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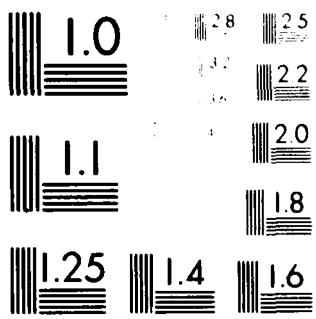

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HYDROLOGY AND MODEL STUDY OF THE PROPOSED PROSPERITY RESERVOIR, CENTER CREEK BASIN, SOUTHWESTERN MISSOURI.

(10)

BY E. J. HARVEY [redacted] L. F. EMMETT

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CONVERSION FACTORS

For use of those readers who may prefer to use metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below.

Multiply inch-pound units	By	To obtain SI units
foot (ft)	3.048×10^{-1}	meter (m)
square foot per day (ft^2/s)	9.290×10^{-2}	square meter per day (m^2d)
foot per second (ft/s)	3.048×10^{-1}	meter per second (m/s)
cubic foot per second (ft^3/s)	2.832×10^{-2}	cubic meter per second (m^3/s)
gallon per minute (gal/min)	5.451	cubic meter per day (m^3/d)
inch (in.)	2.540×10	millimeter (mm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

Hydrology and Model Study of the Proposed Prosperity Reservoir, Center Creek Basin, Southwestern Missouri

By E. J. Harvey and L. F. Emmett

ABSTRACT

A dam and reservoir have been proposed for construction on Center Creek, Jasper County, in southwestern Missouri. Ground-water levels in the hills adjacent to the reservoir will rise when the impoundment is completed. One of the problems is that the proposed site of Prosperity Reservoir is a few miles upstream from the lead-zinc mining area known as the Oronogo-Duenweg belt. In this belt transmissivities are variable but appear to be higher than they are in the immediate area of the reservoir.

Grove Creek lies down-gradient from the reservoir area and separates it from the mining belt. A model study indicates that inflow from the proposed reservoir to the water table could cause water level rises varying from about 20 feet near the reservoir to 0.5 to 1.0 foot in the southern part of Grove Creek drainage basin. These rises will cause significant changes to the natural ground-water flow system. Increased ground-water elevations in the reservoir area could result in increased ground-water gradients and discharge to Grove and Center Creeks. The increase in ground-water discharge to Grove Creek, and in turn Center Creek, will have the beneficial effect of diluting mine-water discharge from the Oronogo-Duenweg belt during periods of low flow.

However, if Grove Creek does not act as an effective drain and if conduits extend beneath Grove Creek to transfer the increased water available to the Oronogo-Duenweg belt, the flow regimen could change in the mining belt west of Grove Creek increasing mine-water discharge to Center Creek downstream from the reservoir.

Bedrock in the area is Mississippian limestone, the deeply solutioned formation that contained the ore deposits. The limestone in the mining

district was greatly altered by solution prior to ore deposition while the limestone in the area of the reservoir was altered less. The extent of the alteration is related to the aquifer characteristics in that high and low values of transmissivity and storage coefficient correspond to greatly altered brecciated rocks in the mining district and less altered, less brecciated rocks in the reservoir area, respectively.

The authors suggest that an ancestral east-flowing White River drained the area about Joplin in Late Mississippian time. This is based on the configuration of the contact between Meramecian and Osagean rocks of Mississippian age. A high topographic area existed in the region about Joplin in which the water table stood 200 feet below the land surface when sinkholes and caverns of that depth were formed. The large number of Pennsylvanian-filled sinkholes in the Joplin area and the smaller number to the east suggest a higher land surface to the west than that to the east. The distribution of paleokarst sinkholes supports the conclusion based on the configuration of the Meramecian-Osagean contact.

INTRODUCTION

The work was undertaken at the request of the Corps of Engineers to describe the hydrology of the Mississippian aquifer, to assess the possible effect of a change in the ground-water regimen on the old Oronogo-Duenweg lead-zinc mining belt downstream from the proposed site of the Prosperity Reservoir, and to determine whether Grove Creek is an effective drain for the area east of the creek.

This report includes a general description of the geology and hydrology of the Mississippian limestone aquifer in the Center Creek basin and contiguous areas, and a detailed description of those features in the area of the proposed Prosperity Reservoir near Joplin, Mo. Figure 1 shows the Center Creek basin, the location of the proposed reservoir, Center Creek and adjacent basins and Oronogo and Duenweg, the principal center of mining in Missouri. The Joplin area as it is used in this report includes the area of Center and Turkey Creek basins from the Kansas line to the proposed reservoir area. The report includes results of a model study that shows rises in ground-water levels in the hills adjacent to the reservoir.

The authors found the residents and landowners very helpful and friendly in supplying information about their water wells and their water supplies, and in allowing water-level measurements to be made.

EARLIER WORK

Much has been written about the lead-zinc deposits, their origin, and history of mining. It was not possible in the short time available for this

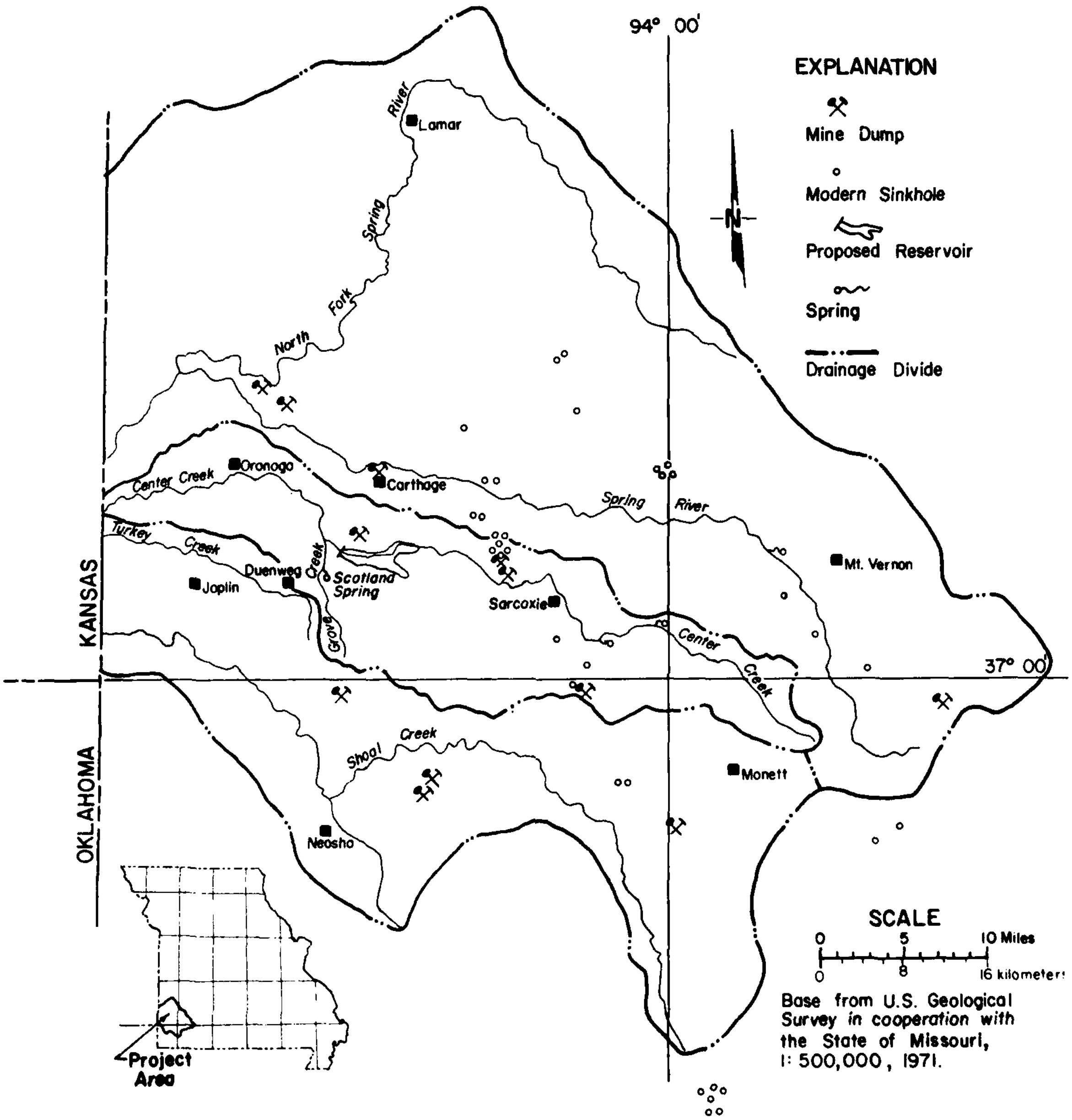


Figure 1.--Map of Center Creek basin showing location of proposed reservoir, mine dumps, and sinkholes.

study to review the literature adequately for historical information on the changes in ground-water and surface-water regimes in the area through a hundred years. A study (Feder and others, 1969) was made in 1963-65 of the hydrology of the Oronogo-Duenweg mining belt and the areas adjacent to it on the west. Later, a second study was made (Barks, 1977) to determine the nature of additions of metals from the Oronogo-Duenweg belt to Center Creek.

The most comprehensive report available describing the Mississippian aquifer is the Joplin District Folio by Smith and Siebenthal (1907). Although their purpose was to describe the geologic history of the preparation of the rocks for mineralization and the occurrence of minerals in the deposits, the information and interpretation presented aid our present understanding of the hydrology. Brockie and others (1968, p. 400-430) have an extensive bibliography in their paper on the area.

HYDROGEOLOGIC SETTING

The geologic section for the area is given in table 1, the same as that used in Feder and others (1969), and Barks (1977). Most of the Mississippian section is limestone while the Cambrian-Ordovician section is dolomite. In Feder's report (1969, p. 7), he refers to the Mississippian limestone section as the shallow aquifer and the Cambrian-Ordovician dolomite section as the deep aquifer. In this report the shallow aquifer is called the Mississippian limestone. The emphasis in this report is on this aquifer.

Basically, the rock section consists of small areas of Pennsylvanian sandstone and shale in outcrop surrounded by Mississippian limestone that is exposed over the remainder of the area. Below the Pennsylvanian the section consists of an average of 300 ft of Mississippian limestone separated from the underlying 1,400-ft thick section of Cambrian-Ordovician dolomite and sandstone by the 20- to 30-ft thick Lower Mississippian Kinderhookina Series which contains shale beds of the Northview Formation, the principal confining bed between the Mississippian limestone and the Cotter Dolomite. Underlying the Cambrian-Ordovician section are Precambrian igneous and metamorphic rocks.

Figure 2 shows the areal geology of the region. The main area of Pennsylvanian rocks is northwest of the project area. Outliers of Pennsylvanian rocks are scattered over the entire area becoming less frequent to the southeast. Many small deposits of shale and sandstone occur in sinkholes and cavern fillings in much of Jasper and Lawrence Counties, evidence of the development of an ancient karst topography.

Table 1.--Generalized section of geologic formations in the Joplin area, Missouri (from Feder and others, 1969)

[The stratigraphic nomenclature generally follows that of the U.S. Geological Survey and the Missouri Geological Survey; however, there are some variations from the current usage of the U.S. Geological Survey.]

SYSTEM	SERIES	GROUP	Stratigraphic Unit	Thickness Feet	Physical Character	Depth to Top of Formation, Feet	Aquifer	Water-bearing Character
QUATERNARY	Holocene		Alluvium	0-30	Unconsolidated silt, sand, and gravel	Outcrop		Yields small supplies for domestic and stock use
PENNSYLVANIAN	Desmoinesian	Cherokee		0-100+	Shales and sandstones with beds of coal	Outcrop		Yields little water to shallow dug wells
MISSISSIPPIAN	Chesterian		Carterville Formation	0-100	Limestones, shales, and siltstones; generally found filling depressions in underlying rocks	Outcrop to 50		Does not yield water to wells
	Meramecian		Warsaw Formation	80-150	Dense limestone with some chert	Outcrop to 150		Yields little water except in isolated solution channels
	Osagean		Burlington and Keokuk Limestones	50-150	Dense cherty limestone, sometimes mineralized with zinc and lead	Outcrop to 300	Shallow Aquifer	Yields little water where massive, but can yield over 100 gpm in brecciated areas. Solution channels may yield large supplies
			Elsey Formation	30±	Fine-grained, very cherty limestone; sometimes all chert and mineralized with zinc and lead	Outcrop to 450		Generally yields adequate supply for domestic and stock use, rarely over 50 gpm. Supplies many springs
			Reeds Spring Formation	5-100	Dark, very cherty, argillaceous limestone; sometimes mineralized with zinc and lead	Outcrop to 500		Generally yields adequate domestic or stock supply. Supplies many springs
			Pierson Formation	10-30	Cherty dolomitic limestone in upper portion; silty dolomite in lower portion	100-600		Yields very small quantities of water
	Kinderhookian		Northview Formation	0-15	Shale or shaly limestone; absent in parts of the area	125-625		Confining bed
			Compton Formation	0-20	Shaly limestone	125-625		Generally does not yield water
			Bachelor Formation	0-0.5	Sandstone	125-[illegible]		Does not yield water to wells
DEVONIAN			Chattanooga Shale	0-10	Fissile, black, carbonaceous shale; absent throughout most of area	150-500		Confining bed
ORDOVICIAN	Lower		Cotter Dolomite	200±	Cherty dolomite; some sandstone beds	150-650	Deep Aquifer	Yields small quantities of water
			Jefferson City Dolomite	200±	Cherty dolomite	350-850		Yields small quantities of water
			Roubidoux Formation	175±	Cherty dolomite and several sandstone beds	550-1,000		Generally yields good supply of water; most supplies between 50-150 gpm
			Gasconade Dolomite	300±	Cherty limestone and dolomite; sandstone bed at bottom of formation	700-1,150		Yields small supplies of water
CAMBRIAN	Upper		Eminence and Potosi Dolomites	200±	Dolomite with drusy chert in lower 50 feet	1,000-1,450		Generally yields good supply of water, especially from lower portion; between 50-400 gpm
			Derby-Doerun, Davis and Bonneterre Formations undifferentiated	150±	Silty dolomites; some siltstones and shales	1,200-1,650		Yields small quantities of water
			Lamotte Sandstone	0-150	Quartzose sandstone	1,350-1,750		Yields very considerably. Formation may be absent over Precambrian highs
PRECAMBRIAN					Granites and rhyolites	1,350-1,850		Generally does not yield water

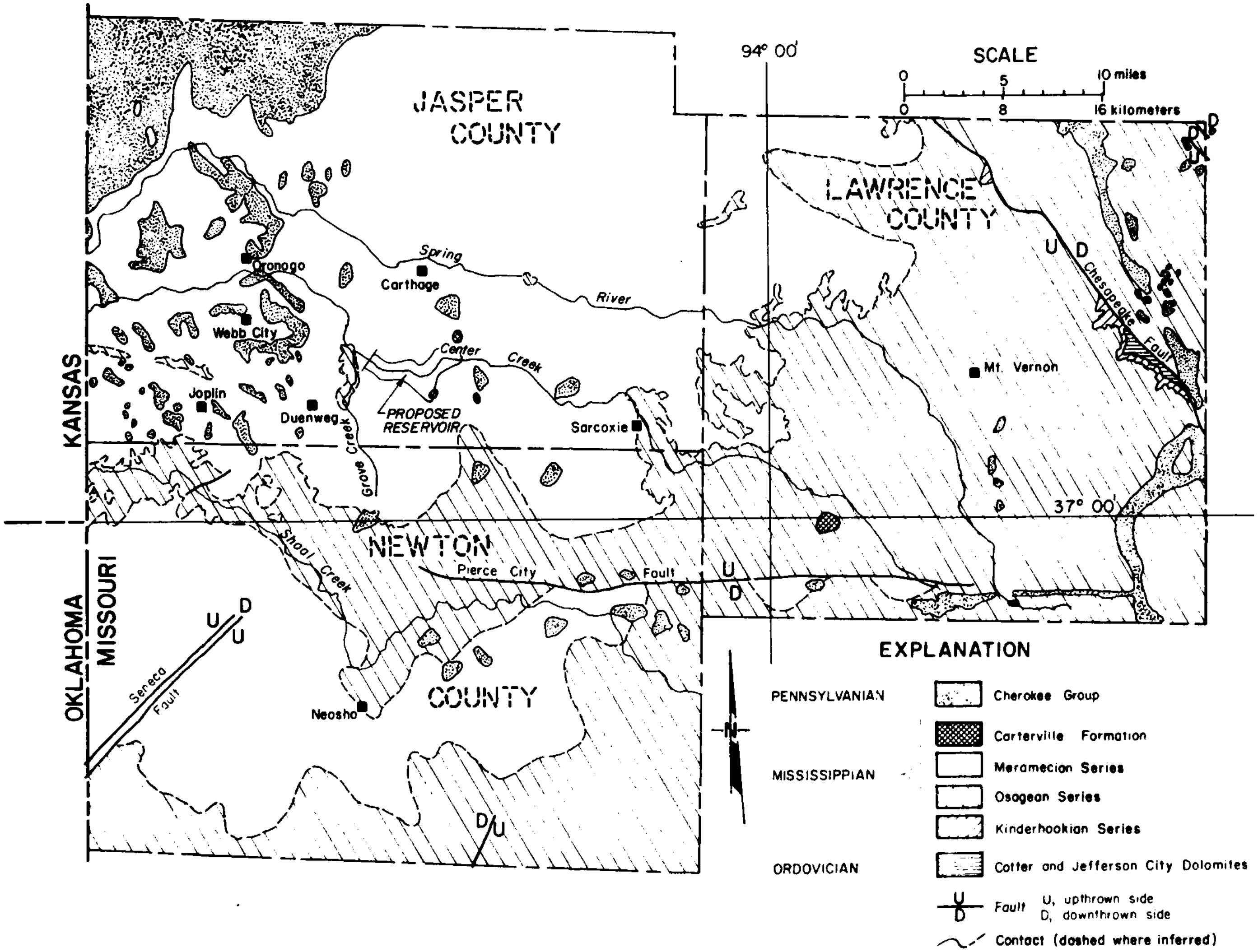


Figure 2. -- Geologic map of Jasper, Lawrence, and Newton Counties, Missouri. Geology from State geologic map of Missouri (Anderson, 1979)

While figure 2 shows the areal distribution of the outcropping geologic formations, the cross section (figure 3) shows the general attitude of the principal units involved in the discussion, and figure 4 shows in greater detail the attitude and thicknesses of the Mississippian formations. The average dip of the rocks is 4° northwest. The cross sections also show the re'ation of the potentiometric surfaces of the Mississippian limestone and the Cambrian-Ordovician dolomite section.

