burlington, Kimmswick, Plattin-Joachim and St. Peter zones, as shown in Figure 4. The name of each zone was derived from the major water producing formation or formations included in the zone. At the upper limit of each zone is a hydrologically "tight", or relatively impermeable, rock unit, which acts as an aquiclude; and the lower limit is the aquiclude for the next lower zone.

The St. Peter formation, a quartz sandstone which ranges in thickness from 80 to 100 feet, occurs in all parts of the St. Louis-Jefferson Counties area. This sandstone has high permeability and provides fresh water to wells in much of the southwest portion of the area. In other parts of the area, the water derived from the St. Peter formation is mineralized. Figure 3 shows the areal distribution of fresh and mineralized water encountered in the St. Peter formation.

The Joachim, Plattin and Decorah formations constitute a section of carbonate rocks, chiefly limestone but with some dolomite, overlain by shale or argillaceous limestone which make up the upper part of the Decorah formation. Some chert occurs in the Plattin formation whereas little is present in the Joachim and Decorah. Little ground water is produced from these three formations. Both fresh and mineralized water have been encountered in them.

The Kimmswick formation is a limestone with appreciable chert content. Maximum production of ground water in an eight inch well ranges from none to 50 gallons per minute. The Maquoketa formation, which overlies the Kimmswick, is chiefly a hydrologically tight shale, although cherty and sandy areas do occur. Well Number 44-5-26 abd is reported to have produced 25 gallons of mineralized water per minute from the Maquoketa shale, although the formation has since been plugged off to cease influx of mineralized water into the well.[2] Well number 45-4-12 cdd is reported to have produced mineralized water from the top of the Kimmswick formation at a rate of 25 to 30 gallons per minute. The hole was plugged up to within three feet of the top of the Maquoketa formation; two gallons of fresh water per minute were then produced from the well.

The Edgewood formation, which is a dolomite of Silurian age and the thin stratum of shale, also of Silurian age, above it occur only in the northeast part of the area. They are not important as water bearing formations.

Fresh water is obtained from the sandstone in the Sulphur Springs formation, which occurs in the southwest and pinches out rapidly to the northeast. Toward the northeast the lithology of the formation grades from sandstone to sandy, shaly limestone. Due to the limited areal extent of the Sulphur Springs sandstone, it is not a major water producer.

A thick sequence of limestone, the Chouteau, Fern Glen and Keokuk-Burlington formations, occurs stratigraphically

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[2]The numbers used in this well nomenclature denote, respectively, the township, range and section in which the well is located; the letters denote position of well within the section; the first letter denotes one-fourth of the section, the second letter one-eighth of the section, and the third letter one-sixteenth of the section. Quadrants are lettered alphabetically counter clockwise, starting in the upper right quadrant.

above the Sulphur Springs formation. The Chouteau formation contains very little chert; the Fern Glen contains appreciable chert in some areas but is usually argillaceous; the Keokuk-Burlington formation contains a high percentage of chert, sometimes as much as 60 percent in five feet of drilling.

The very cherty Keokuk-Burlington limestone is the major water producing formation in the area covered by this thesis. Openings occur at the contacts between chert and limestone beds. Where this formation is exposed at the surface, it has many fractures and solution channels through which surface water can infiltrate and recharge ground water supplies. These fractures and solution channels are reported to occur also at depth. The Fern Glen and Chouteau formations are generally impermeable and yield little water. Where it is somewhat cherty, however, the Fern Glen supplies small quantities of water to wells. Both fresh and mineralized water are encountered in this thick section of limestone.

The Warsaw formation comprises the upper part of the Keokuk-Burlington ground water zone. It is chiefly shale, but the lower portion is sometimes composed of cherty limestone or cherty shale, in which some water has been encountered. Figure 11 shows the areal distribution of mineralized water in the Keokuk-Burlington ground water zone.

The slightly cherty limestones of the Spergen and St. Louis formations contain available ground water of sufficient quantity for residences, which require only small production. A large number of relatively shallow wells have been drilled to these formations. The Pennsylvanian limestones and shales which occur in the area make up the upper part of the St. Louis-Spergen ground water zone. The Pennsylvanian rocks supply a meager amount of ground water in the thesis area, but they are an important source farther north. In the thesis area, all ground water derived from the St. Louis-Spergen ground water zone has been reported as fresh.

From the foregoing it seems that cherty limestones yield the major portion of the ground water produced in the area; sandstones make up a small part of the geologic column, and they are second in importance. Shales and non-cherty limestone provide very little water.

Assuming that the mineralized water encountered in several formations in the St. Louis-Jefferson Counties area is connate water, lithology could very well be a causative factor in its entrapment. Sediments in which sea water was trapped could easily have been enclosed by impermeable sediments. Such lithological relationships could have prevented the flushing of the sea water by fresh water during the after regional uplift. Lithofacies changes within a stratum are necessary to permit the above entrapment; evidence of such changes is shown on the geological cross-sections included in this paper.

The major water-producing formations are in general lithologically consistent in the St. Louis-Jefferson Counties area. The Maquoketa and Warsaw formations exhibit radical lithofacies changes; therefore, the mineralized water in the major water-producing formations probably is not controlled by lithofacies changes, whereas the mineralized water in the Maquoketa and Warsaw formations may be controlled in that manner.

The lithologies of the formations pertinent to this thesis are shown on the geological cross-sections. The southeast portion of cross-section A-A', Figure 6, exemplifies the possibility of mineralized water control by lithofacies changes in the southeast part of the thesis area. The Warsaw formation, as encountered by well number 43-6-33 aaa, consists of shale with small chert content. Well number 43-6-34 b, which is one-quarter mile to the east, is reported to have encountered only shale in the Warsaw formation. The first well mentioned encountered no mineralized water in the Warsaw and the Keokuk-Burlington formations. The second well encountered very highly mineralized water at the contact between the Warsaw shale and the very cherty Keokuk-Burlington formation. This is evidence that a hydrologically tight formation, such as shale, has retained mineralized water, whereas the permeable cherty shale has been flushed free of its mineralized water by permeating fresh water.

Well number 42-6-2 bbb reported no water in the Warsaw shale. Well number 43-6-20 aca, which penetrated shale in the upper half of the Warsaw and shaly limestone in the lower half, encountered mineralized water at the contact between the Warsaw and Keokuk-Burlington formations. Well numbers 43-6-18 acc and 43-6-7 cb, which penetrated cherty shale and cherty limestone in the Warsaw, encountered no mineralized water at the formational contact. This is further evidence that a hydrologically tight formation, such as shale and shaly limestone, has retained mineralized water, whereas the permeable cherty shale and cherty limestone have been flushed free of mineralized water by permeating fresh water.

The contact between the Warsaw and Keokuk-Burlington formations are shown in the southeast portion of cross-section A-A' is very nearly horizontal. However, there is a very shallow syncline present which may be a controlling factor in the occurrence of the mineralized water.

Presence of mineralized water at the base of the Warsaw formation where it is non-cherty shale and absence of mineralized water where the Warsaw formation is cherty shale suggest that chert has an effect on the hydrologic properties of the shale. Chert may increase permeability of shale beds and increase flushing by fresh water, thus displacing mineralized water, whereas non-cherty shale may trap the mineralized water.

The author noted that the general consensus of water well drillers in the area is that low water production is incurred when mineralized water is encountered at the contacts between shale and limestone. However, this is not always the case. In well number 44-5-26 adb, the Keokuk-Burlington cherty limestone supplied one gallon of fresh water per minute whereas the Maquoketa shale supplied twenty-five gallons of mineralized water per minute. The mineralized water production possibly came from the lower contact of the Maquoketa formation rather than the shale itself.

Not infrequently horizons of low fresh water production were penetrated above the major producing zone. Whenever this is the case, fresh water is usually obtained from the well. However, it has often been found that no or very few fresh water horizons are penetrated above a major mineralized water producing zone. This suggests the relation between hydrologically tight formations and the occurrences of mineralized water.

The cable tool drilling method, which employs impact of a sub-sharp cutting bit, tends to crush the rock and obliterate minor fractures in shales and limestones. Because of this, the hydrologic properties of the formations penetrated can not be determined from the cuttings alone. Personal interviews with or good written logs by drillers are necessary as supplementary to study of the cuttings.

Evaporite deposits, if present, would be thoroughly crushed by the cable tool bit and dissolved by water used in the drilling process, unless they occurred in very thick beds. The particles which might survive the crushing of the bit, could easily be lost during the sampling and washing by the driller.

Mr. E. E. Burt, who has drilled water wells in St. Louis County for the last thirty years, informed the author that he has recovered gypsum ($CaSO_4.2H_2O$) while drilling in the Maquoketa formation. Mr. Burt stated that the material he identified as gypsum is the same material he observed in the gypsum beds of Oklahoma, where he had previously worked in the oil fields. He was quite surprised to hear that the Missouri Geological Survey has not reported gypsum in cuttings he had sent them. Unfortunately, the author had no opportunity to identify the material.

Dr. A. C. Spreng, associate professor of geology at the Missouri School of Mines, informed the author that he has observed selenite ($CaSO_4.2H_2O$), a variety of gypsum, in the Maquoketa formation in Pike and Lincoln Counties, Missouri, some fifty miles northwest of the area covered in this thesis.

Along Highway 79, just north of Clarksville, Missouri, the Maquoketa shale contains a considerable amount of selenite crystals. The author observed small selenite crystals in pockets, which were about two inches in diameter, in the shale and disseminated throughout the shale to a depth of at least eighteen inches. Selenite crystals make up about fifteen percent of the shale near the surface at the historic landmark north of Clarksville, southwest quarter of Section 9, Township 53 North, Range 1 East.

Gypsum and anhydrite ($CaSO_4$) deposits, reported in Illinois Geological Survey Circular 226, 1957, occur in the Mississippian St. Louis formation and the Ordovician Dutchtown and Knox formations. Figure 6 on page 11 of the circular shows the thickness of the evaporite-bearing zone in the St. Louis formation. This isopachous map terminates at the Missouri-Illinois state line; the western limit of the evaporite-bearing zone is not known. The zone, which shows evaporite-bearing material of several feet in thickness just east of the Mississippi River, may extend into the St. Louis-Jefferson Counties area.

Sufficient data pertaining to the occurrence of gypsum in the Maquoketa formation are not available to determine its origin. Primary deposition as an evaporite or secondary deposition resulting from chemical reaction between calcium carbonate and pyrite formerly present in the shale or adjacent formations are two theories of origin which may be considered. This paper does not propose to determine the genesis of gypsum in the formation but to present the fact that it does occur.

The occurrence of gypsum in the Maquoketa formation suggests the possibility of associated chloride evaporites within that formation. Should this be the case, concentration of dissolved chlorides and sulphates in ground water may have been derived from the solution of evaporite salts by permeating water. Sufficient evidence is as yet not available to conclusively state that evaporite deposits occur in the thesis area or that mineralization of ground water is due to former evaporite beds.

Limestones with an appreciable chert content are usually permeable and provide most of the ground water supplies in the St. Louis-Jefferson Counties area. Sandstones provide an appreciable supply of water in the southwest portion of the area, but they decrease in importance to the northeast. Cherty shales supply some water to wells, but in general the shales are non-water bearing. Lithology is a controlling factor in the occurrence of ground water. Possibly it is a controlling factor in the mineralization of the ground water.

Entrapped connate water and fresh water mineralized by evaporite deposits are two ways in which the mineralized water encountered by drilling could have originated. Either or both may explain the presence of mineralized water in the St. Louis-Jefferson Counties area.

CHAPTER VII

RELATION OF MINERALIZED WATER TO STRUCTURE

The outstanding structural feature in the St. Louis-Jefferson Counties area is a northeast dipping monocline. This structure is modified by a syncline trending northwest, structural terraces, minor folds trending northeast and several small local basins. Figures 11, 12 and 13 show structural features of the Keokuk-Burlington, Kimmswick and St. Peter formations.

Structural relief and closure in the St. Louis-Jefferson Counties area is of very low magnitude. The maximum dip is about two degrees, and quite often the dip is much less than one degree. Such structure is readily observable only over a large area. Since the folds shown in the geologic cross-sections are continuous from the youngest Mississippian formations into the Ordovician formations, their origin probably is congruous throughout. Low synclines occur in the area.

