GROUND-WATER AVAILABILITY
IN CARBONATE ROCKS OF THE
DANDRIDGE AREA,
JEFFERSON COUNTY, TENNESSEE

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations

Open-File Report 79-1263

Prepared in cooperation with the

Tennessee Division of Water Resources, and the

Town of Dandridge

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METRIC CONVERSIONS

Inch-pound units used in this report may be converted to metric units by the following conversion factors:

Multiply inch-pound units	By	To obtain metric units
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
square foot (ft^2)	0.0929	square meter (m^2)
inch (in.)	25.4	millimeter (mm)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter (L/s)/m
square foot per day (ft^2/d)	0.0929	square meter per day (m^2/d)

Ground-Water Availability in Carbonate Rocks of the Dandridge Area Jefferson County, Tennessee

by

E. F. Hollyday and P. L. Goddard

ABSTRACT

Ground water occurs in solution openings that follow bedding planes and strike joints in the folded and faulted dense limestone and dolomite of the Valley and Ridge physiographic region in the Dandridge area. Recharge beginning at topographic highs in the northwest moves across strike to lows in the southeast; it is intercepted and collected by high permeability beds in the middle of the Knox Group and is routed along strike to discharge at large springs. Exploratory wells were drilled at two sites to test this concept of the flow system. Three wells at Moore Spring site in the recharge area penetrated only mud and solid rock. Four wells at Riley Spring site in the discharge area each penetrated at least five water-bearing openings that gave these wells an average production of 93 gallons per minute and a maximum of 180 gallons per minute. Based upon this test, criteria for locating large-production wells are: (1) near a large spring, (2) near a dry creek, and (3) near the contact between the Copper Ridge Dolomite and Chepultepec Dolomite.

INTRODUCTION

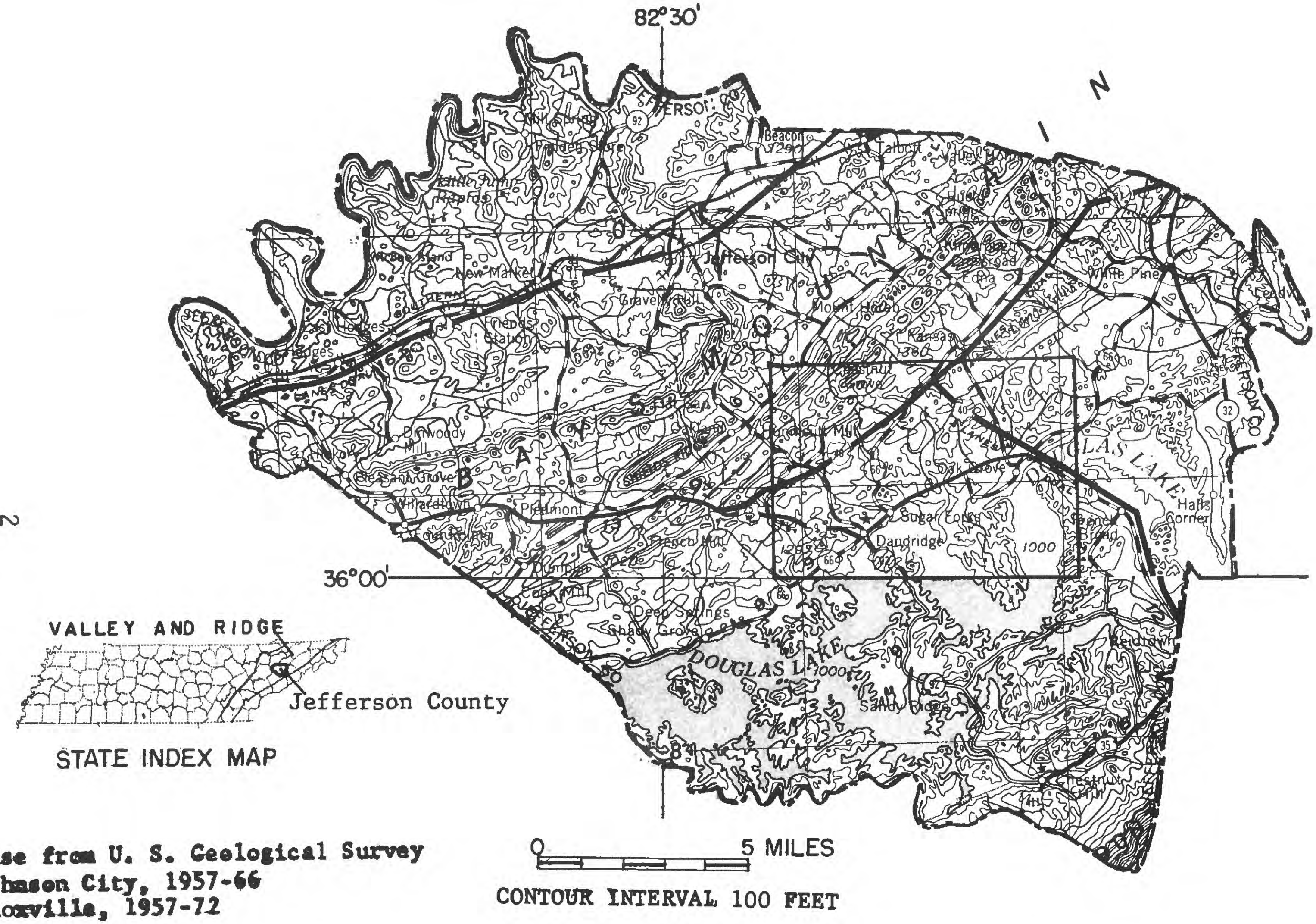
The Dandridge Area is located in east Tennessee in the Valley and Ridge physiographic province (fig. 1).