In table 1 the Elsey Formation is listed and replaces the Grand Falls Formation, the name used in figure 4. Grand Falls Formation and Elsey Formation are not exact equivalents (Robertson, 1968, p. 7). Although the name Grand Falls has been retired from common usage in favor of Elsey, logs used in the cross section show Grand Falls because these wells were logged many years ago on the basis of studies of insoluble residue. Rather than relog the wells, it was expedient to use the old terminology in the cross sections for this report. Similarly, the name Fern Glen Limestone appears in many of the logs and the cross sections (fig. 4) and is the approximate equivalent of the Pierson Formation given in table 1 (Howe, 1961, p. 59-63).

Devonian rocks represented in southwest Missouri by the Chattanooga Shale are not recognized in logs in the project area. Where recognized to the south, the Chattanooga is generally 5-10 ft thick.

The Cambrian-Ordovician section of dolomite and sandstone is present everywhere in the subsurface, is about 1,400 ft thick, and is the source of water for many of the towns, rural households, and industries. The main part of the section is dolomite, sandstone is minor, and the only shale (Davis Formation) of any consequence as a confining bed is near the bottom of the section. Most large-capacity wells do not penetrate the Davis Formation. Most domestic wells completed in the Cambrian-Ordovician section stop in the upper part of the section 100 or so feet below the Mississippian, whereas industrial and municipal wells, which generally have higher yields, penetrate all or most of the section.

Dissolution of limestone has greatly influenced the geomorphic history and hydrology of the area over a long period extending back to the time when the limestone was deposited. It is evident in the distribution of Pennsylvanian rock in the Mississippian outcrop area near Joplin where sinkholes were formed principally at the close of deposition of the limestone. The sinkholes were filled by sandstone, shale, and coal of Pennsylvanian age.

Across Jasper County east into Lawrence County, sinkholes filled with Pennsylvanian rock occur, but are few in comparison to the many in the Joplin area. They are shown in the Joplin District Folio by Smith and Siebenthal (1907), on the geologic maps showing mining and mineralized areas (Missouri Geological Survey and Water Resources, 1922), and on the Lawrence County geologic map by Rutledge (1929). Their abundance in the Joplin area and their relative scarcity east of Grove Creek attest to

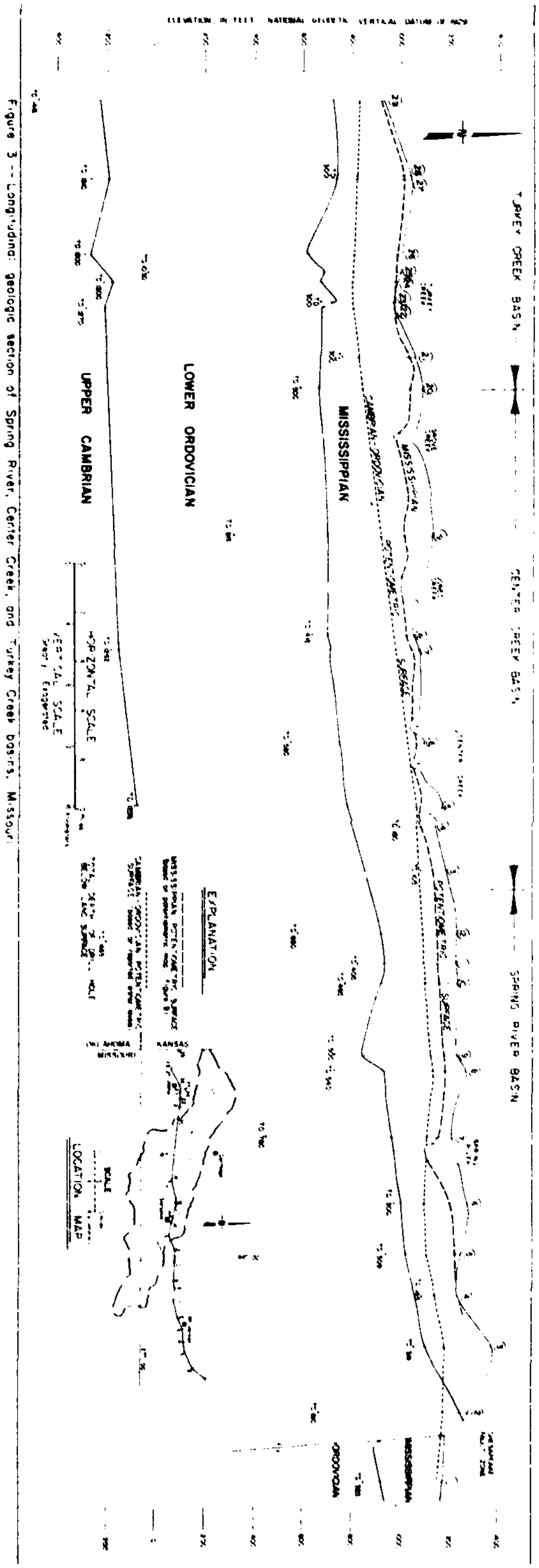


Figure 3 -- Longitudinal geologic section of Spring River, Center Creek, and Turkey Creek basins, Missouri

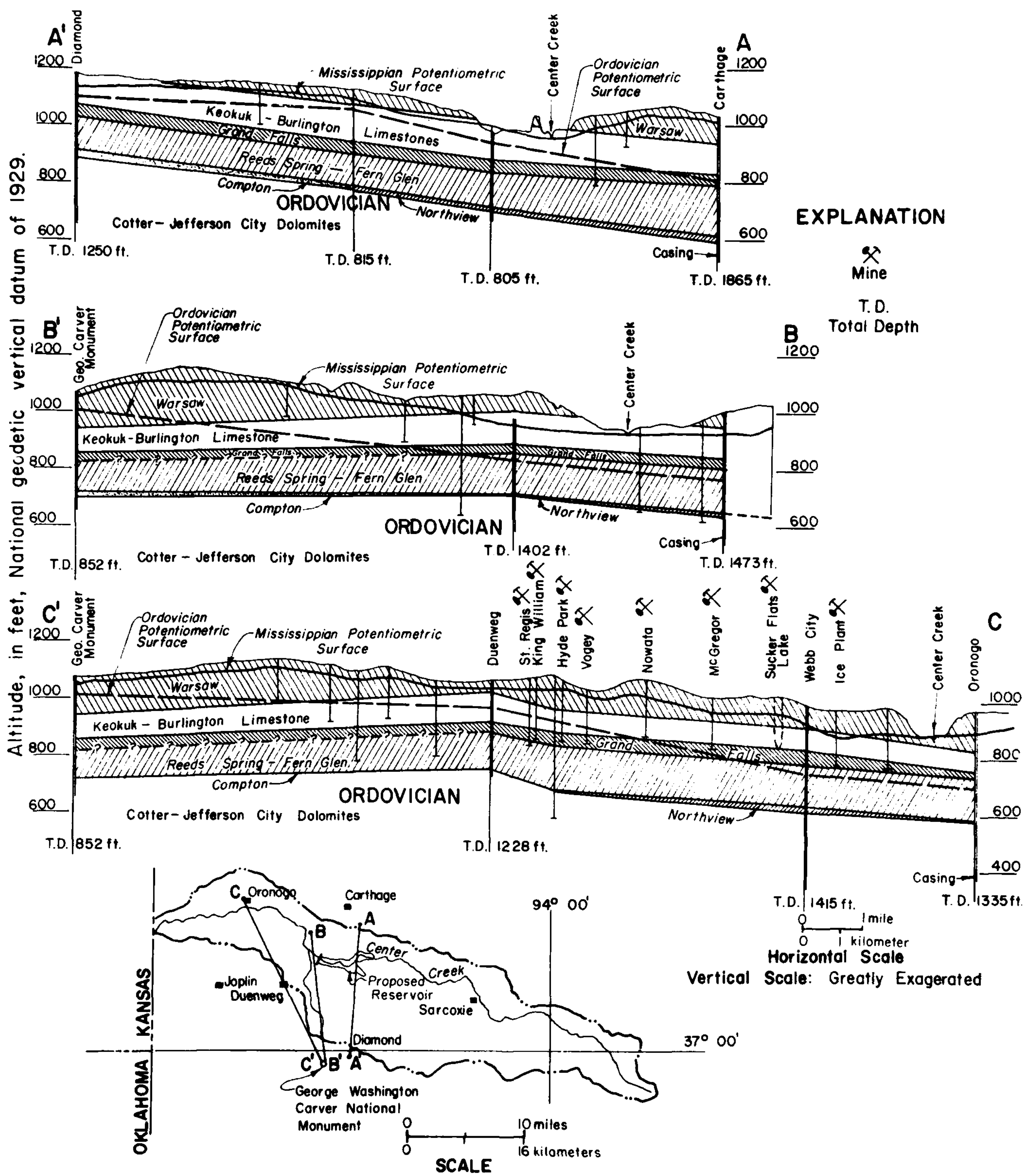


Figure 4.-- Geologic cross-sections in the vicinity of proposed Prosperity Reservoir

the different levels of dissolution activity in the area at the time of their formation.

The distribution of modern unfilled sinkholes on the Springfield Plateau and on the Salem Plateau to the east parallels the ancient distribution of Pennsylvanian-filled sinkholes, a paleokarst. Great clusters of ancient sinkholes (paleokarst) are surrounded by areas of few or no sinkholes just as clusters of modern sinkholes are surrounded by areas devoid of them. Sinkholes are the surface evidence for an underground drainage system where permeability can be expected to be relatively great. In the Joplin mining district the system of caverns developed by solution is the locus of mineral deposits. These have been described in great detail by Smith and Siebenthal (1907), and others.

Modern unfilled sinkholes are uncommon in the Joplin area. New (1956-72) 7½-minute, 1:24,000 scale topographic maps having a contour interval of 10 ft have been examined for sinkholes. The distribution is shown in figure 1. The few that are found in the Shoal Creek-Center Creek-Spring River basins seem to lie along northwest trends that cross the three basins. Approaching the Pennyslvanian outcrop the number of modern sinkholes diminishes showing that the Pennsylvanian forms a protective cover retarding limestone solution since the deposition of the Pennsylvanian. This distribution contrasts with that which existed in Late Mississippian time when the Pennsylvanian cover did not exist and solution was active prior to ore deposition (Smith and Siebenthal, 1907, p. 8).

The geologic history of the Mississippian and Pennsylvanian Periods influenced the development of permeable areas in the Mississippian limestone in which the proposed Prosperity Reservoir is located. The events of most importance to the development of the present hydrologic properties of the limestone extend from the Mississippian Period into the Pennsylvanian Period.

At the close of Meramecian deposition in Late Mississippian time drainage may have been to the east through an ancestral White River that perhaps rose in Kansas and Oklahoma. The river eroded the limestone of the Meramecian and Osagean Series leaving the fluted appearance of the Meramecian-Osagean contact somewhat as we see it today. (See fig. 2). The drainage system established by the ancestral White River has practically disappeared, replaced by the present (1979) system discharging to the west. The Meramecian-Osagean contact is a vestige of the earlier system. During this period the Joplin area was topographically higher than the area to the east. In the area around Joplin, karst topography began to develop. Sinkholes became abundant.

Submergence followed this erosion interval and the Carterville Formation of the Chesterian Series was deposited. Emergence from the sea at the close of the Mississippian resulted in the removal of most of the Carterville and only those deposits protected in sinkholes and a few scattered outcrops remain as evidence. Smith and Siebenthal (1907, p. 5) report that remnants of the Carterville Formation at depths of 200 ft in sinkholes are evidence of the depth to which solution was active and that the water table must have been close to that depth (Smith and Siebenthal, 1907, p. 8). Erosion continued well into the Pennsylvanian Period.

Submergence occurred again in the Pennsylvanian Period. The area was inundated from the west and layers of sand, clay, coal, and a minor amount of limestone were laid down. Sediments were deposited along trends which marked lines of connected sinkholes, similar to the lost rivers of modern cave regions (Smith and Siebenthal, 1907, p. 7). Valleys developed before Pennsylvanian time when drainage was toward the east or southeast and later toward the northwest were filled with Pennsylvanian sediment following the epeirogenic movements referred to by Smith and Siebenthal.

Grove Creek lies near the eastern margin of the area so severely affected by underground solution. This is also shown by the contrast in abundance of Pennsylvanian-filled sinkholes in the west and comparative paucity in the east. Figure 5 shows the distribution of Pennsylvanian sedimentary rocks in a part of southwest Missouri. The map was adapted from the geologic map in the Joplin District Folio (Smith and Siebenthal, 1907), the geologic map of Lawrence County and parts of Jasper and Newton Counties (Rutledge, 1929), and a geologic map of the Granby area (Buckley, 1906). Some areas of exposure of Pennsylvanian rocks are outliers, but many of the small circular outcrops are in sinkholes. The long linear outcrops are in collapsed valleys. Only field examination can determine which deposits east of Grove Creek are sinkhole exposures and which are merely outliers.

Features of karst topography in addition to sinkholes indicative of limestone solution are springs, caves, and losing streams. The large increases in springflow to Spring River, Center Creek, and Shoal Creek are principally in Lawrence and Barry Counties (fig. 2) in the eastern parts of the three basins (Harvey and Maxwell, 1965; Feder and others, 1969). Yet, in this eastern area where springs are plentiful and moderately large, wells in the Mississippian limestone as a rule yield little more than enough for a domestic water supply. In the west, near Joplin, springs are very few and very small. Yet, the chance of obtaining more than 100 gal/min in the Joplin area is considerably enhanced, as several such wells exist, while none is known farther to the east. Thus the spring development is a later one, while the contrast in well yields is the result of paleokarst development.