Subsurface contour maps, Figures 11, 12 and 13, as well as geologic cross-sections, show that mineralized water has been encountered in the low synclines and structural basins. Figure 11 suggests a relationship between synclines and occurrence of mineralized water in the St. Louis-Jefferson Counties area. The mineralized water may be connate, solute from evaporite salt deposits or infiltrated sea water. Connate water is sea water which was entrapped in the interstices of sediments at the time the sediments were deposited. Solute from evaporite salt deposits is mineralized water which procured its dissolved salts from evaporite beds within formations. Infiltrated sea water, as the term is used here, is sea water which percolated to its present position from overlying seas. Evidence that these seas existed is that formations in which mineralized water is encountered are overlain by younger marine sedimentary formations.

Geologic cross-section E-E', Figure 10, illustrates the relation between occurrence of mineralized water and synclines. Wells 43-6-18 acc, 43-6-8 bda and 46-6-4 dac, which penetrate the Keokuk-Burlington formation 86, 56 and 5 feet respectively, encountered mineralized water within the formation or near upper contact. Wells 43-5-24 dcd and 43-6-3 dbb, which are respectively southwest and northeast of the above three wells, penetrated the Keokuk-Burlington formation 58 and 172 feet and encountered no mineralized water. As shown on cross-section E-E', the three wells which encountered mineralized water are in a structural low with respect to the two wells which encountered no mineralized water.

Mineralized water of any of the modes of origin discussed above may be flushed from formations by percolating fresh water, providing the lithologies involved are permeable enough to allow such displacement to take place. The general direction of fresh water movement would have been down dip, although hydrostatic head differences could have caused movement to take place up dip in some instances. Folds in the formations would act as barriers to the flushing out of mineralized water and displacement would be less in troughs of synclinal folds than along limbs and crests of anticlines. Basins and synclines acted as traps in which dense mineralized water collected and remained. Fresh water, which was of less density than the mineralized water, did not force the latter out of the trap but moved over the top of the higher density mineralized water.

Removal of mineralized water by fresh water could have taken place by flushing due to gravity in formations of constant dip, as mentioned above, or by diffusion of ions from the mineralized water to the meteoric water. Thin layers of mineralized water would be diluted relatively rapidly, whereas thick layers of mineralized water, or mineralized water in small closed crevices, would be diluted more slowly. Basins and troughs in mineralized water bearing formations would contain thick layers of mineralized water and less displacement would then take place.

Figure 5a is a schematic section which shows a relatively permeable stratum, U, overlying an impermeable stratum, L. Stratum T, which is also impermeable, caps

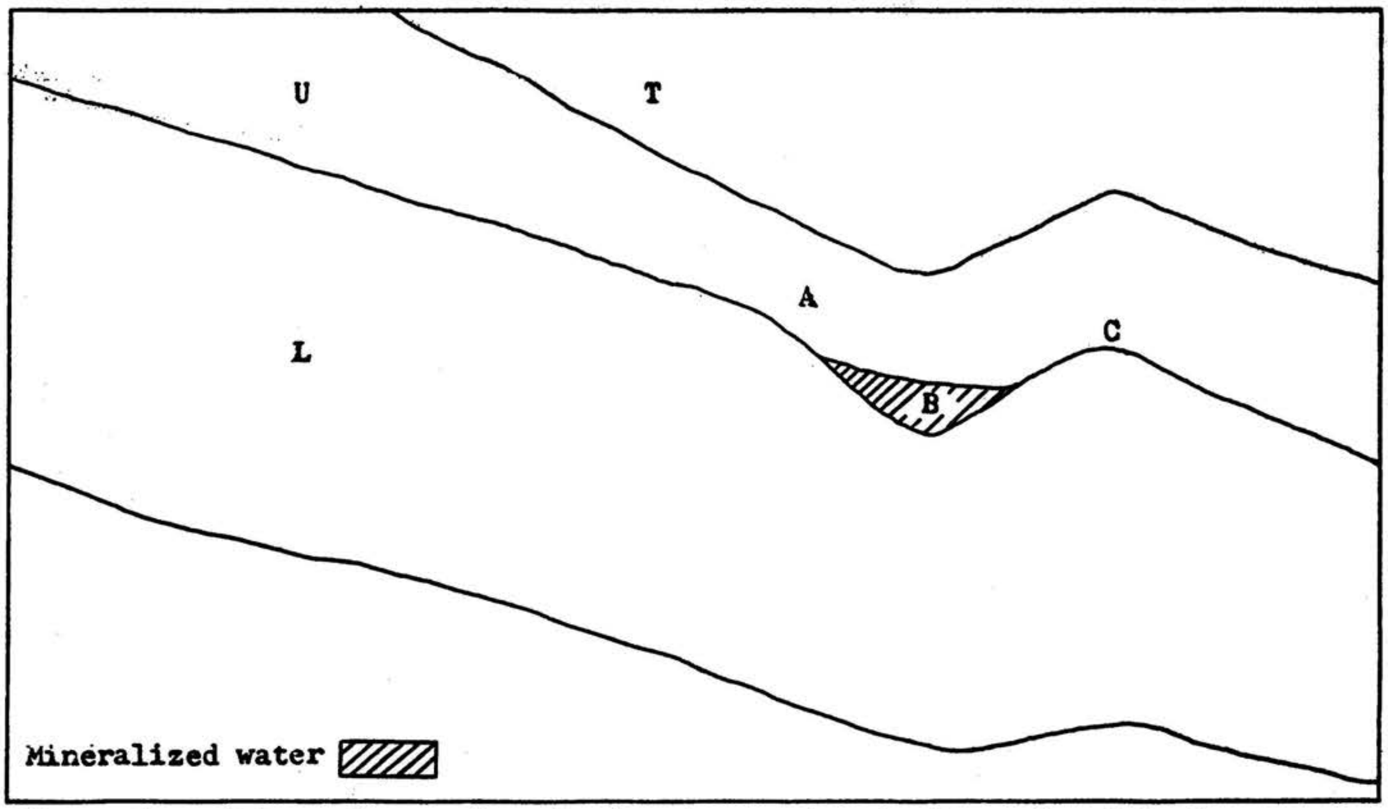

Figure 5a. Schematic section showing depression in formation K acting mineralized water traps.

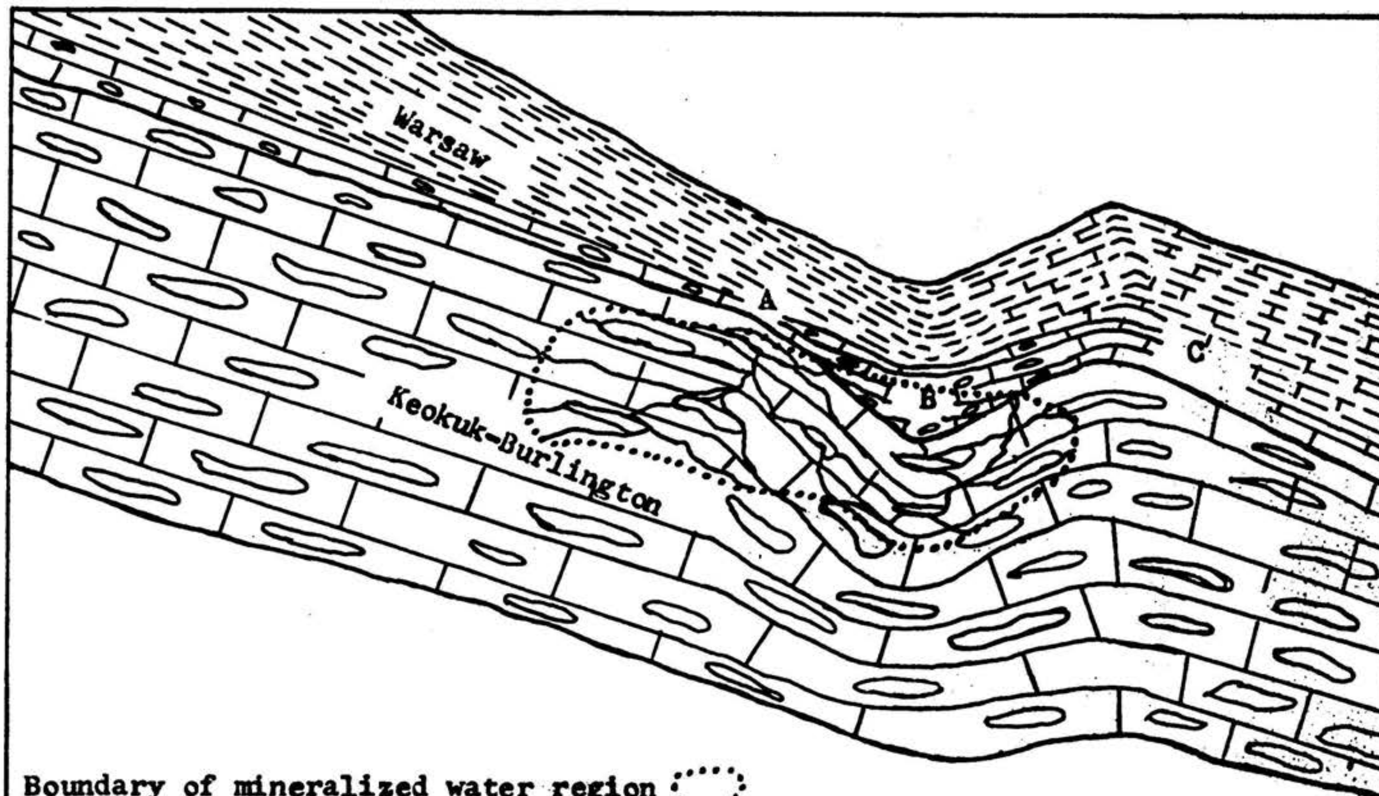

Figure 5b. Detailed cross-section taken from geologic cross-section E-E'.

stratum U. Mineralized water in stratum U is subjected to flushing by fresh water moving from the part of stratum U at the top of the figure down dip to point A. At point B in the section, the surface of stratum L is depressed and forms a pocket. Mineralized water, which has a greater density than fresh water, is much less easily displaced in the lower part of the depression than elsewhere in stratum U. Fresh water moves more or less laterally from point A to point C and continues flushing of mineralized water down dip from point C. The differential displacement of mineralized water by fresh water in stratum U results in occurrence of fresh water on the uninterrupted slope and mineralized water in depressions. Dilution of the mineralized water in the depressions will involve a greater time factor than will direct displacement. This will result in a complete flushing out of mineralized water in some parts of stratum U and a decrease in concentration of dissolved salts in other parts.

Figure 5b is a detailed section which shows the lithology and structure present in the Warsaw and Keokuk-Burlington formations in the St. Louis-Jefferson Counties area. The depression in the upper part of the Keokuk-Burlington formation at point B is filled with permeable cherty limestone which is part of the overlying Warsaw formation. Fractures are known to occur below the depression as they do in many parts of the Keokuk-Burlington formation.

The depression may be the result of roof collapse of solution cavities, which would account for both the depression and fractures in the Warsaw and Keokuk-Burlington formations. Alternatively, the depression may be a tectonic syncline, with which fractures could be associated.

The depression shown in Figure 5b and the fractures in the Keokuk-Burlington formation act as a trap for mineralized water. Mineralized water in the lower part of the Warsaw formation, where that formation is often permeable, and in solution channels along the lower contact of the Warsaw would be readily displaced by fresh meteoric water. Mineralized water in the trap, however, would be protected from displacement and from rapid dilution. The structure and lithologies shown in Figure 9b were taken directly from the middle of geologic cross-section E-E', Figure 10.

The southwest end of geologic cross-section C-C', Figure 8, illustrates relation between occurrence of mineralized water at the Joachim-Plattin contact and a minor structural terrace at well 44-4-15 cdd. This well is reported to have encountered water with chloride ion concentration of 1657.3 parts per million, whereas the two adjacent wells were reported to have encountered fresh water at the Joachim-Plattin contact. The Decorah formation, which is reported to be a slightly cherty argillaceous limestone in well number 44-4-15 cdd, is somewhat thicker at this location than it is at well number 44-4-14 ada. The Plattin formation thins somewhat under the thicker section of Decorah, suggesting presence of a stratigraphic trap for mineralized water in the Plattin formation.