In this area there is very little specific information available as to the occurrence, quantity, and quality of ground water. In an effort to rectify this, Dandridge entered into an agreement with the Division of Water Resources of the Tennessee Department of Conservation and the U.S. Geological Survey to investigate the occurrence and characteristics of ground-water resources in the area.

The purpose of this report is twofold. Firstly, to describe the development of concepts of the physiographic and geologic occurrence of large solution openings in the folded and faulted carbonate rocks in the Dandridge area and secondly, to test these concepts with results of exploratory drilling and aquifer testing.

Previous Studies

The geology of the Dandridge area has been reported in the 1:24,000-scale geologic map of the Jefferson City quadrangle by Hatcher and Bridge (1973) and in an unpublished thesis (Feder, 1963) on the geology of Oak Grove. Bridge (1956) presents a detailed discussion of the stratigraphy and the lithologic criteria used in subdividing the Knox Group into five formations in the adjacent Jefferson City zinc mining district. DeBuchananne and Richardson (1956) present an overview of the ground-water resources of Jefferson County and 27 other counties in east Tennessee.



Base from U. S. Geological Survey
Johnson City, 1957-66
Knoxville, 1957-72

Figure 1.--Location of the study area in Jefferson County, east Tennessee.

They discuss water occurrence and well production in carbonate rocks as compared to shale, give data on the number of springs with more than 450 gal/min flow in each rock formation, and give data on individual wells and springs in Jefferson County. Zurawski (1978) summarizes concepts of ground-water occurrence in the Valley and Ridge as well as five other provinces in the Tennessee Region.

Acknowledgments

We would like to thank Herbert Webb, Mayor of the Town of Dandridge, H. B. Jarnagin, Chairman of the Sewer and Water Board, and Ronald B. Merville, Merville & Keel, Inc., Engineers and Planners, for their cooperation, support, and enthusiastic interest in this study. Joe M. Samples of Jefferson County drilled the exploratory wells and assisted in the collection of geologic and hydrologic data. Gwyn Calfee and Joe Samples shared with us their many years of experience in drilling wells and developing water supplies in the Dandridge area. Mr. Rube Whaley shared his knowledge of springs with us.

J. D. Lewis assisted the authors during field reconnaissance. W. J. Harris and A. M. Jenkins, Tennessee Valley Authority, assisted with the aquifer test.

HYDROGEOLOGIC FRAMEWORK

Physiography

The study area is in the east central part of the Valley and Ridge physiographic region in Tennessee (Miller, 1974), where sets of long, narrow, wooded, northeast-trending ridges that are underlain by sandstone are separated by broad, rolling, agricultural valleys that are underlain by dolomite, limestone, and shale. The area is bordered on the northwest by Bays Mountain which rises about 350 ft above the surrounding terrain to an elevation of 1720 ft above sea level. The area is bordered on the southeast by Douglas Lake, an impoundment on the French Broad River and by low dissected hills on peninsulas in the lake. The area is underlain predominantly by soluble dolomite and limestone, and sinkholes are numerous. However, overlapping sinkholes or large areas with interior drainage are not common (fig. 2). Within the study area sinkholes are most numerous in the outcrop areas of two rock formations. Small springs and seeps are also numerous but there are only four springs known to have flow as much as 450 gal/min.