Grove Creek and the area in which the proposed reservoir is situated lies near the boundary of the great, ancient karst development of the mining district. It has some of the characteristics of a modern karst. Grove Creek

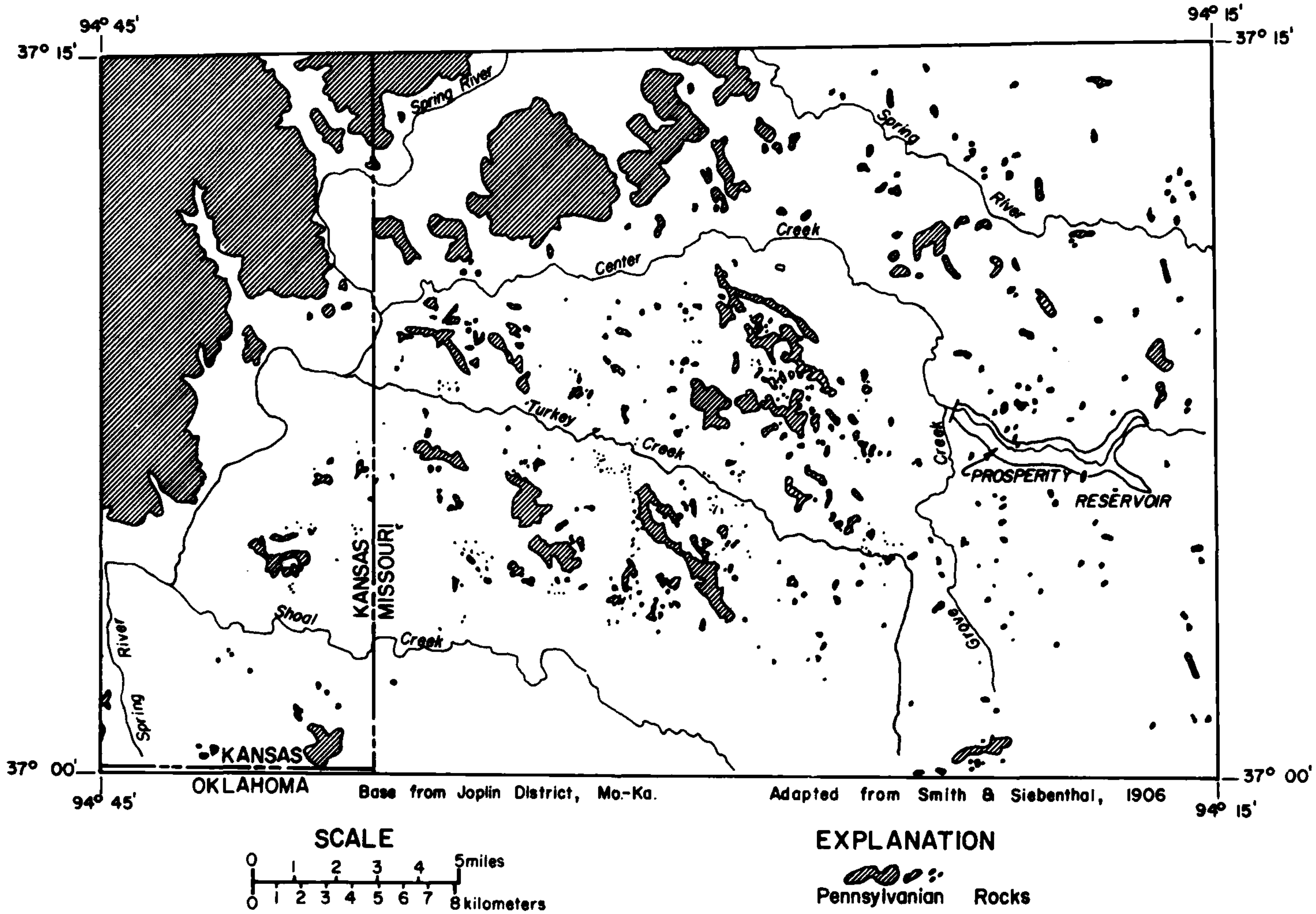


Figure 5.-- Distribution of Pennsylvanian rocks in the Joplin area

is a losing stream in its upper reaches. (See the tabulation of flow estimates in a later section of the report.) Scotland Spring (fig. 1) situated on Grove Creek is supplied by a network of conduits in the limestone extending to the east and south. Grove Creek changes at Scotland Spring from a losing to a gaining stream and perennial flow continues to the mouth. If all the water disappearing in the losing reach reappears in Scotland Spring, then Grove Creek can be considered an effective drain despite its upstream losing reach.

The longitudinal profile (fig. 3) extends from the Chesapeake fault zone in Lawrence County to the state line. The Northview Formation which occurs near the base of the Mississippian limestone is 5 to 10 ft thick and is reported in most of the well logs used in the section. The profile of the potentiometric surface of the Cambrian-Ordovician section lies as much as 200 ft below the water table or potentiometric surface of the Mississippian limestone. In this longitudinal section as in the cross sections, the potentiometric surface of the Mississippian limestone follows the topography, whereas the potentiometric surface of the Cambrian-Ordovician has a more uniform westward slope.

At Spring River in Lawrence County and near Sarcoxie the two potentiometric surfaces are coincident. This suggests that in these two areas local recharge to the Cambrian-Ordovician aquifers occurs despite the presence of the Northview Formation.

The potentiometric surface in the Mississippian limestone slopes with some irregularity from east to west and intersects Spring River and Center Creek at several places, and Grove Creek. From a point west of Spring River the surface slopes uniformly west to Sarcoxie. Comparison of the profile with the potentiometric map (see fig. 9) shows that the profile approximately parallels contours on the potentiometric map and the map shows that ground-water movement is toward Spring River north of the divide. Because of the perspective the profile does not correctly portray the local direction of ground-water movement.

Three cross sections of Center Creek basin compare the hydrology of the Mississippian limestone and the Cambrian-Ordovicain section (fig. 4). The prominent features of the three sections are the following:

1. There is always a separation between the water table of the Mississippian limestone and the potentiometric surface of the Cambrian-Ordovician section and it varies from 50 ft on the south to as much as 200 ft on the north. The proximity of the two surfaces in some parts of the area as indicated on the cross sections may be due in part to the local absence of the Northview Formation. In the absence of the retarding effect of the shale, vertical leakage from the Mississippian limestone to the Cambrian-Ordovician aquifer is less impeded. Pumping from the Cambrian-Ordovician aquifer at such centers as Carthage and Webb City increases the difference.

2. The water table of the Mississippian limestone follows the topography whereas the potentiometric surface of the Cambrian-Ordovician does not. The Mississippian grossly exhibits a water-table condition; the Cambrian-Ordovician exhibits an artesian condition.

3. The general direction of ground-water movement in both the Mississippian and Cambrian-Ordovician is toward the north and the west.

4. The Mississippian limestone water table is uniform while following the topography in the two sections (AA' and BB') upstream from the Oronogo-Duenweg belt and uneven in the mining belt (CC'). The irregularity in the mining belt is the result of local recharge and ponding of water behind collapses in the abandoned mine workings.

Transmissivity Variation

An overlay of the mines and breccia areas (fig. 6) shows their distribution in the Joplin district. The areas of widespread brecciation and mineralization were outlined as areas of high transmissivity for the model. The Oronogo-Duenweg belt is such an area. Areas devoid of brecciation or with significantly less brecciation were assigned a low transmissivity value. In a general way, the variation in well yield corresponds with the distribution of breccia areas.

While the mines represent a completely altered flow system, the mines are not continuously connected from south to north. In the north the mines are more connected than they are in the south. However, the breccia areas are more extensive and more continuous than the mines and they would tend to serve as an avenue for the lateral movement of water between mines. The breccia areas are not continuous throughout the belt and are more discontinuous toward the south than toward the north. If the areas between the breccia areas are dense limestone, locally called "lime bars," then three components make up the flow system: (1) the mines, (2) the breccia areas, and (3) the lime bars.

The mines should have an extremely high transmissivity, perhaps close to infinity. Rock falls in caved areas will reduce the transmissivity. Breccia areas will have a variable transmissivity depending on the amount of secondary silicification and dolomitization of the limestone and chert breccia. If the voids were completely filled by secondary minerals, the tranmissivity would be low. On the other hand, if the voids were not filled the transmissivity could be high. The lime bars are limestone with fractures and bedding planes more or less opened by dissolution. If not altered by dissolution, the transmissivity can be extremely small. If opened, the transmissivity can be somewhat more.

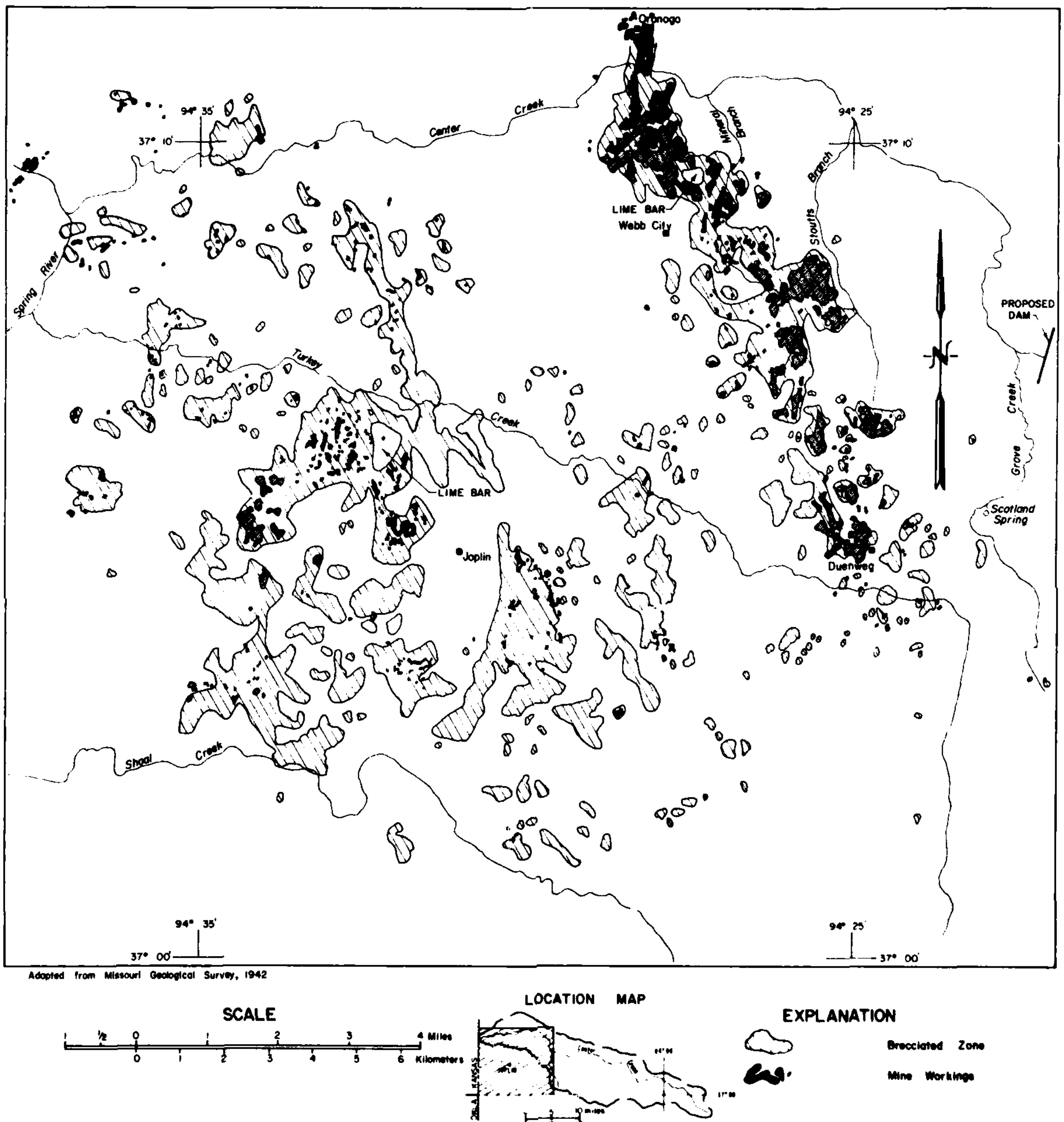


Figure 6.--Brecciated zones and mines in a part of the Joplin District, Missouri

WELL CONSTRUCTION

Weathering of the limestone varies greatly in short distances. The availability of water at shallow depth also varies in short distances. A well drilled 270 ft deep at A (fig. 7) in sec. 7, T. 27 N., R. 31 W., about 3 mi southeast of the proposed reservoir was abandoned because of mud- and water-filled pockets. A new site was selected 15 ft east of the abandoned site (B, fig. 7) where 156 ft of casing was set in the completed well and the total depth was 323 ft. This well stopped in the Ordovician. Two wells at C (fig. 7) stopped at 159 and 118 ft with 45 and 52 ft of casing, respectively. Figure 7 shows well depths and altitudes of water levels in the wells measured in the spring of 1978. These wells illustrate three conditions: An open section supplying adequate water from the main body of the limestone, which has a normal weathered section (wells at C); a weathered section yielding insufficient water (well at A); and a weathered section through the entire thickness of the limestone requiring drilling to the Ordovician (well at B). The location of section 7 is shown in figure 11.

It appears that in many parts of the area investigated, even in an area of 1 mi^2 or less, conditions in the limestone are so heterogeneous and weathering may be so deep that it is necessary to drill into the underlying Ordovician. On the other hand, in places a well can be made at less than 100 ft or 150 to 250 ft in the limestone. In some instances no well can be made in the limestone because it is tight (as at B, fig. 7). Yet, even though weathering to great depths may occur in proximity to hard, tight areas, enough wells completed in the Mississippian exist so that a potentiometric surface can be mapped. Water in the Mississippian is probably confined in many places, but unconfined throughout most of the area. Rather extensive areas of several square miles exist in the uplands where all of the wells range from 150 to 200 ft deep.

In the Center Creek basin, many of the wells required only a minimum depth of casing, 20 ft. Some required an abnormally great depth of casing, 100 to 200 ft. Apparently when abnormally long lengths of casing are required, the wells are in recharge areas. These may be at joint intersections where solution has progressed far.

WELL YIELDS

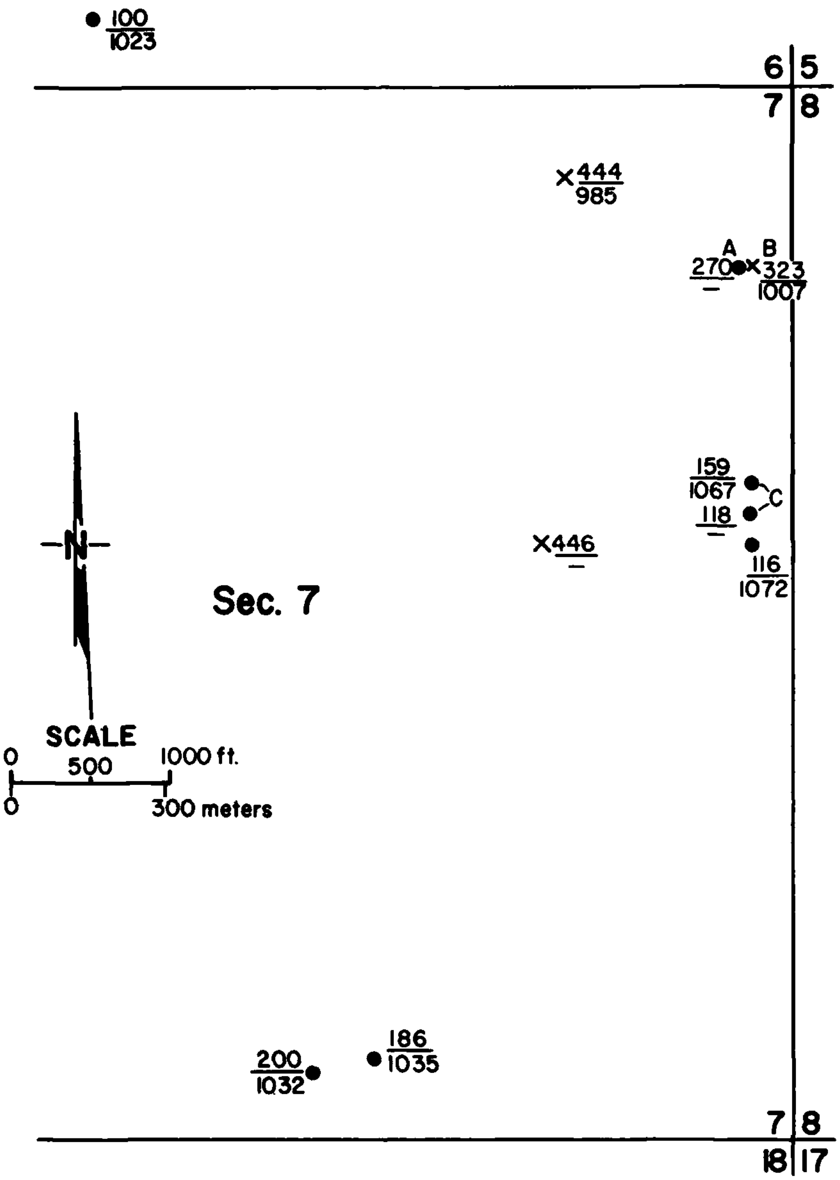
Yields of wells completed in Mississippian limestone range from nearly zero to 400 gal/min according to owners' and drillers' records. Figure 8 shows the distribution of values across a large part of southwest Missouri extending from Springfield to McDonald County. Wells drilled to the Cambrian-Ordovician aquifer but open in the Mississippian are not included. The following table presents the ranges, median, and average values of the yields by areas.