The occurrence of mineralized ground water at the contact between the Sulphur Springs and Kimmswick formations and the pinching out of the Maquoketa in well number 44-4-14 ada, Figure 8, suggest the presence of a stratigraphic trap which prevented the flushing of mineralized water by fresh meteoric water. When well number 44-4-14 ada was drilled, fresh water was encountered at the Plattin-Joachim formational contact. One year later, the water in the well was analysed and contained a chloride ion concentration of 2807.6 parts per million. The mineralized water may have come into the well from the Kimmswick-Sulphur Springs formational contact or from the mineralized water bearing area in the Plattin formation which supplies well number 44-4-15 cdd with mineralized water.

Occurrence of mineralized water is controlled, at least in part, by structural troughs in the St. Louis-Jefferson Counties area. Evidence of this is shown by subsurface contour maps and their comparison with chlorinity maps which are included in this report. Geologic cross-sections, on which structure and reported mineralized water are shown, demonstrate structure-mineralized water relationship.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

In St. Louis and Jefferson Counties, Missouri mineralized ground water is present in Ordovician and Mississippian formations. Mineralized water contains high concentrations of salts in solution, which are detrimental to plumbing, machinery, boilers and other industrial equipment. The undesirable taste of mineralized water renders it unfit for many culinary purposes. The presence of mineralized water is detrimental to the development of ground water resources in the area for industrial and domestic purposes. The purposes of this thesis were to determine the areas in which mineralized water has been and most probably will be encountered in water well drilling, and to determine the geologic conditions which control the occurrence of the mineralized water.

Water well data which were submitted to the Missouri Geological Survey by drillers and which is on file at the Survey were studied. Formation lithologies and structure were derived from water well logs. This information is presented in this report as subsurface contour maps, geologic cross-sections and a composite stratigraphic section, with which lithologic descriptions of formations pertinent to the study are presented. Isochlorinity maps, Figures 14 and

15, represent chloride ion concentration in ground water in the Keokuk-Burlington and Kimmswick ground water zones. The structure contour maps also show the areas in which mineralized water will most probably be encountered in the Keokuk-Burlington and Kimmswick ground water zones.

Comparison of the occurrence of mineralized water with the lithology of formations in which mineralized water was encountered shows that areas surrounded by relatively impermeable lithologies contain mineralized water, whereas areas of permeable lithologies most often contain fresh water. This is not true for the entire area covered by this study, but the relation does occur locally.

Relation between structure and mineralized ground water occurrence may be seen on the subsurface contour maps, Figures 11, 12 and 13, which also show areal distribution of mineralized water in the Keokuk-Burlington, Kimmswick and St. Peter ground water zones. Ground water of high chloride ion concentration is shown in the above Figures to be associated with shallow synclines or basins which are present in the formations included in the ground water zones.

Well data show the St. Peter formation to be a lithologically homogeneous quartz sandstone. Occurrence of mineralized water in this formation is related to depth and structure rather than lithology. Even though the St. Peter formation is very permeable it contains large quantities of mineralized water in most of the area covered in this thesis. Figure 13 shows the general structural features of the upper limit of the St. Peter sandstone and the areal distribution of mineralized water in the formation.

Evaporites may occur in association with the shales and dolomites in the area. Gypsum has been reported in the Maquoketa formation outside the area, but its mode of origin has not been established. The presence of sulphate and chloride salts in the formations may account for high concentration of sulphate and chloride ions in ground water.

Mineralized ground water which occurs in the St. Louis-Jefferson Counties area discussed in this thesis is controlled locally by lithofacies changes and structural features. Hydrologically tight, or relatively impermeable, lithologies impede flushing of mineralized water by fresh meteoric water. Mineralized water in permeable areas within a formation, when completely enclosed by an impereable lithology, is protected from flushing by fresh water. Synclines and fracture zones underlying them act as traps for mineralized ground water and protect it from flushing by permeating fresh water.

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A P P E N D I C E S

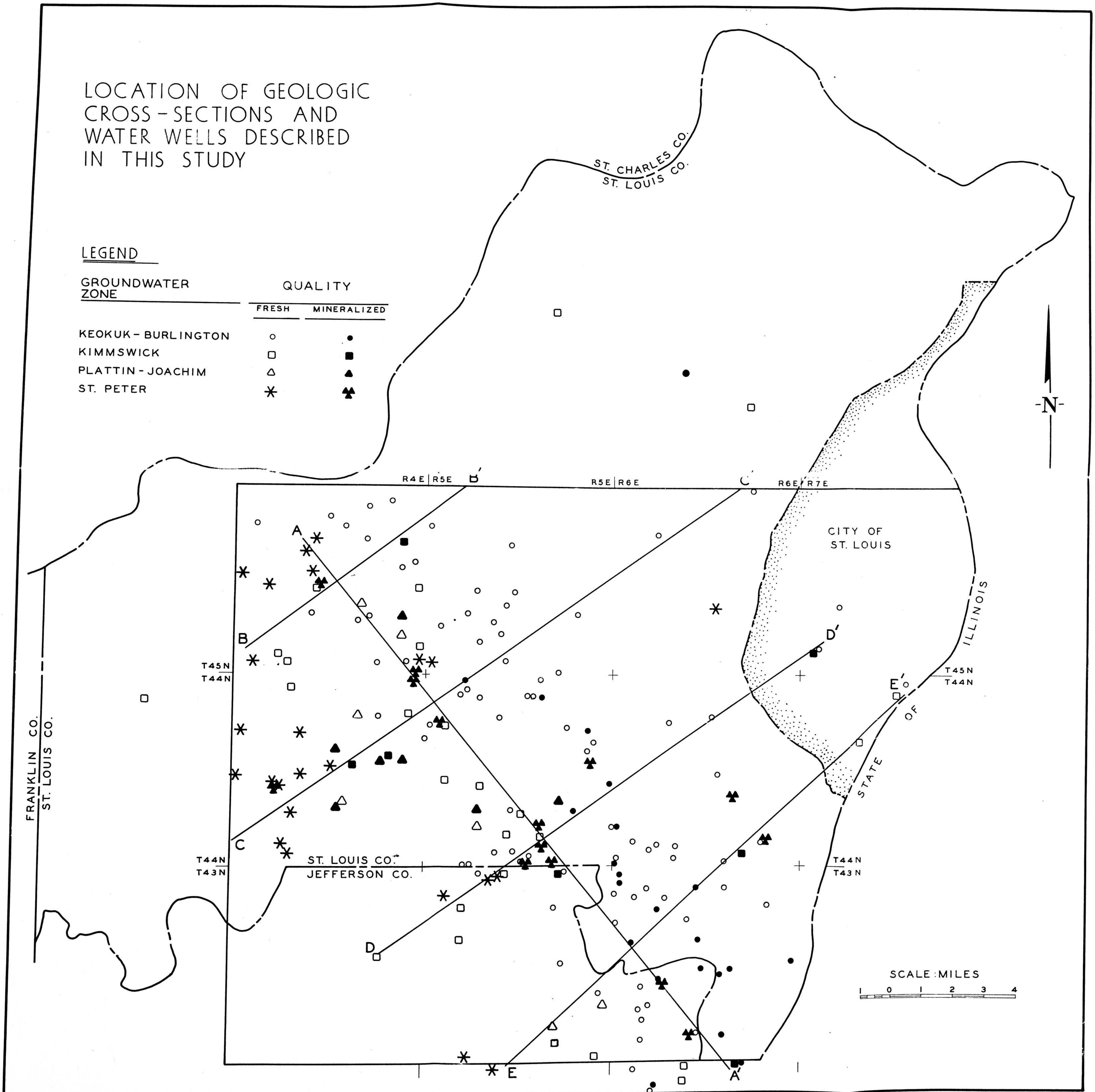

FIGURE-3 LOCATION OF WATER WELLS DESCRIBED IN THIS REPORT AND GEOLOGIC CROSS-SECTIONS WITH RESPECT TO THE ST. LOUIS-JEFFRSON COUNTIES AREA AND ADJACENT POLITICAL AREAS.

COMPOSITE STRATIGRAPHIC SECTION

FORMATION	STRATIGRAPHIC THICKNESS	DESCRIPTION
	0 to 100	interbedded shales with some limestones.
Ste. Genevieve	20 to 70	gray-white, crystalline limestone, slightly cherty and sandy in places.
St. Louis	100 to 170	lithographic to coarsely crystalline limestone, interlayered with some dolomite, shaly and sandy in places.
Spergen	130 to 180	tan, crystalline, oolitic limestone with some chert and dolomite; lenses of shaly limestone and calcareous shale.
Warsaw	60 to 100	grades from soft gray shale to cherty shale, cherty limestone, calcareous shale and shaly limestone.
Keokuk-Burlington	200 to 260	gray-white, coarsely crystalline, massive bedded very cherty limestone.
Fern Glen	15 to 45	red to gray-green limestone, little chert; shaly in places.
Chouteau	0 to 35	gray dense limestone with some chert in places.
Sulphur Springs	0 to 30	quartz sandstone to sandy and shaly limestone.
Edgewood	0 to 103	gray-white, crystalline dolomite overlain by thin layer of black to gray shale which may be a separate formation.
Maquoketa	0 to 140	chiefly gray shale; cherty in places; limy in lower portion in places; in extreme northeast of area 30 feet of limestone overlain by 110 feet of gray shale.
Kimmswick	75 to 120	cherty gray-white crystalline and massive-bedded limestone.
Decorah	25 to 35	dense gray limestone at base; shale or shaly limestone in upper part, slightly sandy in places.
Plattin	100 to 125	cherty gray to white limestone, dolomitic and slightly cherty in places.
Joachim	100 to 125	gray to tan dolomite and dolomitic limestone with a few shale seams in upper and middle parts, slightly sandy in places.
St. Peter	80 to 150	quartz sandstone.

FIGURE 4. COMPOSITE STRATIGRAPHIC SECTION SHOWING STRATIGRAPHIC THICKNESSES AND DESCRIPTIONS OF FORMATIONS

GEOLOGIC CROSS-SECTIONS

The five geologic cross-sections which follow represent lithology, structure and, in some cases, quality of water in formations in the St. Louis-Jefferson Counties area. These data were derived from water well records which are on file in the offices of the Missouri Geological Survey and Water Resources in Rolla, Missouri.

The vertical scale is greatly exaggerated with respect to the horizontal scale. Both scales are shown on each cross-section. Vertical exaggeration is 52.80.

Lithologies are represented by the same patterns by which they are represented in the generalized stratigraphic section, Figure 4. Names of formations are designated on the cross-sections.

The upper limit of each geologic cross-section represents an approximate ground surface. The upper limit was constructed by connecting elevations of tops of wells, with no attempt to portray details between wells. The wells are shown as straight vertical lines and are numbered according to township, range, section and part of section in which they are located.

Mineralized water, which was encountered in some of the water wells, is designated by the symbol (   ) at the level at which it was encountered. Whenever records show approximate mineralized water zones, brackets are used to designate limits within which mineralized water was encountered.