The area is drained by five small streams flowing southeast to the French Broad River. The drainage areas of each of the streams are given in table 1.

Table 1.--Basin drainage areas for streams in Dandridge area

Stream	Area (mi^2)
Spring Creek	2.4
Koontz Creek	3.9
Rimmer Creek	3.3
City Spring Creek	1.5
Goose Creek	2.4

Climate

On the average, the area receives 45 in of precipitation a year. This varies from 4.5 to 5 in per month in January, February, and March to 2.5 to 3 in per month in September, October, and November. Mean annual temperature is about 58° Fahrenheit.

Geology

The area is underlain by a folded sequence of dolomites interbedded with lesser amounts of dolomitic limestone, limestone, shale, and sandstone of Late Cambrian through Middle Ordovician age. As much as 5,000 ft of section is exposed. This thickness is subdivided into nine formations based upon the sequence of rock types, crystal size, bedding thickness, and occurrence of chert or silification (table 2). The Knox Group, which is predominantly chert-bearing dolomite, comprises the middle 60 percent of this thickness.

The limestones were formed by the solidification by heat and pressure over a period of many years of deposits of calcareous mud, fragments of the skeletons of marine organisms, and minor amounts of quartz sand grains. Some limestones have been recrystallized; many that were largely composed of calcite ($CaCO_3$) have been replaced by dolomite ($CaMg(CO_3)_2$). These rocks have virtually no pores, or primary openings, in which ground water might occur or move.

Secondary openings, formed after the sediments were solidified and recrystallized, occur in the rocks along bedding planes, joints, and the innumerable fractures that occur in the rocks. Many of these minute secondary openings have been widened by mildly acid rainwater dissolving the calcite or dolomite crystals along the walls of the minute openings. These solution openings give the otherwise dense rock secondary porosity and permeability in which ground water occurs. However, the frequency and width of these openings are thought to decrease with depth below land surface.

Outcrops of hard rock of the Knox Group are very scarce, requiring that previous geologic mapping of this unit be done largely on the basis of the occurrence of various types of chert and sandstone fragments in the overlying residual soil. The Chepultepec Dolomite is one of the most soluble formations in the Knox Group (Bridge, 1956). It also has the greatest variety of rock types in its bedding sequence (table 2), and its outcrop area has the second most abundant occurrence of sinkholes.