Block (fig. 8)	Description	Number of values	Range (gal/min)	Median (gal/min)	Average (gal/min)
1	East of Chesapeake Fault---------	81	0-45	5.5	10
2	Chesapeake-Pierce City fault block (mainly Lawrence County)-------	30	0-45	10	12.1
3	Joplin-Sarcoxie area (Jasper and northern Newton Counties)-----	26	2-390	20	90
4.	South of Pierce City Fault----	63	½-130	4.0	10

On the basis of the variation in well yield a higher value for transmissivity was assigned in the model analysis in parts of Jasper County than that in the area to the east. Brecciated limestone often associated with zinc has higher permeability where the voids have not been filled with secondary minerals (jasperoid, dolomite, and sulfides). The field inventory which supplemented data from the log file showed that even in the area around Joplin where it is possible to obtain 100 gal/min or more of water from the limestone, limestone of very low permeability exists in which little or no water was obtained.

POTENTIOMETRIC MAPPING

Three potentiometric maps are included in the report. Figure 9 is a map of the entire Center Creek basin and contiguous areas in the Spring River and Shoal Creek basins. All water levels measured and reported are shown on the map. A 25-ft contour interval was used, which generalized variations in slopes of the potentiometric surface.



NOTE:

See figure 11 for location with respect to the reservoir.

EXPLANATION

● 186/1035 — Depth of well / Altitude of water level, March, April, 1978

MISSISSIPPIAN WELL

× 444/985 — Depth of well / Altitude of water level, March, April, 1978

ORDOVICIAN WELL

Figure 7.--Well locations, depths and water-level altitudes in section 7, T. 27 N., R. 31 W., Jasper County, Missouri

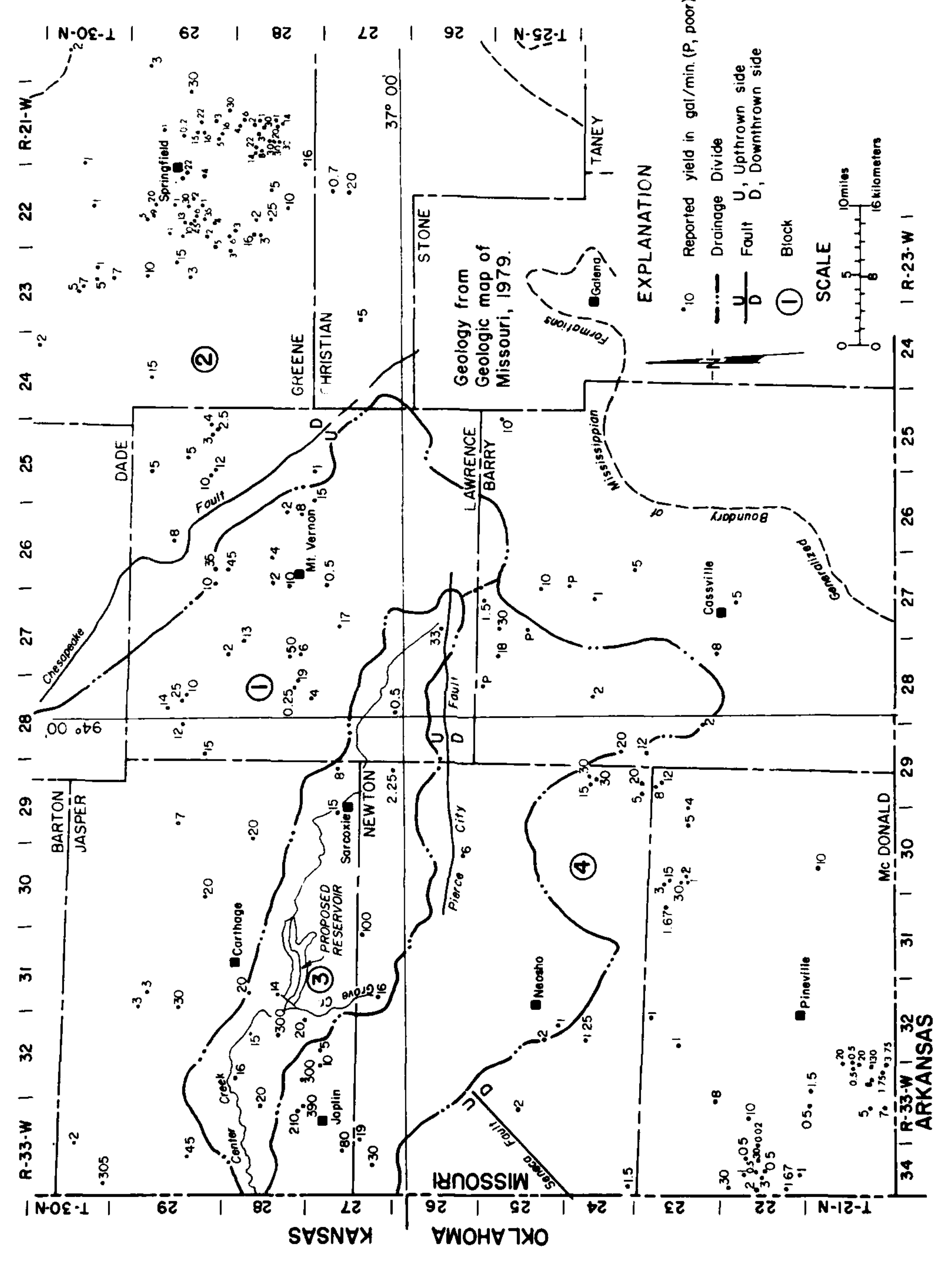


Figure 8.--Yields of wells completed in the Mississippian limestone in southwest Missouri

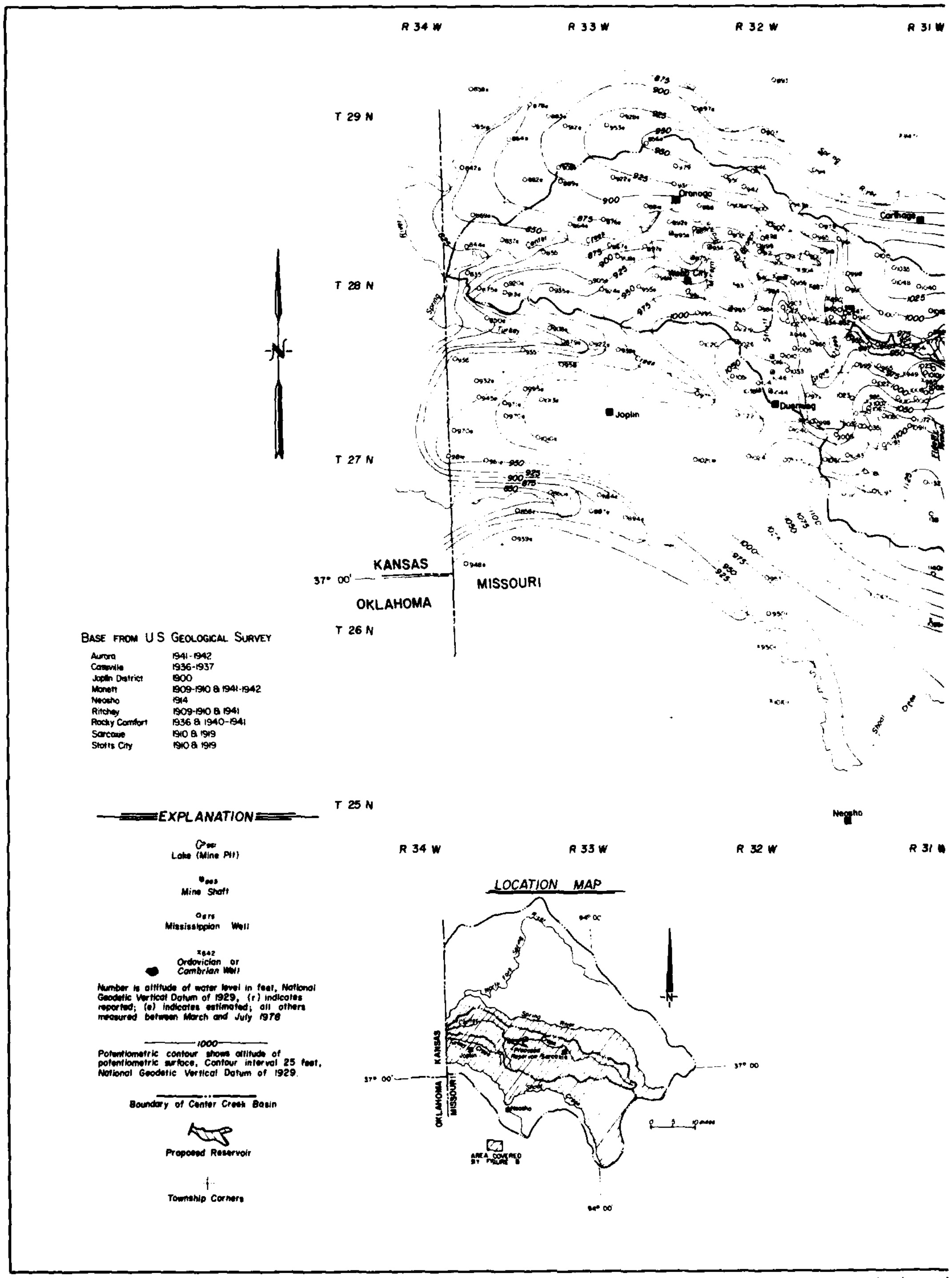
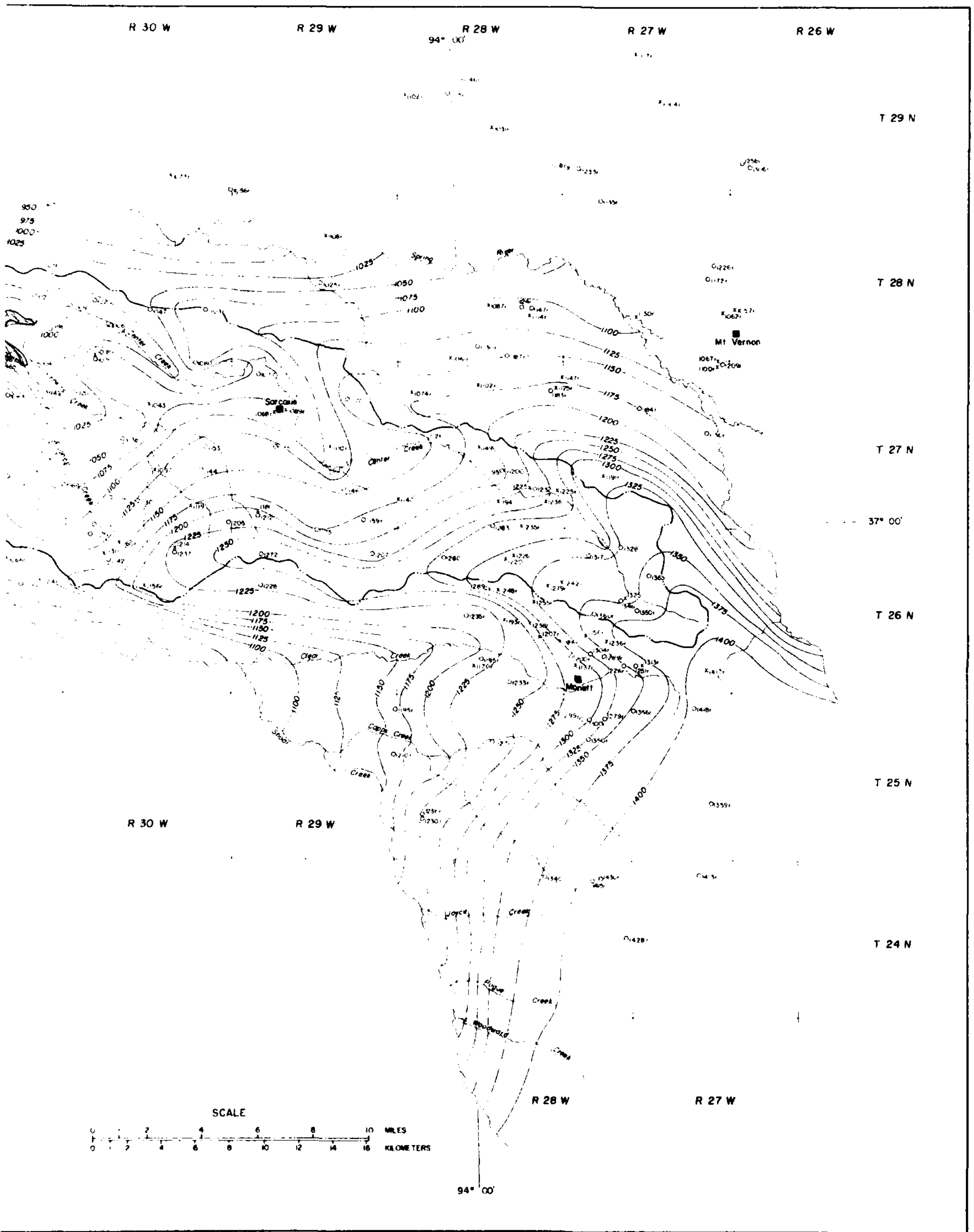


Figure 9.--Potentiometric map of Mississippian limestone aquifer in Center Creek basin and



contiguous parts of Spring River and Shoal Creek basins, Missouri, 1978. (Contour interval, 25 ft.)

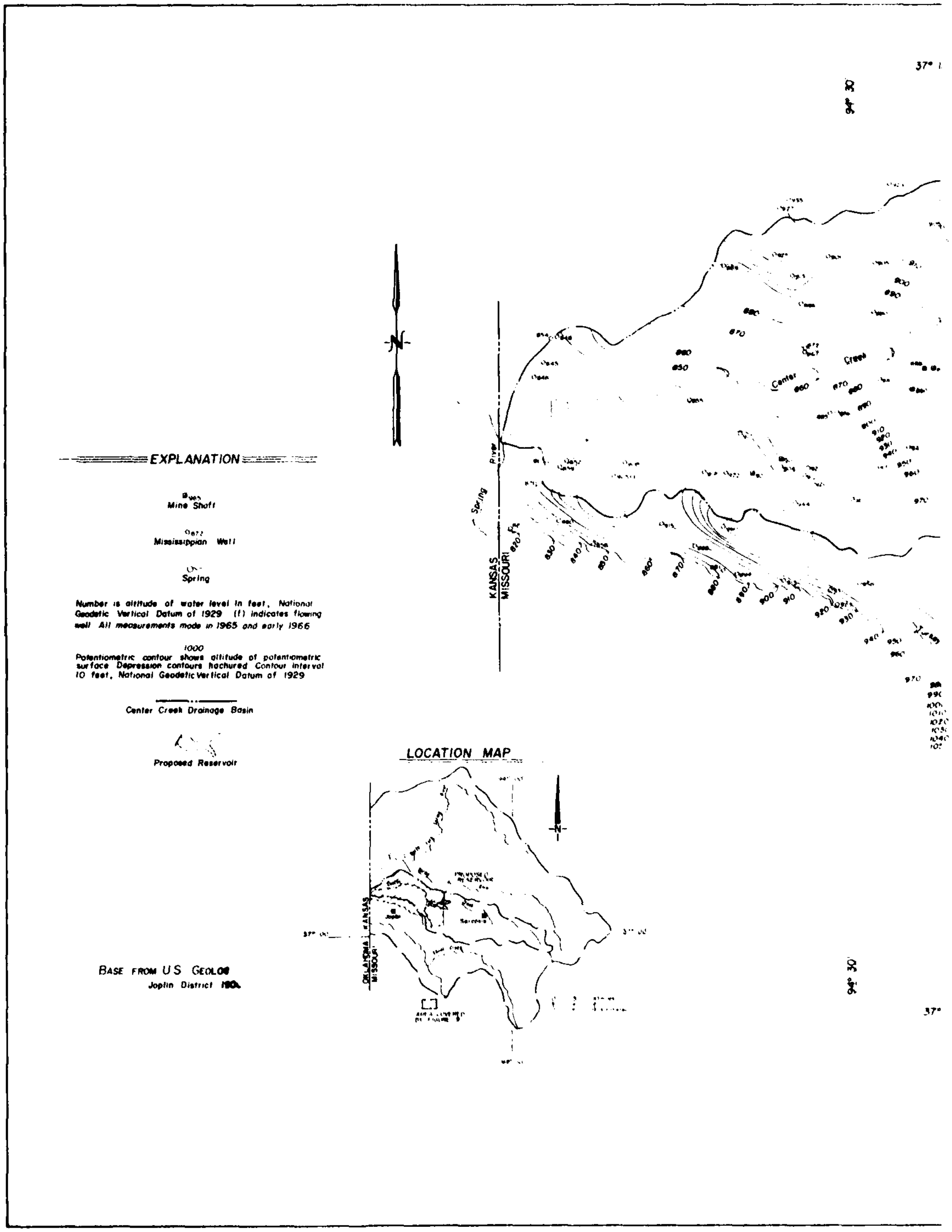
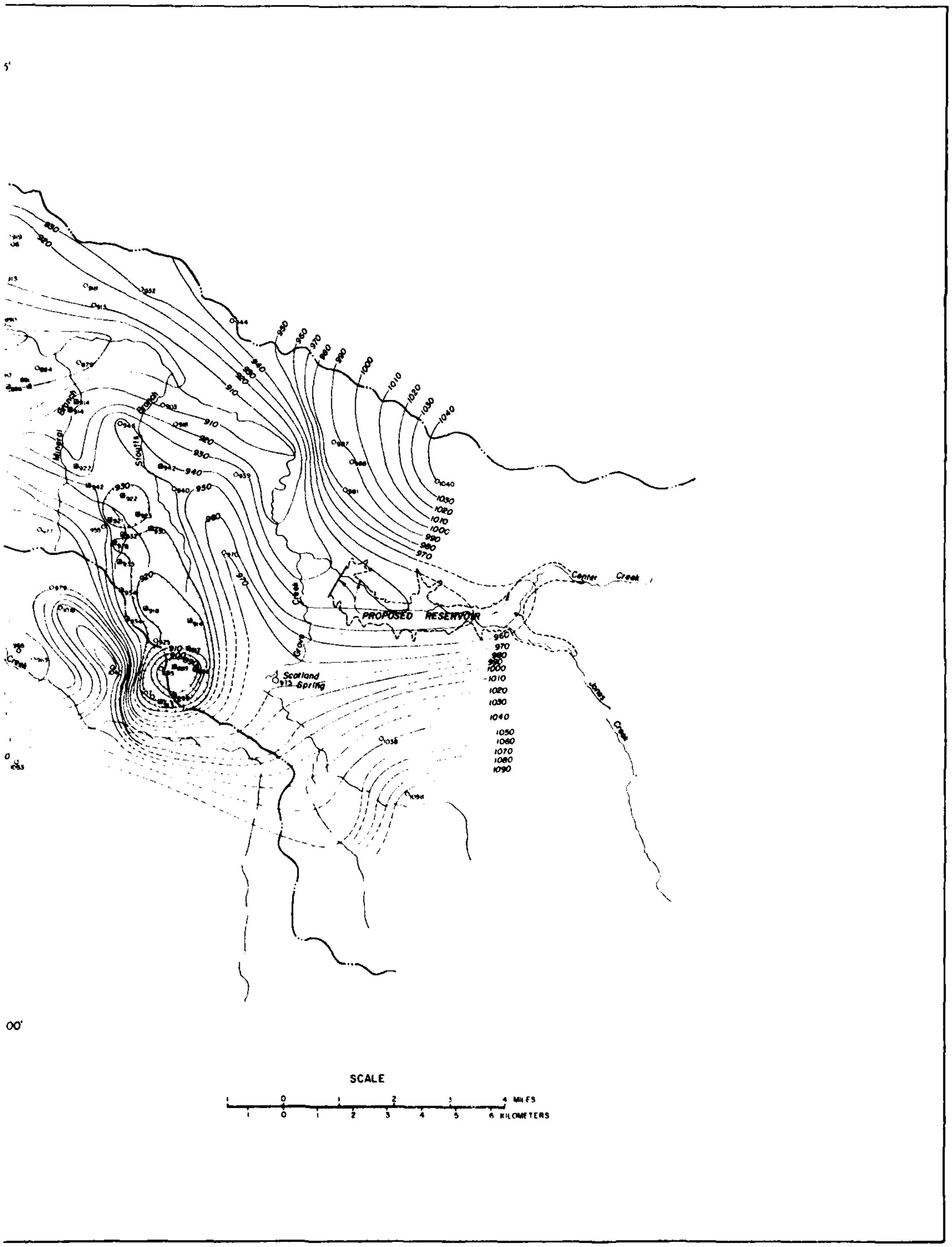