FIGURE 6. GEOLOGIC CROSS-SECTION A-A'

FIGURE 7. GEOLOGIC CROSS SECTION B-B'

FIGURE 8. GEOLOGIC CROSS-SECTION C-C'

FIGURE 9. GEOLOGIC CROSS-SECTION D-D'

FIGURE 10. GEOLOGIC CROSS-SECTION E-E'

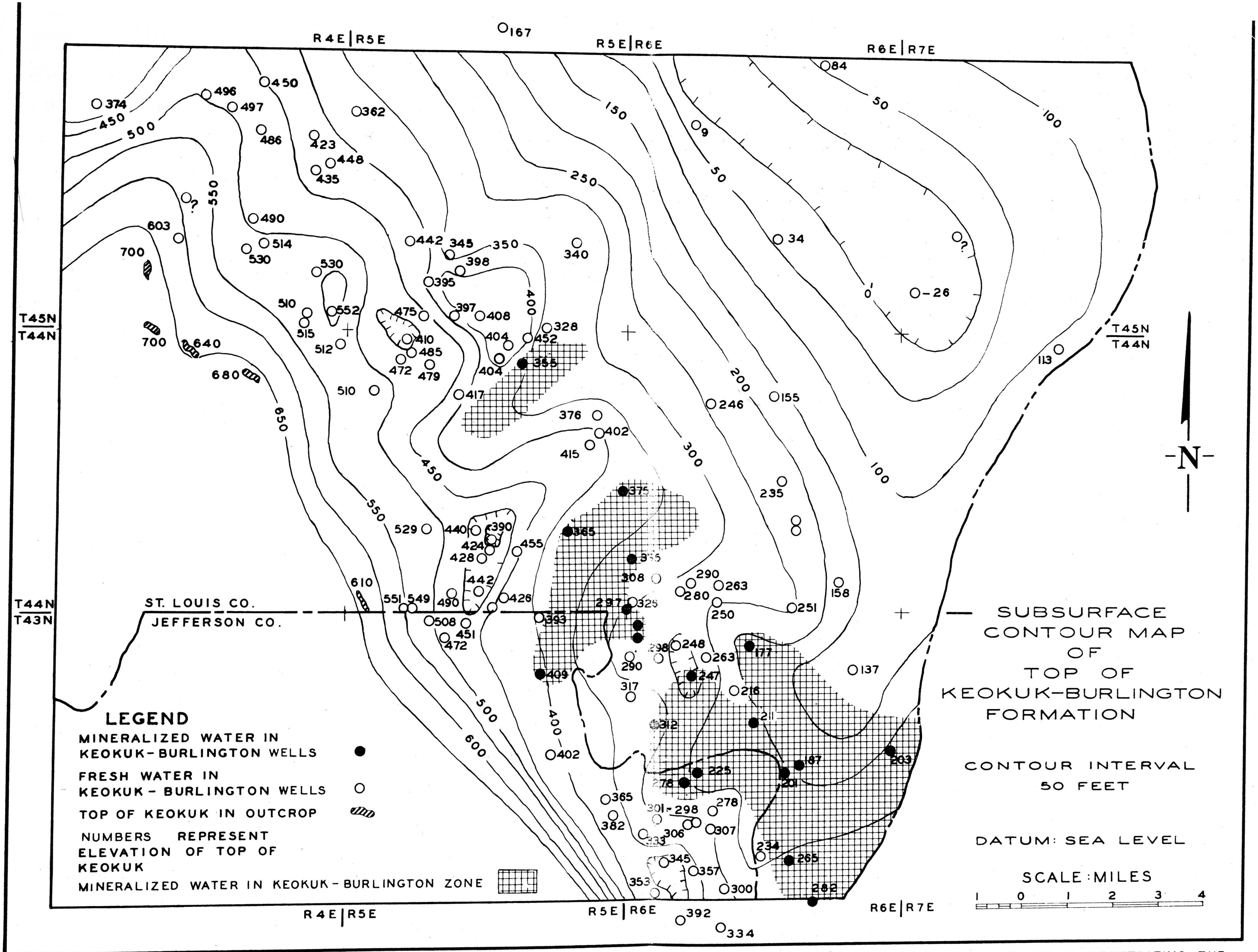

FIGURE 11. SUBSURFACE CONTOUR MAP OF THE TOP OF THE KEOKUK-BURLINGTON FORMATION; SHOWING LOCATION OF WELLS PENETRATING THE KEOKUK-BURLINGTON FORMATION AND LOCATION OF WELLS AND QUALITY OF WATER IN THE KEOKUK-BURLINGTON GROUNDWATER ZONE.

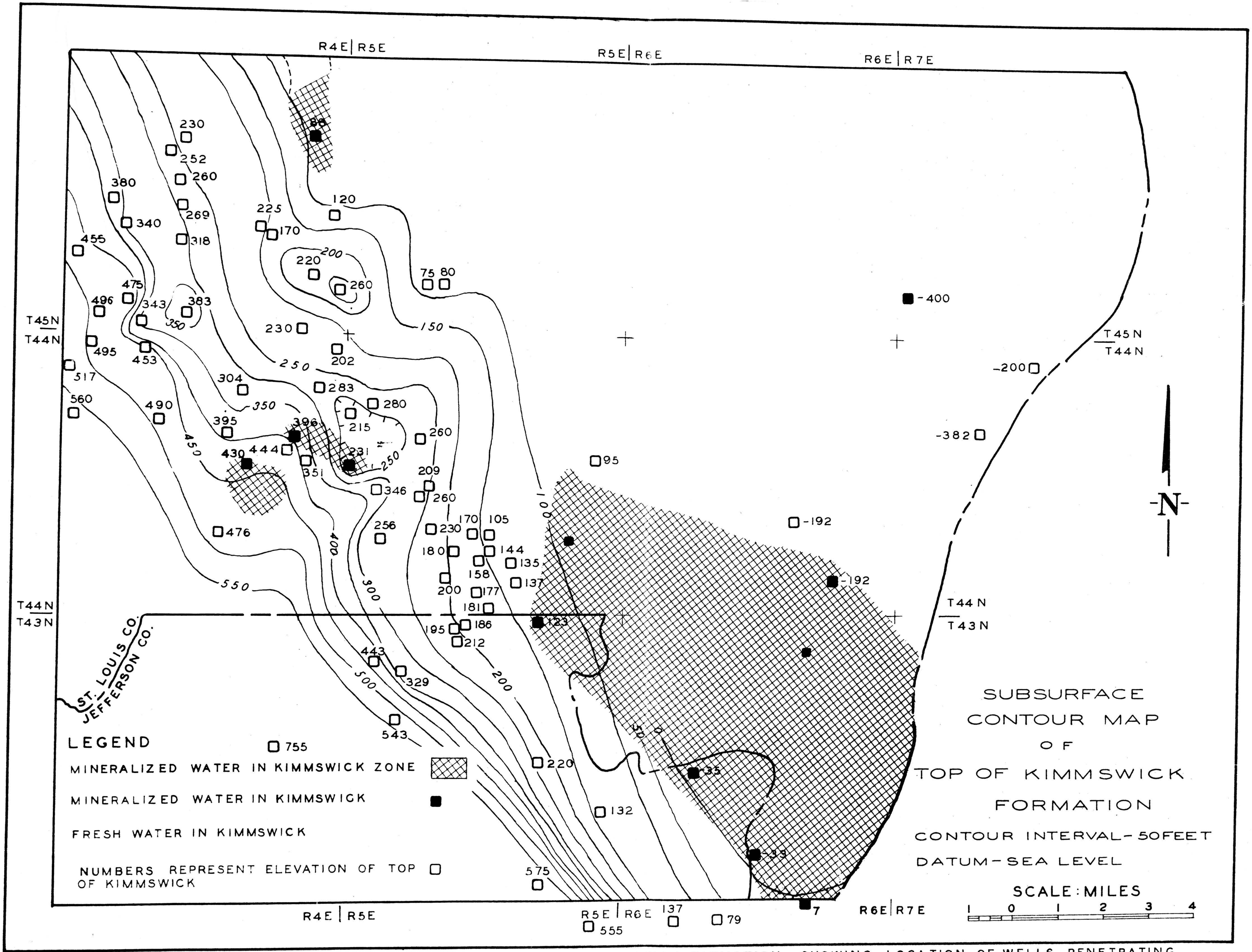

FIGURE 12. SUBSURFACE CONTOUR MAP OF THE TOP OF THE KIMMSWICK FORMATION; SHOWING LOCATION OF WELLS PENETRATING THE KIMMSWICK FORMATION AND LOCATION OF WELLS AND QUALITY OF WATER IN THE KIMMSWICK GROUNDWATER ZONE.

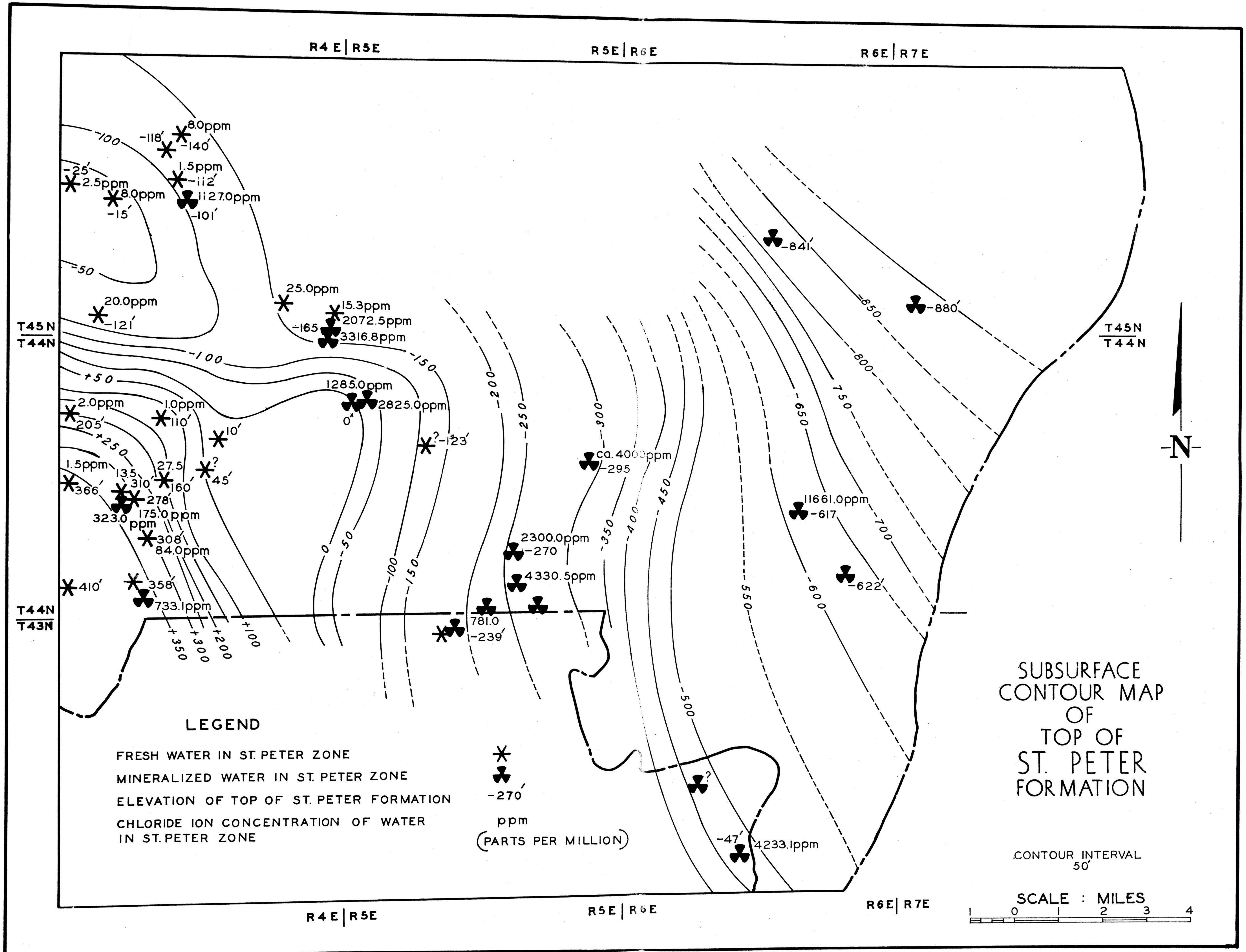

FIGURE 13 SUBSURFACE CONTOUR MAP OF THE TOP OF THE ST. PETER FORMATION; SHOWING LOCATION OF WELLS PENETRATING THE ST. PETER FORMATION AND LOCATION OF WELLS AND QUALITY OF WATER IN THE ST. PETER GROUNDWATER ZONE.