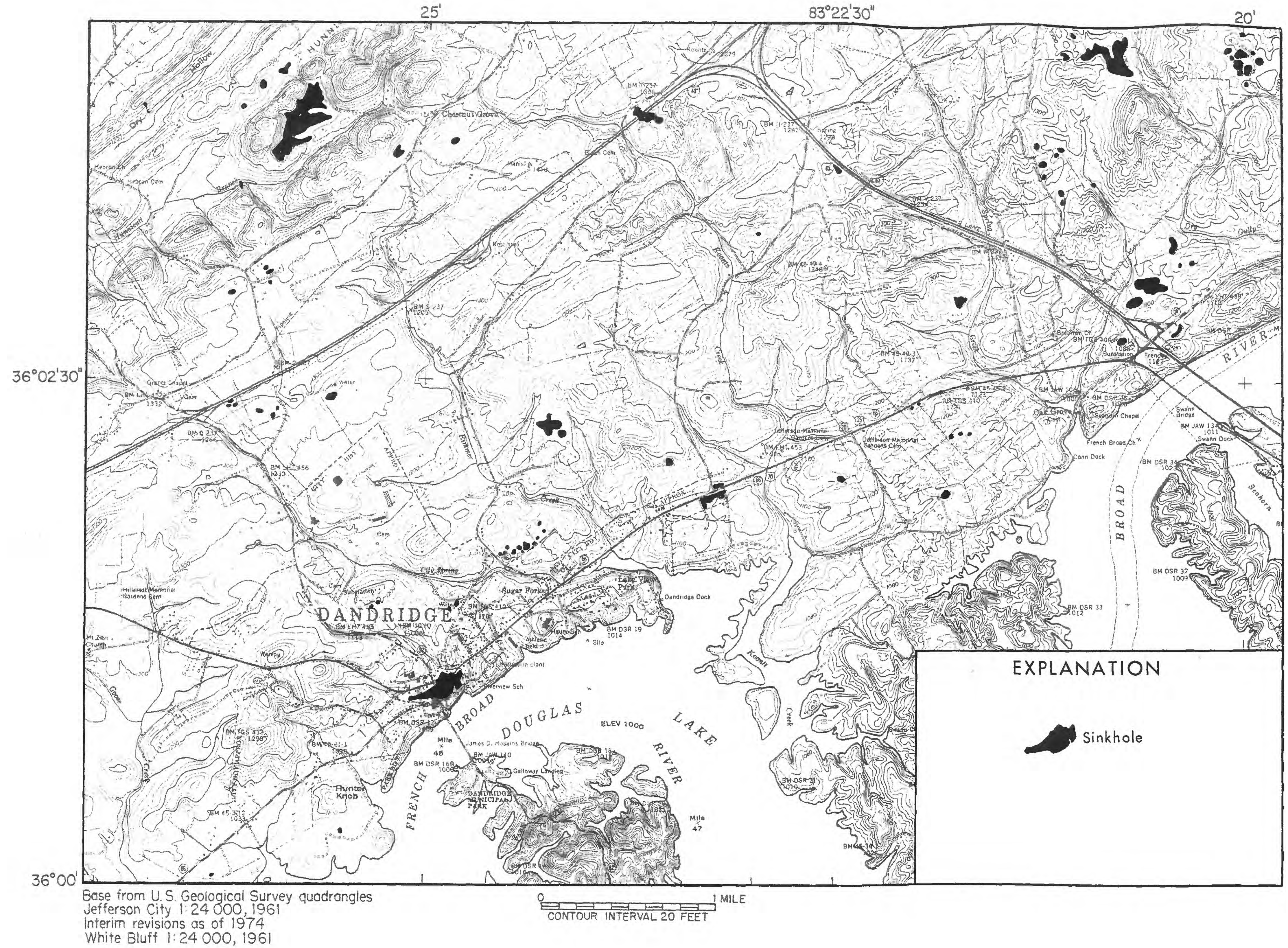


Figure 2.-- Distribution of mapped sinkholes in the Dandridge area.