Figure 10.--Potentiometric map of proposed Prosperity Reservoir are



) in Center Creek basin, Missouri, 1965. (Contour interval, 25 ft.)

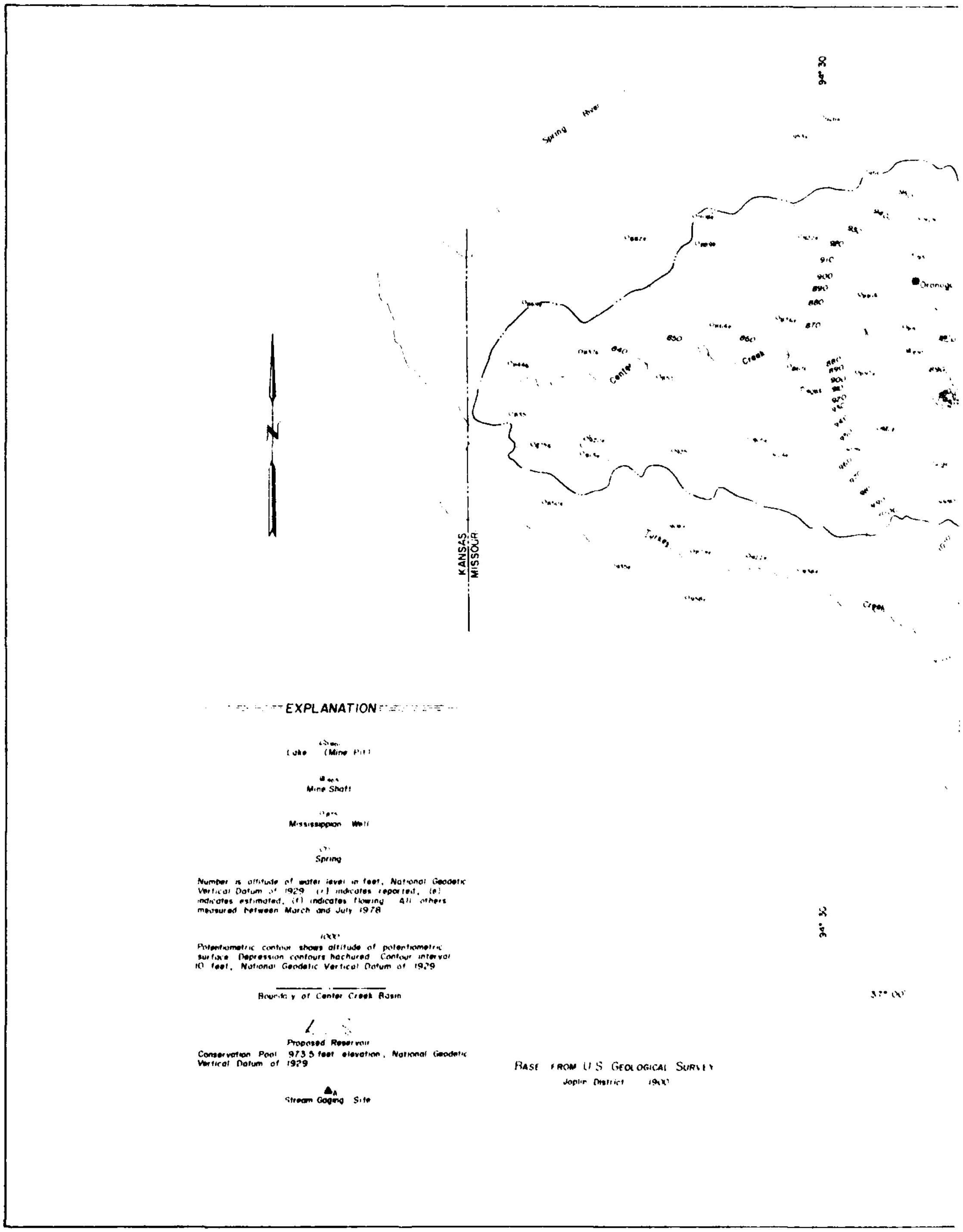
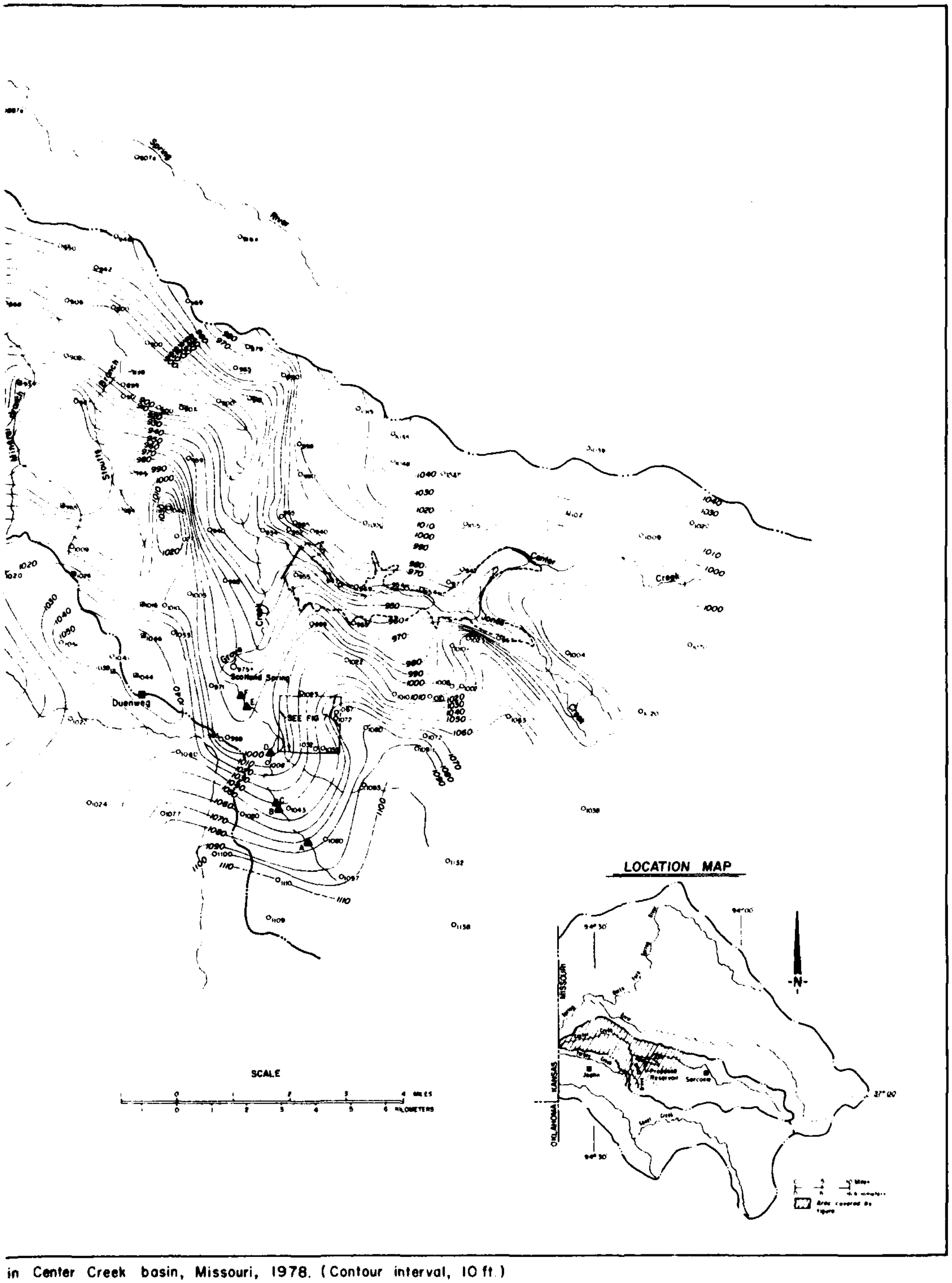


Figure 11.--Potentiometric map of proposed Prosperity Reservoir area



in Center Creek basin, Missouri, 1978. (Contour interval, 10 ft.)

Maps based on data collected in 1965 and 1978 drawn with a 10-ft contour interval show in greater detail the changes in slope of the potentiometric surface (fig. 10 and 11). In addition, comparison of the two maps permits contouring of the change in water level between 1965 and 1978 illustrated in the figure shown in the section on "Digital Simulation Model."

Ground water in the Mississippian limestone section essentially has a water-table configuration that is controlled by the principal streams draining the area. The water-table contours extend upstream along the major streams showing that ground-water flow is from the uplands to the stream. Where the ground-water contours cross the stream valley downstream from the point at which the surface contour with the same altitude crosses the stream, the water table is shallow and a perennial stream occurs, or, at least, flow is continuous until evapotranspiration uses up the water. This is the discharge area. If the ground-water contour crosses the valley upstream from the surface contour crossing, an intermittent stream occurs. This is the recharge area.

In carbonate terrane one might expect streamflow loss in recharge areas downstream from the beginning of perennial flow. Such reaches are not as common in the Mississippian limestone area of the Springfield Plateau as they are in the Cambrian-Ordovician dolomite area of the Salem Plateau farther to the east. This is because solution of the limestone has not been carried to the extreme that it has been carried in many parts of the dolomite area. This difference in solution development is reflected in the relief of the two areas. The authors have observed that in any system of carbonate rocks in the Ozarks the greater the dissection of the land surface, the less precisely the ground-water divides correspond with the topographic divides.

In some areas contours are evenly spaced indicating uniform movement of ground water toward the stream. In other areas the contours are closely spaced. Such areas of close spacing indicate a steep slope in the water table and restriction in the flow of water through the rocks. The restriction may be due to an areal change from open joints, fractures, and bedding planes allowing normal movement of water to a system in which openings are small or few, or filled with secondary minerals and movement is slowed.

All wells measured and used for control points are shown on the map. However, some points were disregarded during contouring. Because most of the wells that were measured were in use, some residual drawdown may cause an abnormally low water level, especially if the yield is low and the water use had been large prior to the time of the measurement.

It is always possible in such a suite of rocks that sufficient water for domestic use may occur at more than one depth. If vertical connection is poor between the several depths of occurrence of water, several different water levels may be measured at a specific location. Yet, it was found in inventorying and measuring water levels that considerable consistency in the depths of wells and water levels occurred in some areas. Such areas were several square miles in extent. In other areas, depths and water levels were very inconsistent. This areal variation between consistent and inconsistent well depths and water levels is due to variations in the development, or lack of it, of solution along the joints, fractures, and bedding planes. For these reasons, water-level contouring is subjective and the product is the best estimate of the investigator of the validity of the data with which he is working and his understanding of how ground water moves through fractured, dissolutioned rocks.

Some wells drilled into the Ordovician and uncased through the Mississippian, have water levels that stand below the potentiometric surface of the Mississippian, which indicates that little water was available in the Mississippian at this site. Other wells drilled into the Ordovician, also uncased through the Mississippian, have water levels that differ little with the potentiometric surface of the Mississippian. A substantial contribution to the well from the Mississippian is indicated.

Most domestic wells drilled into the Ordovician have only 20 to 50 ft of casing and the Mississippian limestone is open to the well. As a result the water level recorded in many Ordovician dolomite wells is a composite of the Mississippian and Ordovician rocks. These wells were not used in contouring the potentiometric surface of the Mississippian limestone although they are shown on the potentiometric maps (figs. 9 and 11).

Comparison of the distribution of brecciation (fig. 6) with the 1978 potentiometric map shows some relationship between such distribution and changes in the slope of the potentiometric surface (fig. 11). For example, the broad area of high water levels in the vicinity of Duenweg is a recharge area encompassing caved-in mine workings. It is bounded on the east by noteworthy steepening of the potentiometric surface toward Grove Creek. Steepening suggests a gross change in the transmissivity to steep gradient and low transmissivity. The abutting of brecciated rocks ("hog chaw") by solid limestone ("lime bars") would account for pronounced gradient changes.

East of Stoutts Branch is another area of high water levels. Bounding this area on the east is an area of steep gradient, essentially parallel to the area of steep gradient east of Duenweg. Immediately east of the point where the ground-water elevation is 1,042 ft (fig. 11), wells are drilled to 400 to 500 ft depth to obtain water from the Ordovician dolomite and sandstone. Drillers and well owners mention the existence of "lime bars" which are interpreted as areas where the Mississippian limestone is relatively tight and little or no water is obtained. Shallow and dug wells constructed years ago in tight areas have since been deepened or replaced as larger volumes of water were needed. For this reason it is suggested that presence or absence of Mississippian wells, occurrence of mineralized areas and brecciated limestone, high and low yields of Mississippian wells, and distribution of gentle and steep ground-water gradients are related. Between brecciated limestone areas within the high transmissivity area of the Oronogo-Duenweg belt the limestone may be tight and low well yields may be obtained. Assignment of a high transmissivity to the Oronogo-Duenweg belt is a very general assumption. It is quite apparent that the Mississippian limestone is very heterogeneous and its transmissivity may change in short distances.

Change in the slope of the potentiometric surface from Deunweg to Oronogo may be explained by rock falls in the abandoned mine workings that create partial bulkheads behind which pools develop. While continuous movement occurs from Duenweg northwest to Center Creek, variations in the rate of movement are indicated by changes in the slope of the potentiometric surface. This is not as apparent in figure 9 (contour interval 25 ft) as it is in figure 11 (contour interval 10 ft) and on the cross section, figure 4.