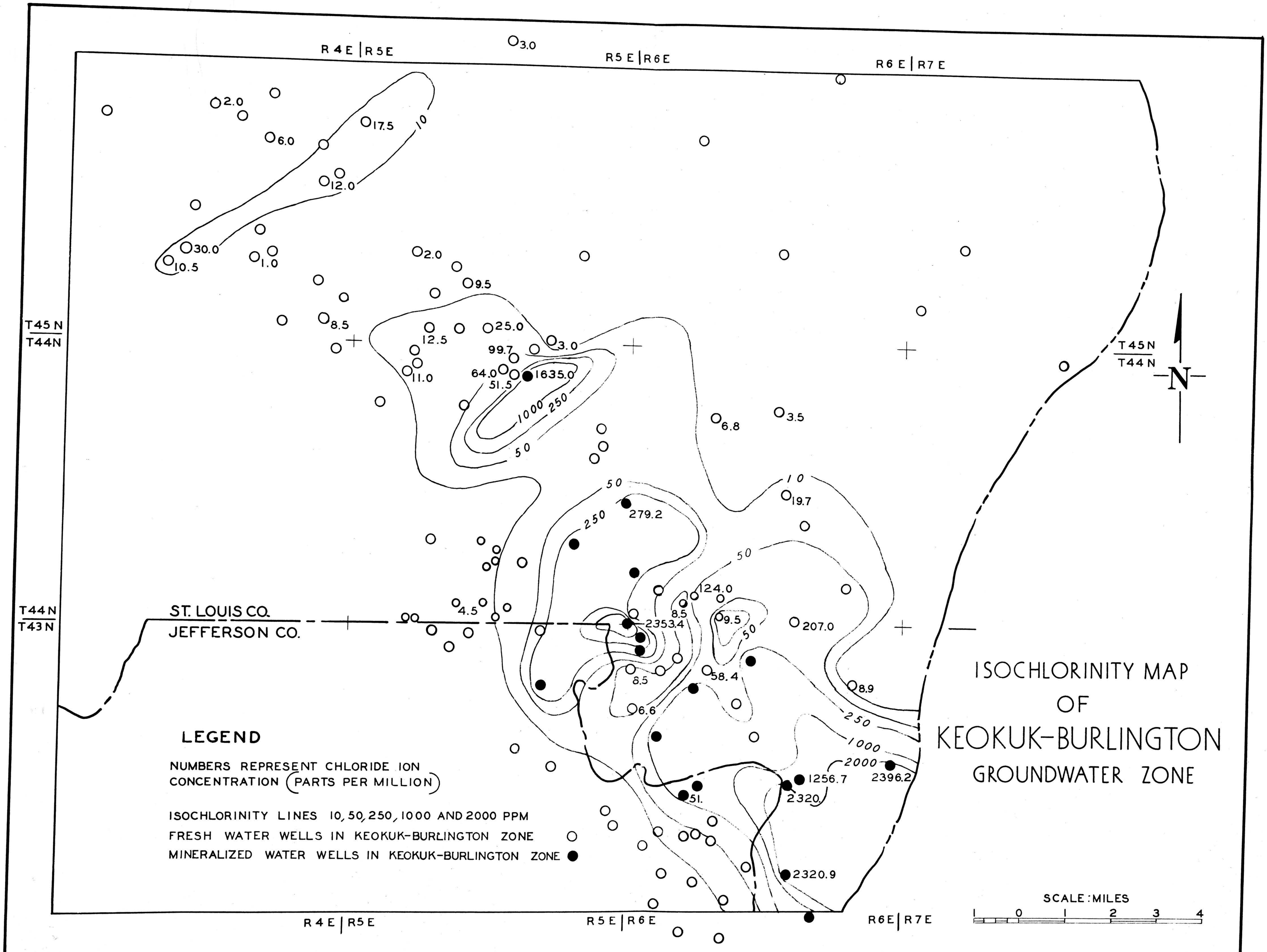

FIGURE 14 ISOCHLORINITY MAP SHOWING AREAL DISTRIBUTION OF CHLORIDE ION CONCENTRATION IN GROUND WATER IN THE KEOKUK-BURLINGTON ZONE.

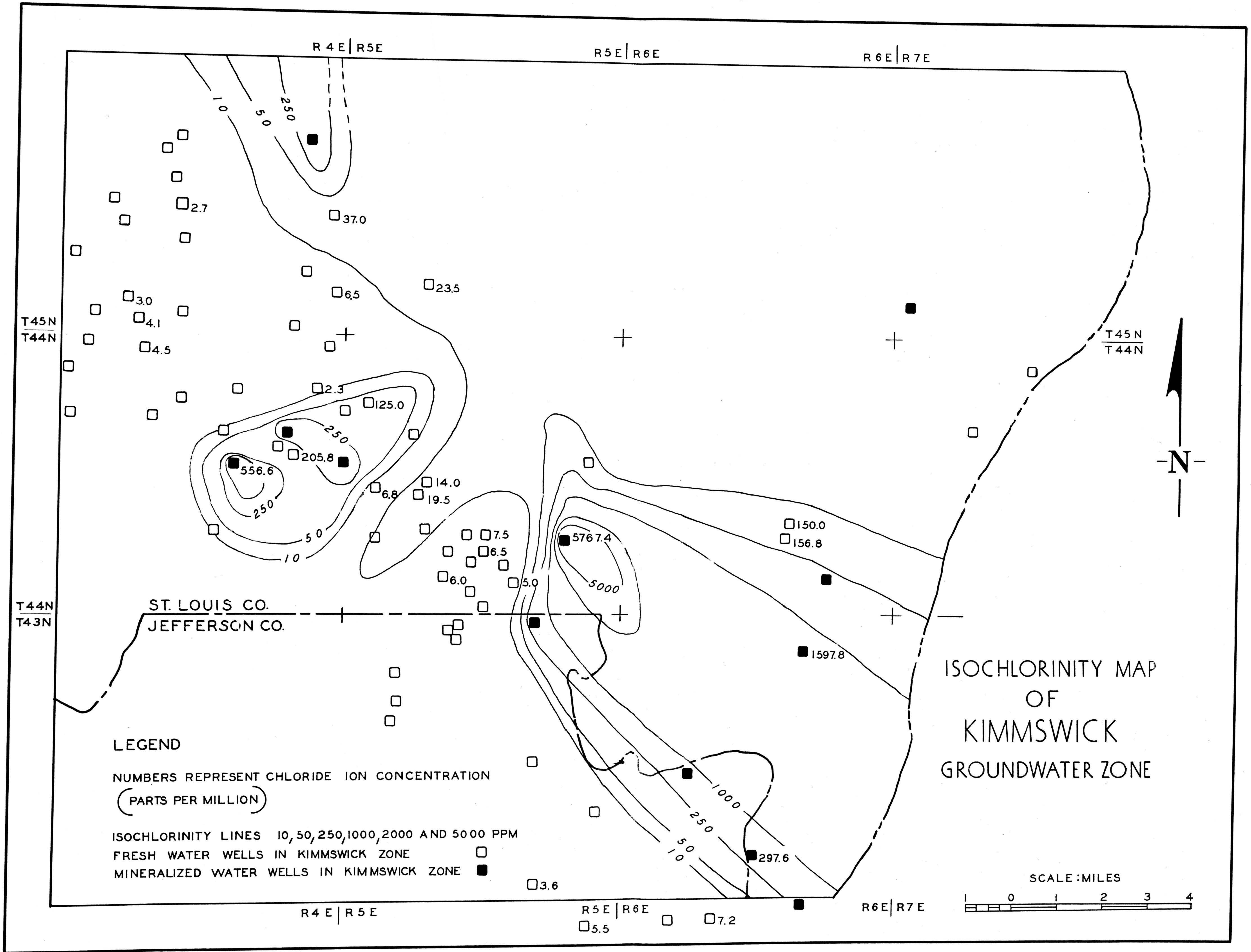

FIGURE 15 ISOCHLORINITY MAP SHOWING AREAL DISTRIBUTION OF CHLORIDE ION CONCENTRATION IN GROUND WATER IN THE KIMMSWICK ZONE.

WATER WELL DATA TABLES

Information which was procured from water well records on file in the offices of the Missouri Geological Survey and Water Resources, Rolla, is herein tabulated to concentrate data pertinent to ground water occurrence in formations in the St. Louis-Jefferson Counties area. This information is presented in five sections; each section is made up of data concerning one ground water zone. The five ground water zones are the St. Peter, Plattin-Joachim, Kimmswick, Keokuk-Burlington and St. Louis-Spergen zones.

The wells are tabulated according to the ground water zones in which they terminate. Information regarding ground water zones other than the zone in which a well terminates is included in the remarks column.

The wells are arranged according to township, range, section and part of section in which the well is located. The first two digits in the well nomenclature represent township, the digit following the first hyphen represents range and the digit or digits following the second hyphen represents section. The small letters represent the part of the section in which the well is located. The first letter designates one-quarter of a section, the second designates one-fourth of that quarter section and the third letter designates one-fourth of that fourth of a quarter section. Each set of four quarters is lettered a, b, c and d in a counterclockwise direction with 'a' in the northeast quarter. Accuracy of location of a well in a section is designated by the number of letters used; only one letter designates accuracy to nearest quarter section, etc.

Well nomenclature is shown in the following diagram:

Location of well x in section 31; 45-5-31 aad

Location of well y in section 31; 45-5-31 dda

Water sample numbers represent samples taken by the author during the summer of 1959. The following abbreviations were used on the tables:

St. Louis	St.L.	Plattin	Ptn.
Spergen	Sp.	Joachim	J.
Warsaw	W.	St. Peter	St.P.
Keokuk-Burlington	KB	Everton	Ev.
Fern Glen	Fg.	Cotter	Ctr.
Chouteau	Ch	Roubidoux	Roub.
Sulphur Springs	Ss.	Gasconade	Gasc.
Maquoketa	Mq.	Gunter	Gntr.
Kimmswick	K.	Not Known	n.k.
Decorah	Dec.	Gallons per minute	gpm

Gallons per hour	gph	Completed	Compl.
Total depth	T.D.	Quality expressed in parts per million	ppm
Static water level	S.W.L.		
Formation	Fm.	Water	wtr.

TABLE I

WELLS COMPLETED IN FORMATIONS BELOW THE ST. PETER GROUND WATER ZONE

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
43-6-33 aaa	394'	1000	1935	flowed	15 gpm	a) TDS-876.0 Cl-297.6 SO_4- 79.8 b) TDS-8769.0 Cl-4293.1 SO_4- 529.0	Ctr.	a) sample taken at drilling depth 538', Dec. b) sample taken at T.D., Ctr.
44-3-35 ccb	506'	800'	1958	75'	135 gpm	n.k.	Gasc.	"Good water".
44-4-15 aba	ca.460'	1180'	1950	n.k.	310 gpm	TDS-11472 Cl- 5415.0 SO_4- 504.9	Roub.	Water Sample No. 1. 50 gpm in St. Peter at 575'.
44-4-32 dac	453'	182'	1936	n.k.	n.k.	TDS-2364.0 Cl- 915.0 SO_4- 70.8	Ctr.	Water Sample No. 12. Present owner states that well is 382' deep and that a deep well was drilled near it and caused contamination of Cl^{-1}. Deep well was later plugged.
44-4-32 dac	439.4'	1110'	1936	14'	n.k.	TDS-1421.0 Cl- 572.7 SO_4- 58.4	Eminence	

TABLE I (continued)

WELLS COMPLETED IN FORMATIONS BELOW THE ST. PETER GROUND WATER ZONE

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
44-5-16 abd	415'	1345'	1930	flowed	216 gpm	a) TDS–11010.0 Cl– 4448.7 SO_4– 545.9 b) TDS– 9648.0 Cl– 4366.0 SO_4– 562.9	Roub.	a) at 957' depth b) at 1247' depth
44-5-17 adb	422'	1430'	1930	flowed	190 gpm	TDS– 9650.0 Cl– 4325.4 SO_4– 546.9	Gntr.	Depth 1152' Gasc. before deepening. Flowed at 630' (St. Peter) 835 gph – originally 300 gph – 6-12-36. When deepened 1152-1275', increased flow to 190 gpm.
44-5-34 adb	412'	1000'	1934	flowed	125 gpm	TDS– 9233.0 Cl– 4330.5 SO_4– 530.2	Ctr.	Sample from depth 823' (Powell).
44-6-22 ddc	458'	1214'	1924	20'	100 gpm	a) TDS– 812.0 Cl– 32.9 SO_4– 161.3 b) TDS– 3049.0 Cl– 1161.1 SO_4– 254.9 c) TDS– 884.0 Cl– 244.9 SO_4– 138.3	Ctr.	a) Sample taken at drilling depth 1075', St.P. b) Sample taken at drilling depth 1125', St.P. c) Sample taken at drilling depth 1175' Ctr.