GROVE CREEK

The potentiometric map of the area of the proposed damsite and Grove Creek (fig. 11) shows that the water table slopes from the uplands east of Grove Creek to it and Center Creek. West of Grove Creek the water table slopes to Grove Creek. The stream is usually dry upstream from Scotland Spring except for a reach about 1 mi long extending from an elevation of 1,040 to 1,060 ft. In this reach under normal weather conditions flow usually occurs early in the summer near the lower end of the reach when the stream is dry downstream from that point to the vicinity of Scotland Spring. Willow growth occurs along the stream between elevation 1,040 ft and 1,060 ft (points A and B on fig. 11). Upstream from elevation 1,060 ft and downstream from elevation 1,040 ft willows are absent. In fact, the change from abundant willows to no willows at elevation 1,040 ft is abrupt, the change taking place in a distance of about 500 to 750 ft (points B and C on fig. 11).

Flow estimates were made several times in the spring and summer of 1978 as given in the following table. Site designations (A-F) are shown in figure 11.

Flow estimates, 1978, in cubic feet per second							
Site (fig. 11)	Mar. 16	Mar. 31	Apr. 28	May 11	June 8	July 25	Remarks
A	---	---	---	---	---	Pools	Along creek in field. Willows and pools absent upstream, present downstream in distance of about one-fourth mile.
B	4.0	5-10	2.0	---	---	0.2	Highway FF. Flow between pools July 25. Willows, sedges, and rushes abundant.
C	Flow	Flow	Flow	---	---	0	Six-hundred feet downstream from Highway FF. Willows, sedges, and rushes absent.
D	1.0	Flow	0.2	2.0	---	0	County road bridge. April 28, pooled 750 ft downstream. July 25, no pools. Willows absent.
E	0	Flow	0	---	0	0	I-44 bridge. June 8 and July 25, no pools. No willows.
F	0	Flow	0	---	---	0	Business I-44 bridge. March 16, April 28, and July 25 no pools. No willows.

From the foregoing data Grove Creek is a losing stream between site B and Scotland Spring. It is likely that the upstream flow in Grove Creek (sites A-B) appears downstream in Scotland Spring. The ground water contours do not suggest loss to Turkey Creek basin or to the Oronogo-Duenweg belt unless a conduit or conduits carries the water in some direction other than that suggested by the contours. A dye trace is needed to confirm a connection between Grove Creek and Scotland Spring and the effectiveness of Grove Creek as a hydrologic boundary.

Water in storage in the Oronogo-Duenweg belt discharges to Grove and Center Creeks. The rise in ground-water levels caused by inflow from the proposed reservoir could range from about 20 ft near the reservoir to 0.5 to 1.0 ft in the southern part of the Grove Creek drainage basin. Any rise in ground-water levels should increase discharge of Grove Creek and Scotland Spring. The increase in ground-water discharge to Grove Creek will have the beneficial effect of diluting mine-water discharge into Center Creek at Mineral Branch during periods of low flow. If conduits extend beneath Grove Creek, on the other hand, increased flow into the mining belt might augment discharge of mineralized water from the belt to Center Creek downstream from the proposed dam.

In the reach of Grove Creek upstream from Scotland Spring, the shape of the contours indicates that ground water is moving toward the stream. However, the relation between the ground-water elevation and the surface elevation at any point along that reach, except in the reach between A and B, indicates that the water table is below the streambed. The absence of flow in the reach between Scotland Spring and C that is receiving ground water from adjacent uplands is due to conductance of the water to Scotland Spring beneath the channel, probably through conduits in limestone. In the reach upstream from A, the ground-water contribution is so small that it can only satisfy evapotranspiration requirements and it is probably a normal dry tributary.

QUALITY OF WATER

Water in the Mississippian limestone is moderately hard and moderately mineralized. The major difference between 1965 and 1976 sampling on the one hand and 1978 sampling on the other, is the broader geographic distribution of samples throughout the Center Creek basin in 1978. Figure 12 shows the distribution of sampling sites in 1965, 1976, and 1978. No samples were collected from the Oronogo-Duenweg belt in 1978, whereas the majority of the samples of 1965 and 1976 were collected from the mining district. Analyses for 1965 are listed in Feder and others (1969, p. 75) and for 1976 are listed in Barks (1977, p. 38) and are not repeated here. Barks, 1977, p. 18) found that ground water from many of the mines contains more than 1,000 mg/L (milligrams per liter) dissolved solids, whereas wells usually contained much less than that amount. Mine water is a calcium sulfate

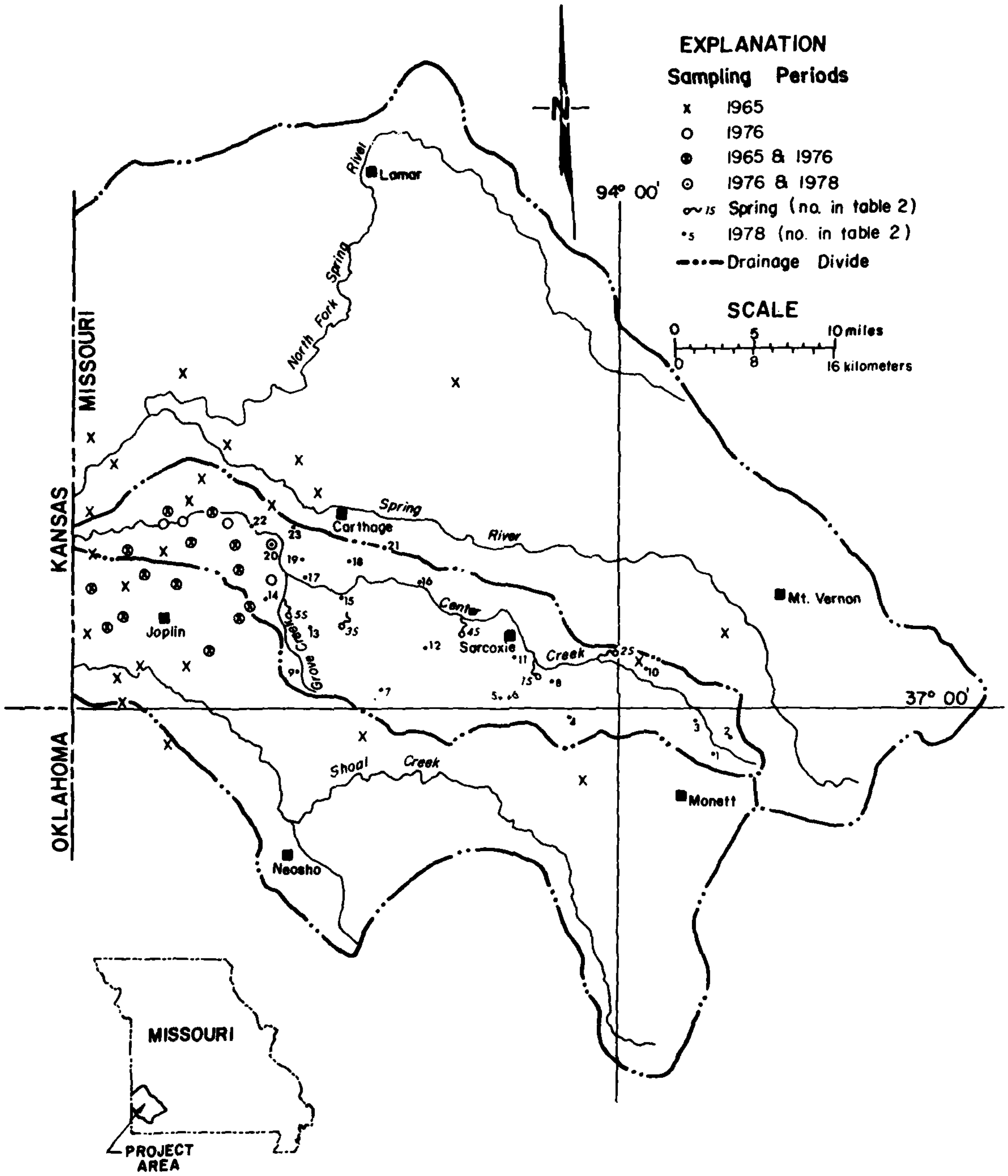


Figure 12.--Wells sampled in 1965, 1976, and 1978, and springs sampled in 1978 in Spring River, Center Creek and Shoal Creek drainage basins, Missouri

type, and concentrations of iron and zinc average 5,100 and 9,400 µg/L (micrograms per liter), respectively. Analyses of water samples collected from wells and springs during the 1978 study are listed in table 2.

A comparison of the analyses obtained in 1965, 1976, and 1978 is shown in table 3. Comparison of median sulfate values for the three sampling periods best illustrates the difference in sample distribution. The difference is probably due to the widespread occurrence of sulfide minerals in the rocks of the mining district, their sporadic occurrence in the remainder of the area. Other parameters show geographic variations but they are not as marked.

The median value of nitrate (as N) in 1978 is 2.7 mg/L (milligrams per liter) compared with 1.0 mg/L in 1965. This does not necessarily mean that ground-water pollution is greater in 1978 than it was in 1965 because the geographic distribution of samples was different at the two times. Figure 13 shows the distribution of values less than and greater than 2.3 mg/L of nitrate (10 mg/L as NO_3) reported as nitrogen (N). Many of the low nitrate values obtained in 1965 were located west of Grove Creek. In 1978 values are in excess of 2.3 mg/L (as N) in a majority of rural domestic wells. Forty-seven percent of the samples collected in 1965 had more than 2.3 mg/L of nitrate (as N) whereas 65 percent of those collected in 1978 exceeded 2.3 mg/L. Only one of 20 samples collected in 1978 exceeded 10 mg/L (as N), the drinking water limit established by the Environmental Protection Agency (1975), whereas 5 of 39 samples collected in 1965 exceeded that limit.

Inasmuch as the Mississippian limestone is exposed at the surface or underlies residuum, the opportunity for downward migration of waste exists. In the rural areas where pasture, stock raising, and fertilizing of crops are extensive and domestic waste is disposed of by means of septic tanks, the source of pollution is present. In the urban areas farming is less extensive and septic tanks are fewer. In suburban areas, between the urban areas and the farming areas, many septic tanks exist and the number of homes is increasing. These are areas where the nitrate content of the water may be expected to increase in the future.

DIGITAL SIMULATION MODEL

When the stage of a reservoir rises above the water table in adjoining aquifers water flows from the reservoir into the aquifers. This water may form a "mound" in the potentiometric surface that did not exist in the aquifers before the reservoir stage rose. The natural ground-water flow system may adjust to this "mound" by diverting flow to new discharge areas, increasing water stored in the aquifer or decreasing the rate of recharge. The changes that occur in the natural flow system depend on the hydraulic properties of the aquifer, types and location of aquifer boundaries, amounts

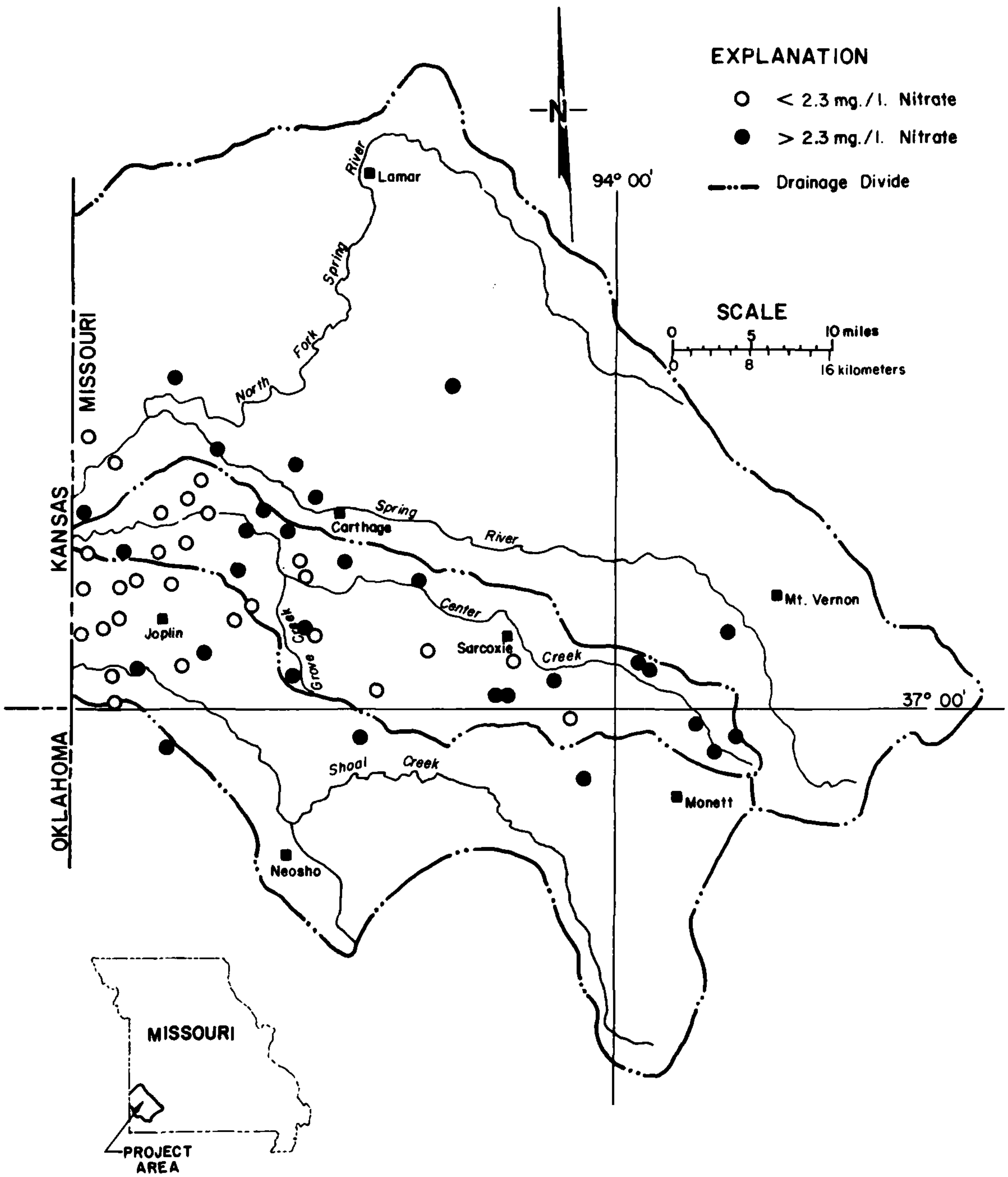


Figure 13.--Variation in nitrate content in water from wells in Mississippian limestone

TABLE 2.--WATER-QUALITY DATA FOR WELLS AND SPRINGS IN CENTER CREEK BASIN, MISSOURI

[WELL NOS. 5, 13, AND 18 ARE IN ORDOVICIAN, WELL NO. 23 IS IN CAMBRIAN, ALL OTHER WELLS ARE IN MISSISSIPPIAN. SPRINGS ARE ALL IN MISSISSIPPIAN.]