TABLE I (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
45-7-31 bab	570'	3882'	1869	n.k.	n.k.	n.k.	Roub.	Salt wtr. at 1040' K [-470' elevation]. Salt wtr. at 1218' Ptn. [-648' elevation]. Sulphur H_2O in Roub. at elevation -1570'.
46-6-23 cca	629'	3070'	1923	n.k.	n.k.	Cl-11000.0 SO_4- 708.6		

TABLE II

WELLS COMPLETED IN ST. PETER GROUND WATER ZONE

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
43-3-2 ad	533'	231'	1941	75'	15 gpm	TDS-376 Cl- 2.5 SO_4- 4.5	St.P.	Water Sample No. 10.
43-5-4 aab	543'	840'	1931	n.k.	60 gpm	TDS-376 Cl- 6.0 SO_4-37.3	St.P.	Water Sample No. 41.
43-5-4 bad	512'	800'	1958	90'	n.k.	TDS-266 Cl- 9.5 SO_4-21.4	Ev.	Water Sample No. 13. Sealed to 350' depth or 162' elevation., K.
43-6-20 aca	ca.445'	935'	1954	n.k.	1/2 gpm	n.k.	St.P.	Hole plugged back to 110' - Abandoned. Decrease in production due to shooting—2 gpm before shooting and after plugging 1/2 gpm after shooting.
44-3-3 dac	806'	525'	1933	200'	n.k.	TDS-346.0 Cl- 3.0 SO_4- 4.5	St.P.	Water Sample No. 9.
44-4-1 ad	552'	802' [-250']	1932	50'	70 gph	a) TDS-566.0 Cl- 11.2 SO_4-175.5 b) TDS-7270.0 Cl-3316.8 SO_4- 441.5	Ptn.	a) TD = 572' Ptn. [-20'] b) TD = 802' St.P.

TABLE II (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
44-4-7 cac	745'	570'	1940	370'	10 gpm	TDS-372.0 Cl- 2.0 SO_4- 48.2	St.P.	Water Sample No. 16.
44-4-9 acd	577'	470'	1933	125'	40 gpm		St.P?	Water at 450' (St.P.?). Water fresh to taste.
44-4-9 cc	ca.600'	515'	1955	n.k.	8 gpm @ 215'? 12 gpm @ 250'?	TDS-438.0 Cl- 1.0 SO_4- 30.0	St.P.	Water Sample No. 21. Some sulphur @ 260' Ptn. Water level dropped @ 410' J.
44-4-15 ccc	495'	550'	n.k.	n.k.	n.k.		St.P.	263' of casing. Good water at 500' St.P.
44-4-19 bb	566'	255'	1940	n.k.	n.k.	TDS-302 Cl-1.5 SO_4-17.3	St.P.	Water Sample No. 17.
44-4-20 bd	ca.620'	330'	1950	225'	17 gpm	TDS-300 Cl-13.5 SO_4-28.0	St.P.	Water Sample No. 18.
44-4-20 dbb	ca.520'	ca.350'	1939	n.k.	n.k.	TDS-886 Cl-323.0 SO_4- 60.9	St.P.	Water Sample No. 19. Went through white sand.
44-4-20 dbb	518'	275'	1939	n.k.	15 gpm	TDS-794 Cl-175.0 SO_4- 64.2	St.P.	Water Sample No. 20. 35' into St.P.

TABLE II (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
44-4-21 bbd	540'	390'	1934	n.k.	n.k.	TDS-457 Cl- 8.2 SO_4-46.1	St.P.	
44-4-21 bbd	ca.510'	375	1934		n.k.	TDS-530 Cl-27.5 SO_4-18.5	St.P.	Water Sample No. 6. S.W.L. "less than 100'".
44-4-29 add	608'	386'	1936	213'	55 gpm	TDS-496 Cl-84.0 SO_4-18.5	St.P.	Water Sample No. 11. 275' casing.
44-5-7 aba	ca.540'	600'	1949	54'	n.k.	TDS-6264 Cl-2825.0 SO_4- 367.9	St.P.	Water Sample No. 30. No samples to Survey. Water salty after continuous pumping; gets fresher after setting; "fresh water hit before salty water" was hit.
44-5-7 aba	ca.540'	515'	1949	90 to 100'	10 gpm	TDS-3068 Cl-1285.0 SO_4- 158.9	St.P.	Water Sample No. 31. TD - 515' ended below St.P. More salty after great deal of use. No water hit until St.P.
44-5-13 caa	ca.575'	983'	1947	123'	92 gpm		St.P.	"Dark precipitate of some kind in bottom of swim., pool." Old record shows 4000 ppm Cl-1.

TABLE II (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
44-5-27 dbd	585'	855'	1931	n.k.	n.k.	a) TDS-684.0 Cl-252.3 SO_4- 81.7 b) Cl-2300	St.P.	a) After plugged to 610' depth. b) Before plugging. Most water @ 545-550' (Dec.-K. contact. Well plugged to 610' depth (Ptn.
44-5-34 ccc	551'	840'	1934	100'	50 gpm	TDS-2108.0 Cl- 781.0 SO_4- 231.9	St.P.	Salty only in lower 5' of drilling well into St.P. Water was fresh to taste above that. Drilled 5' intervals in St.P., then let it settle, then tasted it.
44-5-35 cd	531'	865'	1922	n.k.	n.k.			"Water is salty". Well was shot with nitro-glycerine.
44-6-35 ac	568'	1200'	1931?	80'				Salt water at 820', K. Salt water at 820', Ptn. Gas show @ 860' Oil show @ 860 to 1180'.
45-4-9 dcc	585'	805'	1932	140'	31 gpm	a) TDS-563.0 Cl- 29.2 SO_4- 11.7 b) TDS-429.0 Cl- 11.7 SO_4- 4.1		a) Bailer Sample - depth 580'. b) Bailer Sample - depth 768'. c) Water Sample No. 7: TDS-430 Cl- 8.0 SO_4- 6.6

TABLE II (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
45-4-16 baa	592'	797'	1936	150'	10 gpm	n.k.	St.P.	
45-4-16 dcb	613'	735'	1938	?	?	TDS-302 Cl-1.5 SO_4-18.9	St.P.	Water Sample No. 8. Owner states water fresh even after filling pool.
45-4-18 dd	625'	675'	1947	200'	10.5 gpm	TDS-282 Cl- 2.5 SO_4-23.0	St.P.	Water Sample No. 15.
45-4-20 bbb	635'	680'	1938	110'	15 gpm	TDS-374 Cl- 8.0 SO_4- 8.2	St.P.	Water Sample No. 14. Water level dropped from 87' to 110' when St.P. was hit.
45-4-21 acb	669'	800'	1938	175'	11½ gpm	TDS-2678 Cl-1127.0 SO_4-230.0	St.P.	Water Sample No. 4. Salt water after continuous pumping. Fresh when drilled.
45-4-31 daa	726'	670'	1942	270'	20 gpm	TDS-370 Cl-20.0 SO_4-20.2	St.P.	Water Sample No. 5. 300 gpm on 6-29-53--Paul Clark.
45-4-35 adc	617'	811'	1928-30	n.k.	10 gpm	TDS-278 Cl- 25.0 SO_4-104.7	St.P.	Water Sample No. 23. "Water becomes salty after prolonged pumping."
45-4-36 cc	620'	800'	1934	n.k.	n.k.	TDS-4599 Cl-2072.5 SO_4- 331.7	St.P.	

TABLE II (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
45-4-36 dca	573'	806'	1929	n.k.	50 gpm	TDS-542.0 Cl-15.3 SO_4-94.2		"Bottoms in lower St.P. or top of Ctr.
45-6-22 cdd	449'	1442'	1938	5'				Oil speculation hole. 127' of liner put in to case off shale. 8-10 barrels of oil. "Pretty much salt and sulfur".

TABLE III

WELLS COMPLETED IN PLATTIN-JOACHIM GROUND WATER ZONE

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
42-5-18 ac	872'	430'	1944	n.k.	360 gpm	n.k.	Ptn.	
43-5-25 abc	637'	645'	1939	175'	80 gpm	n.k.	Ptn.	
43-5-26 ccd	555'	210'	1954	flowed	25 gpm	n.k.	Ptn.	
43-6-2 cbc	583'	700'	1910	n.k.	8 gpm	TDS-3368.0 Cl-1597.8 SO_4- 172.0	Ptn.	"Lime all the way and finished in Black Rock".
44-4-10 aad	604'	551'	1941	n.k.	6 gpm	TDS-356.0 Cl- 12.2 SO_4- 23.7	Ptn.	
44-4-13 cba	506'	300'	1924	70'	300 gpday	Fresh	Ptn.	Salt water--plugged hole @ 280' (Ptn.)
44-4-14 ada	606'	460'	1940	n.k.	140 gph	TDS-6761.0 Cl-2807.6 SO_4- 345.0	J.	Slightly salty water at 220' (K.). Fresh water @ 440' "sweetened" it up (J.).
4-4-14 dcb	419'	305'	1926	n.k.	n.k.		J.	Salt water @ 285' (J.) plugged back to 225'.
44-4-15 cdd	627'	495'	1936	n.k.	n.k.	TDS-3487.0 Cl-1657.3 SO_4- 1.0	J.	Salt H_2O 400-495', Ptn.-J., plugged back to 425' Successful in plugging off salt H_2O.

TABLE III (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
44-4-20 acd	484'	150'	1937	75'	10 gpm	n.k.	J.	First water at 145' (J.).
44-4-27 bad	516'	285'	1941	n.k.	3½ gpm	TDS-1086.0 Cl- 42.6 SO_4- 240.7	J.	
44-4-27 bd	516'	253'	1941	50'	15 gpm		J.	10-20 gpm @ 220' Fresh (J.-Ptn.). Sulfur wtr. @ 253', plugged back to 235' (Ptn.).
44-5-18 ccc	496'	406'	about 1935	n.k.	n.k.		Ptn.	"Slight Mineralized".
44-5-28 adb	600'	580'	1938	n.k.	10 gpm	n.k.	Ptn.	80 gph @ 500' (K.). "Big water" below this from 500-580' (K.-Dec.-Ptn.).
44-5-29 ada	590'	570'	1940	n.k.	80 gph	TDS-2406 Cl- 64.5 SO_4-1321.0	Ptn.	Water Sample No. 36.
44-5-29 dca	636'	705'	1936	225'	5 gpm	TDS-418.0 Cl- 31.9 SO_4- 49.6	J.	No samples down to 635' depth.
44-5-33 da	582'	534'	1945	130'	4 gpm	n.k	Ptn.	Water encountered below B-K.
44-7-19 a	406'	950'	1930-31	n.k.	n.k.		Ptn.	Sulfur wtr. @ 860-885' Dec.

TABLE III (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
45-4-23 cbc	625'	585'	1948	n.k.	n.k.	n.k.	Ptn.	
45-4-23 cd	ca.580'	505'	1944	30'	7 gpm	TDS-619 Cl- 10.0 Na- 83.5 SO_4-232.09	Ptn.	Wtr. @ 200' in (BK).
45-4-25 cdb	665'	625'	1934	150'	108 gph	TDS-453.0 Cl- 9.0 SO_4- 66.5	Ptn.	
45-4-30 bdb	635'	365'	1939	180'	5 gpm	n.k.	Ptn.	Water at 335-365' (Ptn.).
45-4-33 dbb	693'	610'	1932	n.k.	n.k.	n.k.	J.	Water at: 140' - BK. 230' - BK-Fg. 540' - Ptn.
45-5-28 ddd	ca.570'	810'	1951	80'	n.k.	n.k.	J.	Water @ 200' (BK).

TABLE IV

WELLS COMPLETED IN KIMMSWICK GROUND WATER ZONE

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
42-5-1 cba	ca.735'	300'	1943	240'	10 gpm	TDS-282. Cl- 5.5 SO_4- 13.2	Dec.	Water Sample No. 64.
42-6-2 bbb	577'	605'	1928	n.k.			Ls.	67 gph @ 425' (B^K). Salt water @ 504'(Fg.). Salt water @ 605' (shale below 7' Ls. layer in Mq. Driller thought salt water was @ 570-577', or in the 7' Ls. layer in Mq.
42-6-4 cba	554'	560'	1938	80'	50 gpm	TDS-621.0 Cl- 7.2 SO_4- 47.1	K.	
43-5-2 bba	548'	525'	1933	160'			K.	8 gpm before shooting. 42 gpm after shooting. Began to show salt & H_2S, Spring 1934. Plugged back to 425' depth--no reduction in Cl-. Plugged back 15' more--still high Cl-. First plug - 113' elev., K. Second plug - 128' elev., Mq. Pump set at 255' depth; salt water not cleared out.
43-5-4 abc	611'	500'	1941	150'	5 gpm	Fresh	K.	

TABLE IV (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
43-5-35 cbc	788'	242'	1936	155'	very little		K.	Water at 242' (K.) shows 3.6 ppm Cl-.
44-4-5 add	648	308'	1939	85'	10 gpm	TDS-318. Cl- 4.5 SO_4- 43.6	Dec.	Water Sample No. 27.
44-4-12 bad	528'	300'	1932	57'	40 gph	TDS-359.0 Cl- 2.3 SO_4- 14.0	K.	No Maquoketa in stratigraphic section here.
44-4-14 daa	519'	185'	1936	n.k.	n.k.	TDS-466. Cl- 14.0 SO_4- 40.3	K.	Water Sample No. 28. 5' of shale which may be Mq.
44-4-15 cda	675'	335'	1936	260'	15 gph	TDS-3445.0 Cl-1556.6 SO_4- 258.8	Dec.	
44-5-7 aba	ca.580'	415'	1949	105'	45 gph	TDS-616 Cl-125.0 SO_4- 28.0	Dec.	Water Sample No. 29. Water at 175' BK - 45 gph. Well shot at 250' - no improvement.
44-5-19 adc	421'	215'	1925	n.k.	500 gph	TDS-311.0 Cl- 6.8 SO_4- 27.0	K.	
44-5-20 ac	515'	365'	1939	45'	1 gpm	TDS-578. Cl- 19.5 SO_4-132.9	Dec.	Water Sample No. 34.

TABLE IV (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
44-5-20 adb	474'	365'	1940	n.k.	n.k.	TDS-424 Cl-14.0 SO_4-49.4	Dec.	
44-5-26 adb	555'	492'	1935	185'	25 gpm (saline)	TDS-11927 Cl- 5767.4 SO_4- 563.1	K.	1 gpm from Burlington. 25 gpm from M_q. "Water below 300' mineralized." — Driller. Hole plugged back to 305' depth, 250' elev.
44-5-27 bc	ca.520'	510'	1959	n.k.	n.k.	TDS-364. Cl- 7.5 SO_4- 52.7		Water Sample No. 37.
44-5-27 cbb	559'	500'	1938	n.k.	5 gpm	TDS-370. Cl- 6.5 SO_4- 41.3	K.	Water Sample No. 38.
44-5-33 bbd	520'	420'	1938	60'	400 gph	TDS-418. Cl- 6.0 SO_4- 76.5	K.	Water Sample No. 35.
44-5-34 acd	427'	389'	1937	30'	8 gpm	TDS-292. Cl- 5.0 SO_4- 23.3	K.	Water Sample No. 39.
44-6-27 aba	460'	600'	1924	n.k.	n.k.	TDS-730.0	Chouteau	

TABLE IV (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
45-4-12 cdd	508'	437'	1932	n.k.	160 gph		K.	Salt water encountered at top of K. elev. 88'. Well plugged back to 383' (elev. 125') and produced fresh water.
45-4-21 ac	664'	464'	1933	Wtr. at 300'	7.5 gpm	TDS-333 Cl- 2.7 SO_4-14.0	K.	
45-4-24 adc	695'	675'	1937	200'	150 gph	TDS-456. Cl- 37.0 SO_4- 46.9	Dec.	Water Sample No. 24. Pump had to be pulled up above Mq. shale.
45-4-32 bdd	ca.750'	305'	1954	125'	3/4 gpm	TDS-346. Cl- 3.0 SO_4- 23.9	K.	Water Sample No. 26.
45-4-32 dac	738'	503'	1938	n.k.	n.k.	TDS-380.0 Cl- 4.1 SO_4- 24.7	K.	Fred Vesper - well "dosed down."
45-4-36 aab	672'	527'	1939	100'	110 gph	TDS-382. Cl- 6.5 SO_4- 42.4	Dec.	Water Sample No. 32.
45-5-29 ddc	545'	500'	1954	105'	20 gpm	TDS-434. Cl- 23.5 SO_4- 66.3	K.	Water Sample No. 33.

TABLE IV (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
46-5-2 cb	484'	915'	1924	15'	85 gpm	TDS-459.0 Cl- 6.2 SO_4- 6.4	K.	Well pumps muddy water at times.

TABLE V

WELLS COMPLETED IN KEOKUK BURLINGTON GROUND WATER ZONE

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
43-5-2 bab	543'	325'	1943	150'	12 gpm	TDS-380. Cl- 4.5 SO_4- 41.0	KB	Water Sample No. 40. Owner: "Well on property ca.800' deep, (St.P.?), little fresh water, but was salty after shooting." Near deep well which had salt water.
43-5-11 bdd	594'	310'	1940	93'	10 gph		KB	Salt water between 180 and 300' depth. (KB). Plugged back to 180' and shot.
43-5-24 dcd	580'	273'	1938	95'	1 gpm	n.k.	KB	
43-6-4 dac	497'	324'	1936	55'	33 gph		KB	Salt water @ 324' - (173' elev.) in top of (KB) plugged to 305' depth.
43-6-5 cbc	593'	390'	1946	130'	1½ gpm	n.k.	KB	"Water encountered @ 370'- (223' elev.) (KB) production 20 gpm to 370'."
43-6-5 ddc	598'	365'	1936	n.k.	7 gpm	TDS-790.0 Cl- 58.4 SO_4- 37.0	KB	Shot with 200 lbs. dynamite.
43-6-6 bbc	552'	335'	1934	n.k.	n.k.	TDS-514.0 Cl- 8.5 SO_4- 38.9	KB	

TABLE V (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
43-6-6 cab	ca.548	407.5'	1950	190'	n.k.		KB	First water - 387' in (KB). Salt water @ 407.5' in (KB).
43-6-6 bdb	536'	330'	1947	50'	½ gpm		KB	Salt water @ 325' (211' elev.) (KB). Plugged back to 325'. Driller said it freshened up.
43-6-7 cb	517'	231'	1915	55'	16 gph	TDS-457.0 Cl- 6.6 SO_4- 13.6	KB	
43-6-8 bda	582'	362'	1939	153'	24 gph		KB	Plugged back to 333' to shut off salt water. Depth to salt water not given.
43-6-9 caa	561'	400'	1936	135'	200 gph	n.k.	KB	
43-6-11 aad	492'	395'	1938	45'	5 gpm	TDS-487.0 Cl 8.9 SO_4- 36.8	KB	
43-6-13 ddc	563'	398'	1938			a) TDS-644.0 Cl-100.9 SO_4- 36.2	KB	a) After plugging. Well plugged back to 350' 1 gpm - S.W.L. 170'. Salt water at 395' (168' elev.) (KB). Water samples taken when well was 395' deep: 1) Sample at top (150') - 159.9 ppm Cl. 2) Sample at top (395')-2396.3 ppm Cl.

WELL Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
43-6-16 adc	546'	357'	1936	95'	20 gph		KB	Water at 150' (Spergen). Salt water at 340-345' (upper part of (KB).
43-6-18 acc	502'	275'	1936	275'	n.k.		KB	Water at 110' (W.). Salt water at 275'(227' elev.). 85' into (KB).
43-6-20 aca	ca.445'	220'	1954	35'	25 gph		KB	Hit sulfur water at 210' (upper part KB). Hit sulfur and salt at 220' (KB).
43-6-20 cab	493'	225'	1941	n.k.	n.k.		KB	Driller: "Slightly saline water."
43-6-22 a	432'	290'	1936	36'	n.k.	TDS-2936.0 Cl-1256.7 SO_4- 154.7	KB	Salt water at 270' (162' elev.) (KB).
43-6-22 bdc	446'	283'9"	1928	62'	7½ gpm	TDS-2936.0 Cl-1256.7 SO_4- 154.7	KB	Salt water at 270' (176' elev.) (K_B).
43-6-34 b	565'	322'	1928	163'	3-4 gpm	a) TDS-4883 Cl-2320.9 SO_4- 226.7	KB	a) Gleason's paper shows saline.
44-4-11 bc	540'	130'	1948	80'	2 gpm	TDS-386. Cl- 0.5 SO_4- 12.8	KB	Water Sample No. 58.

TABLE V (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
44-5-3 bda	554'	225'	1952	n.k.	n.k.	TDS-796. Cl- 64.0 SO_4- 46.9	KB	Water Sample No. 52.
44-5-3 cab	509'	240'	1933	n.k.	3 gpm	TDS-638.0 Cl- 99.7 SO_4- 47.7	KB	? Sample not taken.
44-5-3 dab	ca.560'	194'	1940	149'	20 gpm	TDS-3726. Cl-1635.0 SO_4- 255.1	KB	Water Sample No. 60. Owner: "Water is salty." (8-4-41) Large amount of shale in W. and Spergen. Analysis: TDS-4569 ppm. Cl-2500 ppm. Water at 180-185'(v. cherty Ls of KB) near W.-KB contact.
44-5-3 dac	480'	260'	1948	76'	10 gpm		KB	Salt water at 180' (KB). Sulfur water at 260' (KB). Bailer test at 230' - ½ gpm (KB). Bailer test at 260' - 10 gpm (KB). Analysis: Cl-3150.0 ppm.
44-5-5 cb	622'	325'	1941?	n.k.	100 gph	TDS-370. Cl- 11.0 SO_4- 66.3	KB	Water Sample No. 48. Owner: "Can be pumped dry."

TABLE V (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
44-5-24 add	650'	450'	1933	n.k.	n.k.	TDS-943.0 Cl-279.2 SO_4- 73.2	K_B	
44-5-24 cd	n.k.	300'	logged 1949	n.k.		a) TDS-10273.0 Cl- 5437.5 SO_4- 534.2	KB	a) Sample sent to Survey in clorox bottle!!! 4 gph at 190' fresh-(KB). 14 gph at 200' fresh and salt-(KB). 400 gph at 300' salt and sulfur--(KB).
44-5-29 bdb	n.k.	205'	1951	60'	2/3 gpm		Fg.	Water at 90' (K_B). Water at 205' (Fg.).
44-5-33 cbd	640'	328'	1936	170'	312 gph	TDS-345.0 Cl- 4.5 SO_4- 35.0	KB	
44-5-34 cad	481'	265'	1954	40'	30 gpm	n.k.	Fg.	Water at 85' (K_B). Water at bottom of hole (Fg.).
44-6-8 dad	606'	402'	1936	40'	3 gpm	TDS-415.0 Cl- 6.8 SO_4- 21.4 F- 3.2	KB	Water at: 120' (Spergen). 225' (Spergen Ls.-Sh.) 335' (Sh. and Ls. in W.) 400' (KB).
44-6-10 bca	480'	350'	1946	20'	2.5 gpm	TDS-362. Cl- 3.5 SO_4- 17.0	K_B	Water Sample No. 61. Well used quite a bit. 25' into KB.
44-6-15 bbb	581'	366'	1936	60'	3 gpm	n.k.	W.	