MAP NO. (FIG. 12)	STATION NUMBER	DATE OF SAMPLE	DEPTH OF WELL, TOTAL (FEET)	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH (UNITS)	TEMPER-ATURE (DEG C)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)
1----	365748093535601	78-06-14	138	255	6.7	17.5	120	26	45	2.6	4.8	.6
2----	365831093524901	78-06-13	102	310	7.1	17.0	150	32	51	4.8	4.4	.7
3----	365914093550701	78-06-14	86	270	7.0	16.0	130	13	49	2.6	4.7	.7
4----	365927094033701	78-06-14	1240	360	7.3	17.0	180	25	66	3.5	3.1	1.1
5----	370044094075901	78-06-20	196	350	7.4	18.0	150	10	54	3.5	8.0	.6
6----	370044094075902	78-06-20	453	320	7.3	19.0	160	7	60	3.2	5.8	.4
7----	370106094164101	78-06-22	192	390	7.5	16.5	210	8	59	16	3.2	.6
8----	370136094043801	78-06-20	96	420	7.2	18.0	230	21	92	1.0	2.9	.5
9----	370157094223001	78-06-22	151	350	7.5	19.0	190	21	65	5.5	3.6	.6
10----	370158093562401	78-06-15	179	410	7.6	17.5	190	59	71	4.0	2.9	.6
11----	370258094071701	78-06-14	---	250	7.1	17.5	130	3	47	2.6	4.0	1.5
12----	370320094131901	78-06-20	150	370	7.6	17.0	180	14	53	11	4.4	.8
13----	370436094205701	78-06-21	118	263	7.4	16.5	120	1	47	1.5	5.8	.6
14----	370552094240501	78-06-15	200	600	7.3	18.0	340	170	130	4.1	4.4	.4
15----	370604094185101	78-06-13	805	310	7.6	18.5	170	21	37	18	4.4	1.4
16----	370654094133201	78-06-15	180	430	7.6	18.5	240	34	82	9.1	3.0	.8
17----	370730094213001	78-06-14	235	460	7.3	16.5	150	0	39	12	59	.8
18----	370734094163501	78-06-14	222	520	7.5	17.0	270	51	93	9.7	7.9	.6
19----	370826094213801	78-06-15	186	500	7.3	17.0	270	17	82	17	6.9	.6
20----	370829094230701	78-06-14	362	400	7.4	17.5	210	3	53	18	14	1.1
21----	370848094161601	78-06-13	278	510	7.2	16.5	250	7	88	8.0	13	.6
22----	370953094250101	78-06-14	285	450	7.4	16.5	230	28	83	6.2	3.7	.7
23----	370955094215601	78-06-13	245	420	7.5	18.0	230	40	65	16	3.8	.6

TABLE 2.--WATER-QUALITY DATA FOR WELLS AND SPRINGS IN CENTER CREEK BASIN, MISSOURI--CONTINUED

MAP NO. (FIG. 12)	DATE OF SAMPLE	BICAR-BONATE (MG/L AS HCO3)	CAR-BONATE (MG/L AS CO3)	ALKA-LINITY (MG/L AS CACO3)	CARBON DIOXIDE DIS-SOLVED (MG/L AS CO2)	SULFATE DIS-SOLVED (MG/L AS SO4)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	PHOS-PHORUS, DIS-SOLVED (MG/L AS P)
1----	78-06-14	118	0	97	38	2.8	13	.0	11	156	154	3.5	.00
2----	78-06-13	140	0	115	18	1.1	10	.1	11	189	179	6.0	.02
3----	78-06-14	146	0	120	23	3.8	5.7	.0	10	152	161	2.8	.01
4----	78-06-14	188	0	154	15	28	4.5	.1	9.7	206	216	1.6	.00
5----	78-06-20	170	0	139	11	12	6.7	.1	8.7	197	192	2.9	.00
6----	78-06-20	190	0	156	15	6.1	3.6	.1	9.3	169	195	2.9	.00
7----	78-06-22	250	0	205	13	6.3	2.2	.0	8.5	204	221	.50	.00
8----	78-06-20	260	0	213	26	6.6	4.7	.0	12	253	259	2.6	--
9----	78-06-22	200	0	164	10	4.5	3.4	.1	9.4	188	202	2.6	.00
10----	78-06-15	164	0	135	6.6	5.2	12	.0	9.8	276	253	15	.00
11----	78-06-14	152	0	125	19	9.0	5.5	.0	9.7	140	159	1.1	.01
12----	78-06-20	200	0	164	8.0	7.1	2.4	.1	8.3	175	192	1.5	.00
13----	78-06-21	150	0	123	9.6	6.6	2.6	.1	8.9	148	160	2.8	.02
14----	78-05-15	210	0	172	17	120	48	.0	9.5	396	431	2.6	.01
15----	78-06-13	178	0	146	7.2	13	2.6	.1	10	156	175	.12	.00
16----	78-06-15	254	0	208	10	8.9	4.7	.1	11	241	259	3.1	.00
17----	78-06-14	318	0	261	26	8.7	1.5	.1	8.6	267	288	.29	.00
18----	78-06-14	270	0	221	14	26	12	.1	10	305	322	6.7	.00
19----	78-06-15	314	0	258	25	17	2.3	.1	9.5	273	295	.90	.00
20----	78-06-14	248	0	203	16	13	4.2	.8	8.7	210	236	.19	.00
21----	78-06-13	300	0	246	30	7.2	6.6	.1	12	284	301	4.0	.01
22----	78-06-14	250	0	205	16	16	4.6	.1	9.6	245	259	2.7	.00
23----	78-06-13	230	0	189	12	17	7.3	.1	9.6	249	260	6.1	.00

TABLE 2.--WATER-QUALITY DATA FOR WELLS AND SPRINGS IN CENTER CREEK BASIN, MISSOURI--CONTINUED

MAP NO. (FIG. 12)	DATE OF SAMPLE	CADMIUM DIS-SOLVED (UG/L AS CD)	COPPER, DIS-SOLVED (UG/L AS CU)	IRON, DIS-SOLVED (UG/L AS FE)	LEAD, DIS-SOLVED (UG/L AS PB)	MANGA-NESE, DIS-SOLVED (UG/L AS MN)	ZINC, DIS-SOLVED (UG/L AS ZN)
1----	78-06-14	--	--	40	--	110	--
2----	78-06-13	--	--	0	--	0	--
3----	78-06-14	--	--	20	--	0	--
4----	78-06-14	--	--	30	--	5	--
5----	78-06-20	--	--	10	--	10	--
6----	78-06-20	--	--	20	--	5	--
7----	78-06-22	--	--	10	--	0	--
8----	78-06-20	--	--	--	4	0	40
9----	78-06-22	--	--	10	--	0	--
10----	78-06-15	2	1	0	37	0	340
11----	78-06-14	1	6	20	16	5	70
12----	78-06-20	--	--	20	--	10	--
13----	78-06-21	5	1	20	51	10	160
14----	78-06-15	--	--	40	--	5	--
15----	78-06-13	--	--	60	--	10	--
16----	78-06-15	--	--	20	--	5	--
17----	78-06-14	--	--	30	--	5	--
18----	78-06-14	--	--	20	--	0	--
19----	78-06-15	7	5	30	38	10	990
20----	78-06-14	--	--	60	--	5	--
21----	78-06-13	--	--	20	--	5	--
22----	78-06-14	--	--	10	--	5	--
23----	78-06-13	--	--	10	--	0	--

TABLE 2.--WATER-QUALITY DATA FOR WELLS AND SPRINGS IN CENTER CREEK BASIN, MISSOURI--CONTINUED

MAP NO. (FIG. 12)	STATION NUMBER	STATION NAME	DATE OF SAMPLE	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	TEMPERATURE (DEG C)	HARDNESS (MG/L AS CACO3)
1S----	370150094050501	27N-29W-27ACB1 HADDOCK SPRING	78-06-21	285	6.9	15.0	--
2S----	370255094002101	27N-28W-17DDA1 CLARKSON SPRING	78-06-21	282	6.9	15.0	140
3S----	370426094184401	27N-31W-10CBB1 FIDELITY SPRING	78-06-21	290	6.6	16.0	140
4S----	370442094101401	27N-30W-11AAB1 DUKARTS SPRING	78-06-21	292	6.7	16.0	150
5S----	370533094225101	SCOTLAND SPRING, ATLAS POWDER COMPANY	78-06-22	257	7.0	15.5	120

MAP NO. (FIG. 12)	DATE OF SAMPLE	HARDNESS, NONCARBONATE (MG/L CACO3)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	BICARBONATE (MG/L AS HCO3)	CARBONATE (MG/L AS CO3)	ALKALINITY (MG/L AS CACO3)	CARBON DIOXIDE DISSOLVED (MG/L AS CO2)	SULFATE DISSOLVED (MG/L AS SO4)	CHLORIDE, DISSOLVED (MG/L AS CL)	FLUORIDE, DISSOLVED (MG/L AS F)
1S----	78-06-21	--	--	--	--	--	150	0	123	30	5.3	4.9	.0
2S----	78-06-21	25	52	2.8	4.2	1.4	142	0	116	29	--	--	--
3S----	78-06-21	21	50	2.7	4.4	1.2	140	0	115	56	11	6.2	.0
4S----	78-06-21	15	55	2.1	4.1	1.1	160	0	131	51	6.8	6.5	.0
5S----	78-06-22	23	45	2.3	3.7	1.2	120	0	98	19	8.4	4.6	.0

MAP NO. (FIG. 12)	DATE OF SAMPLE	SILICA, DISSOLVED (MG/L AS SIO2)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)	NITROGEN, NO2+NO3 DISSOLVED (MG/L AS N)	PHOSPHORUS, DISSOLVED (MG/L AS P)	IRON, DISSOLVED (UG/L AS FE)
1S-----	78-06-21	9.7	168	--	4.3	.01	--
2S-----	78-06-21	10	--	--	4.9	.01	0
3S-----	78-06-21	9.8	164	169	3.2	.01	20
4S-----	78-06-21	9.9	174	183	4.2	.01	10
5S-----	78-06-22	10	142	147	2.8	.01	20

Table 3.--Comparison of analyses of water samples collected in 1965, 1976, and 1978, from Mississippian wells in the Joplin area, Missouri

[units are milligrams per liter, except as indicated]

Character or constituent-----	Zinc			Ca/Mg ratio			Sulfate		
Year----	1965	1976	1978	1965	1976	1978	1965	1976	1978
No. of values--	38	21	4	39	21	20	39	21	[illegible]
Median--	.9	.43	.25	7.6	7.6	7.6	53	42	7.1
Range---	.05-6.7	.02-8.8	.07-.99	1.4-75	1.6-229	2.9-55	1.6-466	.8-560	2.8-120

Character or constituent-----	Chloride			Nitrate plus nitrite as N			Potassium		
Year----	1965	1976	1978	1965 [a]	1976	1978	1965	1976	1978
No. of values--	39	21	20	39	0	20	39	21	20
Median--	4.1	3.6	4.7	1.0	----	2.7	1.0	.9	.6
Range---	.2-130	1.7-30	1.5-48	0-63	----	.3-15	.4-43	.3-8.5	.4-1.5

Table 3.--Comparison of analyses of water samples collected in 1965, 1976, and 1978, from Mississippian wells in the Joplin area, Missouri--continued

Character or constituent-----	Sodium			Dissolved solids (residue at 180 °C)			Hardness		
Year-----	1965	1976	1978	1965	1976	1978	1965	1976	1978
No. of values---	39	21	20	39	19	20	39	21	20
Median---	7.5	6.2	4.4	288	258	237	231	220	190
Range----	3.0-106	1.7-20	2.9-59	162-925	214-516	151-396	138-597	76-800	120-340

Character or constituent-----	pH (field)		
Year-----	1965	1976	1978
No. of values---	39	21	20
Median---	7.9	7.1	7.3
Range---	6.1-8.3	5.1-7.6	6.7-7.6

[a]1965 values nitrate only.

and location of recharge and discharge, and on the amount and timing of the change in stage of the reservoir.

Because the changes in the natural flow system can be complex, this flow system must be quantitatively understood to predict the total effects of a rise in stage of a reservoir. However, the "mound" that a rise in reservoir stage will cause in an adjoining aquifer can be estimated from less comprehensive data. Such an estimate provides a useful basis from which further studies can be planned to more fully evaluate the effects of the "mound" on the natural flow system.

The ground-water mound that could form in the shallow aquifer if Prosperity Reservoir is built on Center Creek was evaluated with a digital model. The simulation model assumes two dimensional ground-water flow. The computer program used for this analysis has been documented by Trescott (1976).

Finite-Difference Grid

This analysis requires that the study area be subdivided into a rectangular, block-centered, finite-difference grid. The modeled area which includes the Center Creek basin was subdivided into a finite-difference grid having 37 rows and 52 columns. A variable grid spacing was used so that the grid would be finer in the vicinity of the proposed reservoir. The overall dimensions of the grid were 49 in. by 29.7 in. The scale of the grid was 1:62,500. (See figure 14.)

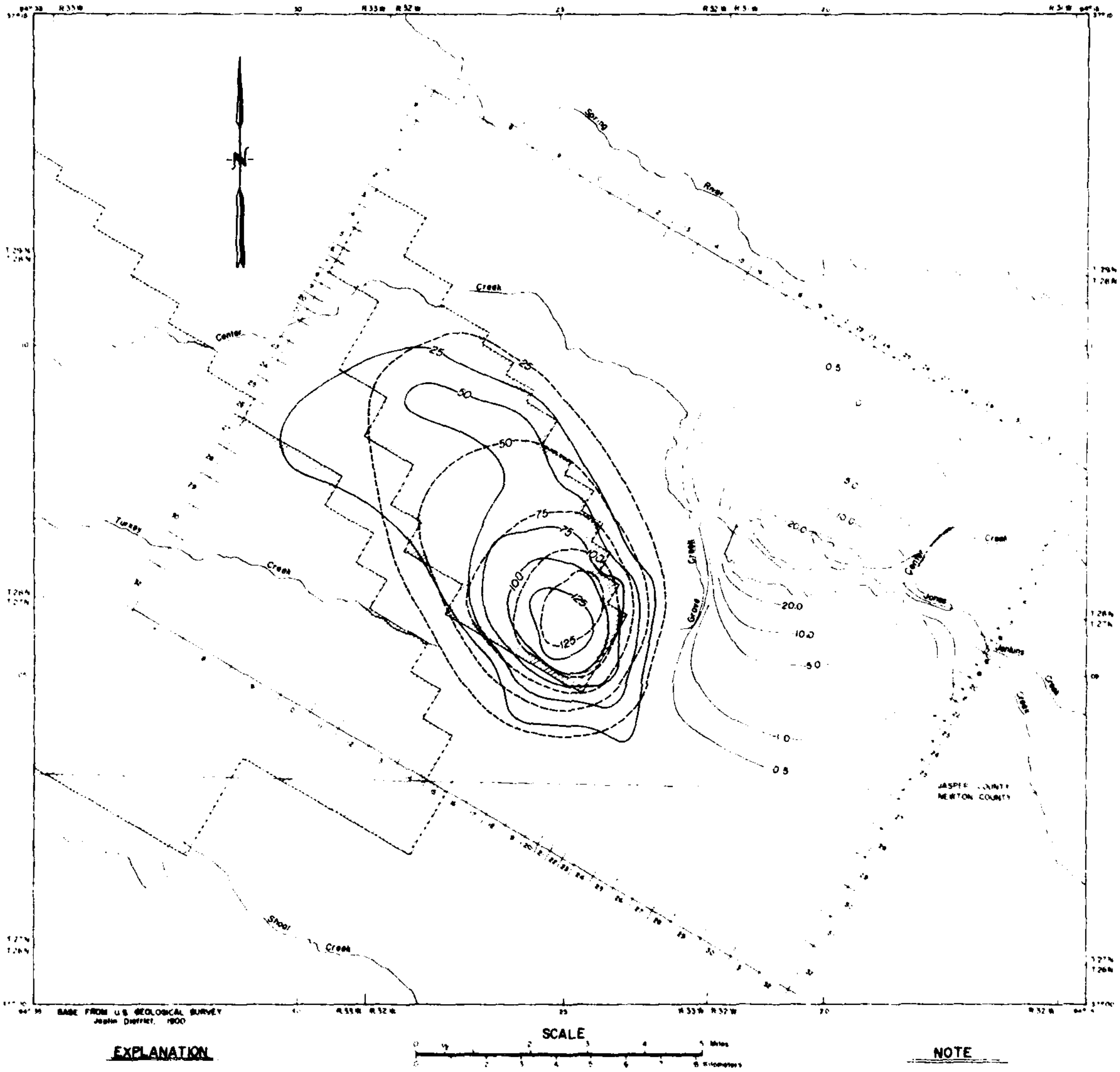
By convention, nodes are located at the centers of the cells of the grid. Any specific node or cell may be referenced by citing its row and column location.

Boundary Conditions and Hydraulic Stresses

All of the perennial streams were modeled as constant-head boundaries. Spring River and Shoal Creek, both perennial streams, bound the modeled area on the north and south sides, respectively. The east and west sides of the area were modeled as no-flow boundaries. The area of interest, Prosperity Reservoir, is far enough away from the east and west boundaries to be unaffected by assuming the no-flow boundaries when the head change is imposed in Prosperity Reservoir.

Sites of known mine discharge in 1965 were represented in the model by specifying a constant flux at the corresponding nodes.

Pumpage of large amounts of water from the shallow aquifer (as occurred in 1965) caused the head in the shallow aquifer to be lower than the head in the deep aquifer causing upward leakage through the confining bed. In



EXPLANATION

—25— Line of equal head change (1965–78). Contour interval 25 feet

- - -25- - - Computed line of equal head change (1965–78). Contour interval 25 feet

0.5 Computed line of equal head change that may occur due to Prosperity Reservoir. Contour interval variable, in feet

NOTE

Rows 9-32 and columns 7-32 of the finite difference grid are numbered on this map

Cells within the shaded area were assigned a transmissivity of 1,000 ft²/d, all other cells were assigned a value of 100 ft²/d

Turkey Creek and Grove Creek are shown only from the beginning of perennial flow where modeled as constant head boundaries

Spring River, Center, Jones, and Shoal Creeks are modeled as constant head boundaries

Figure 14 -- Observed and computed head change (1965-1978) for the Oronogo-Duenweg area, and projected head change that may occur due to Prosperity Reservoir

the model the confining layer was assigned a uniform thickness of 10 ft. Initially the vertical hydraulic conductivity assigned to the confining layer was 1.0×10^{-9} ft/s. The initial vertical hydraulic conductivity used was determined from a water-resources study in the Springfield area, Missouri (Emmett and others, 1978). This value was later changed to 0.5×10^{-9} ft/s by calibration.