TABLE V (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
44-6-22 baa	565'	460'	1943	65'	15 gpm	TDS-363.0 Cl- 19.7 SO_4- 43.0	KB	Old well deepened from 187' to 461'. Well shot at bottom and at 145-150' with increase in flow from 5½ gpm to 15 gpm.
44-6-30 ccc	570'	390'	1938	n.k.	n.k.		KB	"Salt water."
44-6-31 cc(?)	567'	409'	1941	n.k.	½ gpm	a) TDS-5052.0 Cl-2362.7 SO_4- 262.5 b) TDS-5021.0 Cl-2353.4 SO_4- 275.5	KB	a) Sample from top. b) Sample from bottom. Salt water at 360-409' (KB). Plugged back to 360'
44-6-bdd	600'	460'	1942	n.k.	270 gph	TDS-588. Cl-124.0 SO_4- 32.5	KB	Water Sample No. 59.
44-6-32 cba	615'	465'	1944	n.k.	800 gph	TDS-274. Cl- 8.5 SO_4- 23.2	KB	Water Sample No. 54. "No salt water."
44-6-33 ccb	585'	420'	1939	125'	2 gpm	TDS-412. Cl- 9.5 SO_4- 21.5	KB	Water Sample No. 53.
44-6-34 dcc	571'	525'	1938	n.k.	n.k.	a) TDS-733.0 Cl-207.0 SO_4- 36.4 b) TDS-388.0 Cl- 21.2 SO_4- 20.6	Fg.	a) Drilling depth 415' (KB). b) Drilling depth 515' (Fg.).

TABLE V (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
45-4-10 bbb	621'	367'	1941	145'	8 gpm	TDS-346. Cl- 2.0 SO_4- 14.5	Fg.	Water Sample No. 43.
45-4-11 cca	619'	ca.360'	1941	118'	10 gpm	TDS-372. Cl- 6.0 SO_4- 19.7	Fg.	Water Sample No. 44.
45-4-13 cab	ca.605'	405'	1950	125'	5 gpm	TDS-356. Cl- 12.0 SO_4- 28.0	Fg.	Water Sample No. 45.
45-4-13 dbb	ca.628'	475'	1958	165'	2½ gpm	TDS-400. Cl- 12.0 SO_4- 41.3	Ch.	Water Sample No. 46. Water at 400' top of Fg.
45-4-26 dbc	650'	420'	1939	140'	3 gpm	TDS-380. Cl- 9.5 SO_4- 26.9	Ch.	Water Sample No. 42.
45-4-27 add	650'	350'	1941	105'	3 gpm	TDS-328. Cl- 1.0 SO_4- 10.3	Fg.	Water Sample No. 57.
45-4-28 bcc	656'	260'	1936	60'	90 gph @ 175' in (KB)	TDS-300.0 Cl- 10.5 SO_4- 11.7	Fg.	
45-4-36 cbd	562'	102'	1932	n.k.	8 gpm	TDS-598.0 Cl- 8.5 SO_4- 90.1	KB	

TABLE V (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
45-5-7 bc	527'	400'	1937	58'	7½ gpm	TDS-384. Cl- 17.5 SO_4- 14.8	Fg.	Water Sample No. 56.
45-5-28 caa	578'	425'	1939	n.k.	n.k.	TDS-412. Cl- 9.5 SO_4- 21.0	Fg.	Water Sample No. 50.
45-5-29 bab	632'	420'	1939	175'	7 gpm	TDS-358. Cl- 2.0 SO_4- 19.9	Fg.	Water Sample No. 49.
45-5-30 dbd	530'	150'	1938	30'	n.k.	TDS-410. Cl- 12.5 SO_4- 26.1	KB	Water Sample No. 47.
45-5-32 bdd	553'	430'	1936	n.k.	n.k.	TDS-483.0 Cl- 13.1 SO_4- 57.2	Mq.	
45-5-33 dad	628'	460'	1938	n.k.	n.k.	TDS-434. Cl- 25.0 SO_4- 38.4	KB	Water Sample No. 51.
45-5-35 cdc	623'	385'	1937	60' at 310'	7-8 gpm	TDS-364. Cl- 3.0 SO_4- 34.3	KB	Water Sample No. 65.
45-7-20 dca	?	550'	n.k.	n.k.	n.k.			On log: "Undoubtedly bottoms in KB--gives fresh water." Driller promised Huffman the log.--Not on strip log.

TABLE V (continued)

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
46-5-34 baa	602'	680'	1938	100'	15 gpm	TDS-410. Cl- 3.0 SO_4- 25.5	Fg.	Water Sample No. 55. Water at 200' St.L.
46-6-12-cbb	513'	805'	1936	75'	17 gpm	TDS-2450.0 Cl- 918.6 SO_4- 329.8	KB	
46-6-16 cb	644'	584'	1933	n.k.		TDS-867.0 Cl- 31.7 SO_4-175.9	KB	At T.D. 535', well made 45 gph (fresh) from horizon 350-375' depth, very cherty Ls. in Spergen. Struck water at 580' (64' elev.) (KB), yield 5 gpm, "slightly salty?"
46-6-35 dcc	549' (South well)	825' (South well)	1937 (South well)	n.k.	50 gpm (South well)	a) TDS-552.0 Cl- 89.08 SO_4- 47.72		a) South well. Sample taken with bailer at 765' when well was 825' deep.
	552' (North well)	790' (North well)	1937 (North well)	n.k.	53 gpm (North well)	b) TDS-5393.0 Cl-2673.0 SO_4- 267.3		b) North well.

TABLE VI

WELLS COMPLETED IN ST. LOUIS-SPERGEN GROUND WATER ZONE

Well Number	Surface Elev.	Total Depth	Date Drilled	S.W.L.	Water Production	Quality of Water	Fm. Compl. in	Remarks
43-6-3 dbb	578'	330'	1946	75'	1.5 gpm	n.k.	W.	
44-5-2 bbb	633'	230'	1942	85'	480 gph	n.k.	W.	
44-6-17 cbb	605'	202'	1936	60'	130 gph	n.k.	Spergen	Water at 190-200' (Spergen).
44-6-18 ab	628'	435'	1935	170'	6 1/3 gpm 380 gph	TDS-396.0 Cl- 3.2 SO_4- 22.2	?	May have been completed in (KB).
44-6-18 aba	614'	150'	1936	60'	1 gpm	n.k.	Spergen	Water at 110' (Spergen).
44-6-20 ada	532'	162'	1940	23'	1 gpm	n.k.	W.	
44-6-20 dad	554'	218'	1940	45'	140 gph	n.k.	W.	
44-6-25 cdd	504'	324'	1938	290'	3 gpm	n.k.	Spergen	
44-6-26 bcc (?)	532'	195'	1947	29'		n.k.	Spergen	Could not bail dry. Water at 183' (Spergen). bcc(?) does not check with elev.
44-6-27 add	580'	188'	n.k.	50'	4.5 gpm	n.k.	Spergen	
44-6-28 aad	580'	272'	1939	100'	1 gpm	n.k.	W.	
44-6-28 ad	584'	105'	1940	35'	5 gpm	n.k.	Spergen	
44-6-29 ccb	613'	127'	1937	40'	150 gph	n.k.	Spergen	Water at 125' (Spergen).
44-6-35 dca	595'	324'	1940	60'	5 gpm	n.k.	W.	

TABLE VII

ADDITIONAL WELLS USED IN THIS STUDY

Well Number	Total Depth	Water Production	Fm. Compl. in	Well Number	Total Depth	Water Production	Fm. Compl. in
42-6-6 aab	350'	66 gph	BK	43-6-6 ddc	371'	2 gpm	KB
43-3-3 ?	255'	10 gpm	St.P.	43-6-24 cab	605'	n.k.	Fg.
43-3-3 ?	333'	15 gpm	St.P.	43-6-29 acc	302'	3.5 gpm	KB
43-3-16 add	309'	6 gpm	Ctr.	43-6-29 cac	315'	68 gph	KB
43-3-19 abb	327'	9 gpm	?	43-6-29 cc	274'	5 gpm	KB
43-4-14 dac	627'	20 gpm	Ev.	43-6-29 daa	212'	70 gph	KB
43-5-5 aad	350'	225 gph 3.7 gpm	Fg.	43-6-30 aab	292'	n.k.	KB
43-5-6 acc	200'	300 gph	Fg.	43-6-30 dbb	270'	10 gpm	KB
43-5-6 bdc	252'	100 gph	Mq.	43-6-31 add	257'	1 gpm	KB
43-5-8 bba	290'	15 gpm	K.	43-6-32 cc	250'	75 gph	KB
43-5-8 cab	240'	10 gpm	K.	43-6-33 cca	295'	15 gpm	KB
43-5-14 ccd	265'	4½ gpm	KB	44-4-2 ca	190'	n.k.	KB
43-5-17 bbb	220'	20 gph	K.	44-4-3 db	200'	n.k.	KB
43-5-23 b	765'	n.k.	J.	44-5-5 bda	154'	ca.3 gpm	KB
43-5-32 cc	415'	n.k.	St.P.	44-4-6 abc	476'	850 gph	J.
43-6-6 ccc	345'	20 gpm	KB	44-4-6 cb	525'	600 gph	J.

TABLE VII (continued)

Well Number	Total Depth	Water Production	Fm. Compl. in
44-4-15 bdb	280'	135 gph	Ptn.
44-4-25 cca	150'	4 gpm	K.
44-4-31 bcb	178'	25 gpm	Powell
44-4-32 acb	1043'	n.k.	K.
44-5-3 aa	300'	20 gpm	KB
44-5-4 cdd	100'	20 gpm	KB
44-5-5 bbd	302'	270 gph	KB
44-5-5 bdd	187'	½ gpm	KB
44-5-5 ddb	350'	n.k.	Mq.
44-5-7 ac	237'	240 gph	KB
44-5-7 cb	330'	75 gph	K.
44-5-7 ddd	305'	2.5 gpm	KB
44-5-9 bdd	250'	48 gph	KB
44-5-12 cd	600'	5 gpm	Mq.
44-5-13 bad	315'	1½ gpm	KB
44-5-14 Center	160'	n.k.	KB
44-5-21 bbb	245'	1½ gpm	Fg.
44-5-28 caa	480'	10 gpm	Ptn.
44-5-28 dad	390' (Well #3) 238' (Well #4)	500 gph (Well #3) 175 gph (Well #4)	K.
44-5-29 aca	165'	3 gpm	KB
44-5-30 adc	425'	1 gpm	Ptn.
44-5-32 ccd	370'	8 1/3 gpm	Mq.
44-5-32 cd	327'	80 gph	Fg.
44-5-35 bbd	200'	70 gph @ 100' 110 gph @ 155' 140 gph @ 175'	KB
44-6-15 bbb	385'	n.k.	W.
44-6-15 bcc ?	280'	n.k.	W.
44-6-30 caa	253'	200 gph	W.
44-6-31 acd	402'	45 gph	KB
44-6-31 ccb	305'	n.k.	KB
44-6-33 bcc	386'	8 gpm	KB
44-6-33 ccc	405'	85 gph	KB
44-7-3 cc	901'	n.k.	K.

TABLE VII (continued)

Well Number	Total Depth	Water Production	Fm. Compl. in	Well Number	Total Depth	Water Production	Fm. Compl. in
45-4-2 cad	415'	n.k.	Fg.	45-4-35 dc	300'	n.k.	KB
45-4-5 cac	35'	n.k.	Alluvium	45-5-26 aaa	443'	7 gpm	Fg.
45-4-7 acd	440'	4 gpm	Fg.	45-5-28 bcd	405'	3½ gpm	KB
45-4-10 acc	406'	20 gpm	Fg.	45-5-28 caa	315'	7 gpm	KB
45-4-13 dab	412'	200 gph	Fg.	45-5-28 cad	387'	8 gpm	KB
45-4-25 ba	730'	70-80 gph	J.	45-5-33 cac	582'	15 gpm	KB
45-4-26 bbd	420'	2 gpm	Fg.	45-6-8 ca	649'	8 gpm	KB
45-4-26 bcc	364'	2 gpm	Fg.				