Aquifer Properties

One of the aquifer properties needed for the simulation is a value for transmissivity. The transmissivity of an aquifer reflects the rate at which ground water of the prevailing kinematic viscosity will flow through a unit width of the aquifer under a unit hydraulic gradient (Lohman and others, 1972).

The area modeled was divided into a high and a low transmissivity area on the basis of maps showing the distribution of breccia areas in the vicinity of Joplin, Mo. (Missouri Geological Survey and Water Resources, 1922), and on the distribution of well yields in the area.

No aquifer-test data were available for the shallow aquifer in the Joplin area. However, transmissivity of the brecciated area in the southern part of the Oronogo-Duenweg belt was estimated to be 2,000 ft^2/d. The estimate was by the closed-contour method as described by Lohman (1972, p. 46-49). The data used were a water-table contour map and discharge data collected in 1965. On the basis of well-yield data, it is estimated that the low transmissivity area is probably an order of magnitude lower than the brecciated area.

Time-dependent simulations require a value for storage coefficient for the aquifer. The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit of surface area of the aquifer per unit change in head (Lohman and others, 1972). Values for storage coefficient are not available for the shallow aquifer in the Joplin area. Feder and others (1969, p. 27) do indicate that artesian conditions occur in the nonbrecciated areas of the shallow aquifer and that water-table conditions occur in the brecciated areas.

Calibration of the Model

To demonstrate that the simulation model is realistic, field observations of the aquifer must be compared with corresponding simulations using the model.

The field data used were a head change map from 1965-78 (fig. 14). In 1965 seven mine shafts were being pumped (table 4). In 1978 none of the mines were being pumped. In order to simulate the head change map, a steady-state model was used in which the transmissivity of the brecciated area was estimated as 2,000 ft^2/s, and the transmissivity of the rest of the

Table 4.--Summary of mine discharges represented in the model

Mine	Node	Discharge (ft³/s)
Athletic------------------	27, 16	0.60
George H.-----------------	24, 12	.49
Hyde Park-----------------	26, 16	1.67
Ice Plant-----------------	20, 9	.60
King William--------------	28, 16	.18
Kramer--------------------	34, 4	.07
St. Regis-----------------	28, 17	.18
Total---		3.79

area was estimated as 200 ft^2/s. A vertical hydraulic conductivity of $1.0X10^{-9}$ ft/s was used for the confining layer. This resulted in an insufficient head change. Several simulation trials tested different combinations of reduced transmissivity. The final selection resulted in a reduction in the value used for transmissivity in both the brecciated and nonbrecciated areas (1,000 ft^2/s and 100 ft^2/s, respectively). The model was calibrated in the mined area where dewatering had taken place. It was not possible to calibrate the model in the area of the proposed reservoir. Consequently, the value of the calibration is dependent upon the similarity of the transmissivity of the nonbrecciated area near the mines to the reservoir area.

After mining had ceased following World War II, pumping from the mines by industries was negligible. In the early 1960's the chemical industry began to pump mine water for their operations. Two small short-lived mining developments (George H. and Hyde Park) started up in the 1963-65 period. Water supplies for two gravel-washing operations were obtained from mines. In all, seven shafts were pumped, but only one (the Hyde Park) was pumped for the purpose of dewatering.

The next step in the calibration procedure was to simulate a mine hydrograph which showed the effects of mine dewatering. The hydrograph was from a mine that is 1½ mi from the mine being dewatered (Feder and others, 1969, p. 25). This time-dependent model required a value for the storage coefficient of the shallow aquifer. Several simulation trials tested different combinations of storage coefficient. A storage coefficient of 0.0001 in the nonbrecciated area and 0.001 in the brecciated area gave the best fit between the observed and simulated hydrograph. To get a closer fit, several simulations were then made using different values for the vertical hydraulic conductivity of the confining layer. A vertical hydraulic conductivity of $0.5X10^{-9}$ ft/s was finally chosen as giving the best fit (fig. 15).

The steady-state model (step one) was then recalibrated using the reduced value for vertical hydraulic conductivity. Transmissivity values of 100 ft^2/d in the nonbrecciated area and 1,000 ft^2/d in the brecciated area still gave the best fit for the change map (fig. 14).

A time-dependent simulation was made imposing the head change on those nodes that would underlie the conservation pool of the lake. These nodes are treated as constant-head boundary cells. The equilibrium simulated head change in the shallow aquifer caused by construction of the lake is shown in figure 14. The head change projected by the reservoir assumes Grove Creek is a fully penetrating drain on the aquifer. Two additional simulations were made. In one simulation the storage coefficients were each increased an order of magnitude. In the other simulation the transmissivity values were each increased five times. Figure 16 compares the results of these two simulations with the initial simulation. A ten-fold increase in the storage

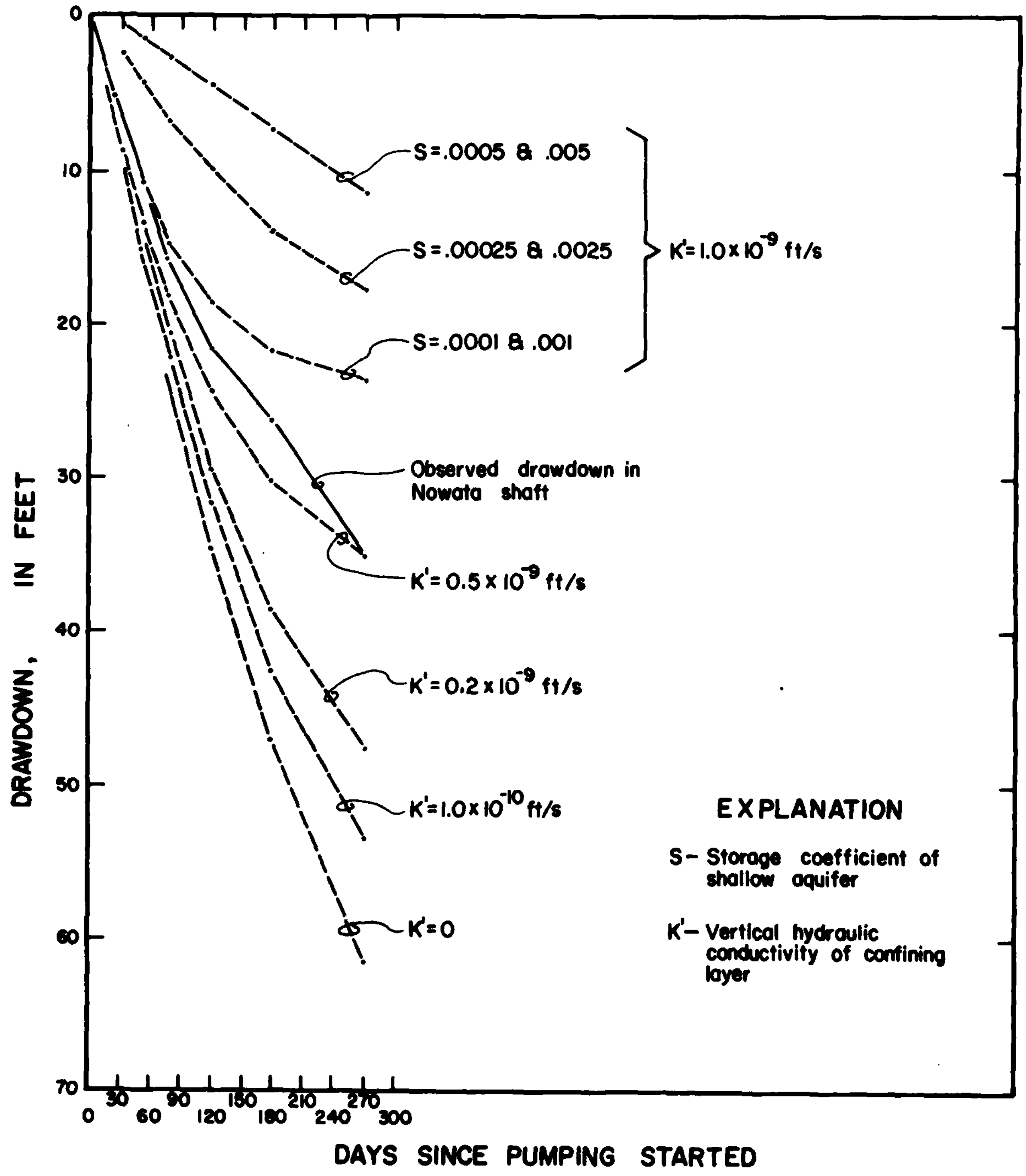


Figure 15.-- Simulation of hydrograph

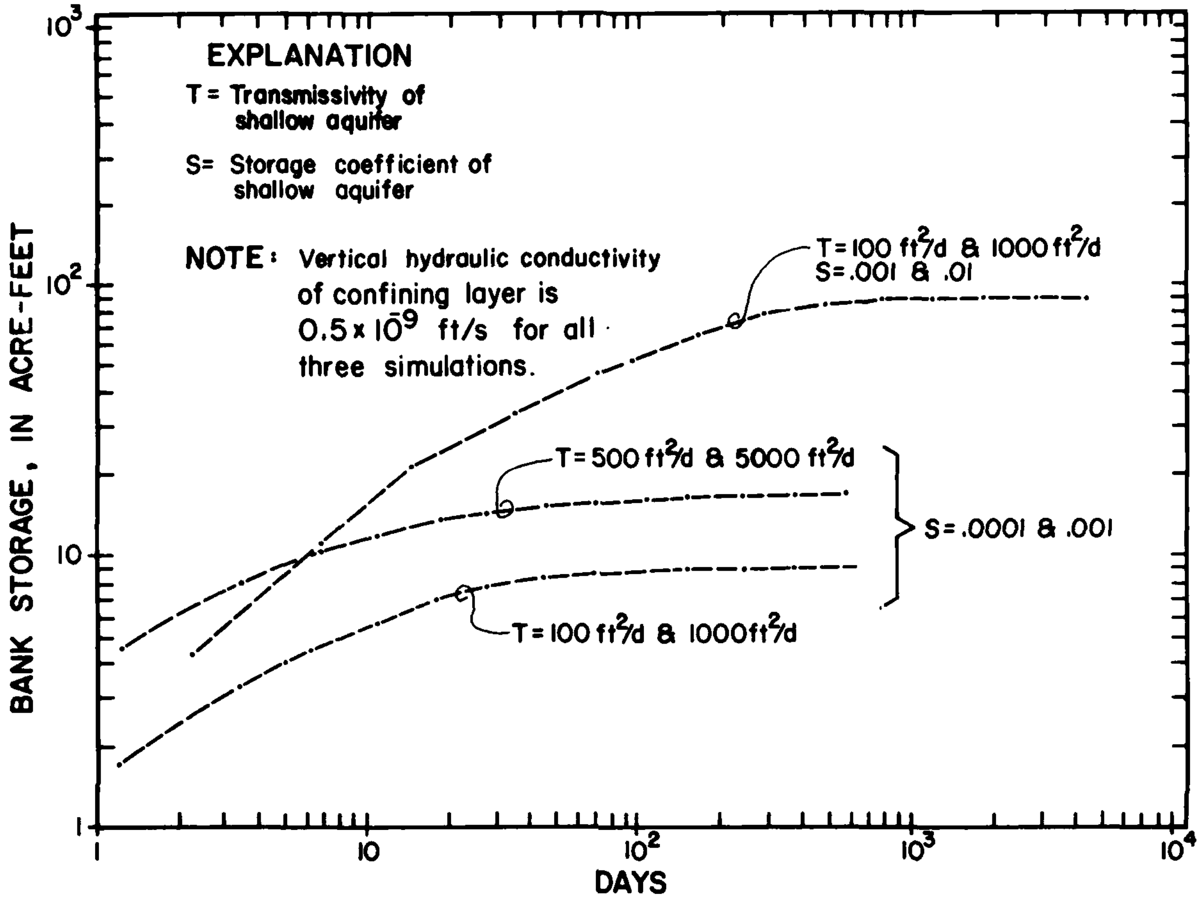


Figure 16.--Computed increase in storage due to construction of Prosperity Reservoir

coefficient results in a ten-fold increase in the amount of water that goes into storage and a longer time (about 11 years) for the cone of impression ("mound") to stabilize than in the initial simulaiton. In the initial simulation the cone of impression stabilized in about 1.4 years. The simulation in which transmissivity was increased resulted in about a two-fold increase in the amount of water that went into storage; however, the cone of impression stabilized in the same time as the initial simulation.

SUMMARY AND CONCLUSIONS

Major aquifers in the study area consist of a shallow limestone aquifer of Mississippian age, which underlies the proposed reservoir, and a deep dolomite aquifer of Cambrian and Ordovician age. The two aquifers are separated throughout 90 percent of the area by about 10 ft of low permeability shale.

In some localities west of Grove Creek, solution activity was great enough to result in the development of permeability estimated to be an order of magnitude higher than that developed east of Grove Creek. Grove Creek lies near the eastern margin of the Oronogo-Duenweg belt where secondary permeability is estimated to be high.

The potentiometric surface in the shallow aquifer slopes with some irregularity from east to west and intersects Spring River and Center Creek at several places, and Grove Creek. The potentiometric surface in the deep aquifer is usually 50-200 ft below that of the shallow aquifer. Major discharge points of ground water from the Mississippian limestone aquifer to the streams lie along Center Creek and the lower reach of Grove Creek.

Water in the Mississippian limestone is moderately mineralized. Ground water from the mining belt generally contains more than 1,000 mg/L dissolved-solids concentration, is a calcium sulfate type, and concentrations of iron and zinc average 5,100 and 9,400 μg/L, respectively.

A model study of the area surrounding the proposed reservoir indicates that water will flow from the reservoir into the adjoining aquifer and from a mound in the potentiometric surface. The mound will be about 20 ft high near the reservoir and extend to the southern part of the Grove Creek basin where it will be only 0.5 to 1 ft high. Any increase in ground-water altitude could result in increased discharge to Grove Creek or perhaps to the Oronogo-Duenweg mining belt. Also, the natural flow system will adjust to the mound by diverting flow to new discharge areas, increasing storage, or decreasing the rate of discharge. The increase in ground-water discharge to Grove Creek will have the beneficial effect of diluting mine-water discharge at Mineral Branch during periods of low flow.

The adjustment of the natural flow system to the mound in the potentiometric surface caused by the proposed reservoir has not been evaluated. Additional work is necessary to evaluate this response, its possible effects on flow to and from the Oronogo-Duenweg belt, and the contribution of mineralized water to Center Creek.

1. Additional field data are needed to better define the aquifer characteristics, aquifer boundaries, and the properties of the confining beds. Detailed seepage runs should be made on Grove Creek and a dye trace should be made to confirm a connection between Grove Creek and Scotland Spring and to help evaluate the efficiency of Grove Creek as a hydraulic boundary. To define the vertical hydraulic conductivity of the confining beds would require tests with observation wells completed above and below the confining beds.

2. These field data need to be analyzed through additional model runs to determine the maximum possible area that could be affected by the proposed dam. Such an analysis will help evaluate the possibility that the proposed dam might increase the flow of mineralized water from the Oronogo-Duenweg mining belt to Center Creek.

3. A monitoring network should be designed and put in operation so that background conditions of flow, altitudes of water levels, and water quality can be established prior to dam construction.

4. Measurements of natural flow in Grove Creek downstream from Scotland Spring, taking into account the quantity used by industry correlated with the flow lost from the upstream reach, would help to corroborate the results of a dye trace and establish Grove Creek as an effective hydrologic boundary.

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16. Abstract (Limit: 200 words)

A reservoir has been proposed on Center Creek, Jasper County, southwestern Missouri. Ground-water levels in the limestone uplands adjacent to the reservoir will rise when the impoundment is completed. The site is a few miles upstream from the Oronogo-Duenweg belt in the Tri-State zinc district. Grove Creek joins Center Creek downstream from the reservoir separating it from the mining belt.

A model study indicates water-level rises varying from about 20 feet near the reservoir to 0.5 to 1.0 foot in the southern part of the Grove Creek drainage basin. A significant rise in the water table adjacent to the reservoir could increase mine-water discharge if Grove Creek is not an effective drain. However, it is probable that Grove Creek is an effective drain, and that higher ground-water levels in the reservoir area will increase ground-water discharge to Grove Creek, and in turn, Center Creek. The increase in ground-water discharge to Grove Creek will have the beneficial effect of diluting mine-water discharge from the Oronogo-Duenweg belt during periods of low flow.

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