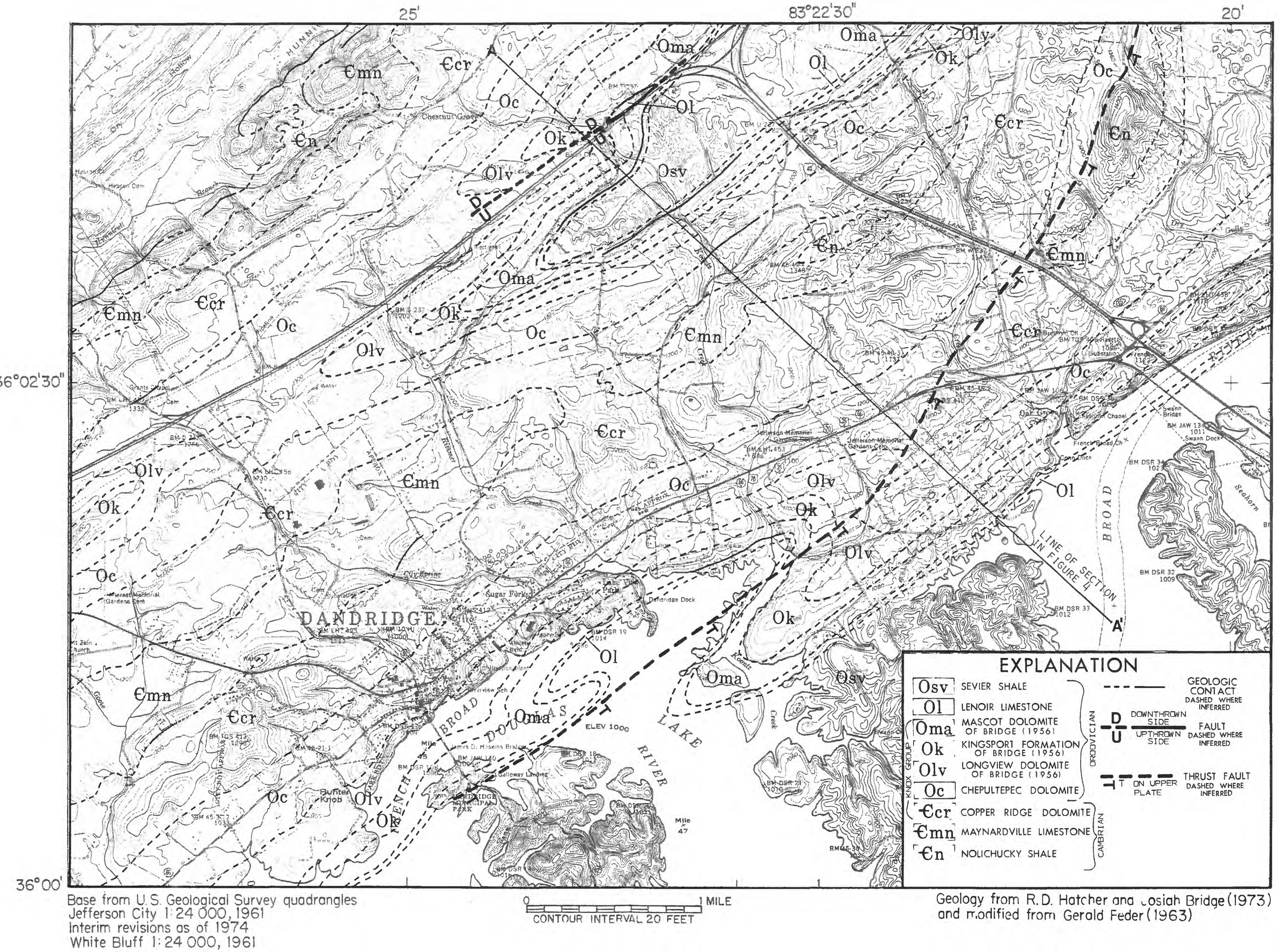


Figure 3.-- Geologic map of the Dandridge area.

In general, limestone, particularly dolomitic limestone, appears to be more soluble than dolomite. Where outcrops are few, dolomite is more common in outcrop than limestone. In outcrop, the dolomite often has closely spaced, fine lines or grooves in two sets that are not at right angles to one another but form a rhombic network, one angle of which is about 120°. These grooves give the weathered surface of the rock a gashed or slashed appearance. They are always associated with dolomite (Bridge, 1956). Microscopic examination reveals these gashes to be microfractures in the dolomite from which the calcite filling has been dissolved (Feder, 1963).

In the eastern third of the Dandridge area, the Copper Ridge Dolomite appears to be largely limestone rather than dolomite, although the evidence is meager because outcrops are very scarce (Feder, 1963). Perhaps this is one reason why the Copper Ridge Dolomite has the greatest abundance of sinkholes (table 2) in this area.

The distribution of the bedrock formations underlying the residual soil is shown in figure 3. The contacts between formations strike northeast. In most places, the beds dip at least 30° to the southeast or northwest depending upon the position of the bed on the flanks of several folds (fig. 4).

Although the Dandridge area is representative of the belt of folding situated between the thrust faults of Bays Mountain on the northwest and English Mountain on the southeast, the area does contain one thrust fault and one minor reverse fault. Rocks along these faults are more intensely broken and fractured than elsewhere. In some places this more intense fracturing may have increased the extent of solution development.

Initial Hydrologic Concept

According to the principles of hydrology, ground water moves from points of higher elevation or greater pressure to points of lower elevation or less pressure. However, the path that it takes is constrained by porosity and permeability of the host material. In limestone in eastern Tennessee these paths are composed almost exclusively of solutioned openings. Previous studies in the limestone terrain of the Savannah Valley area in Hamilton County, Tennessee (D. R. Rima, U.S. Geological Survey, written commun., 1978), have shown that the most likely path of movement will be along bedding planes in the direction of strike and then along joints and fractures transverse to the strike in the direction of the dip. A concentration of transverse fractures is usually revealed by the presence of a stream valley cutting across the strike of the upturned beds. Ground-water flow and solution channel development are likely to be concentrated along these transverse fractures and along the more soluble beds in the sequence (fig. 5). In these locations it should be possible to tap large ground-water supplies with wells.

Table 2.--Geologic description and water-baring characteristics of rock formations in Dandridge area

Geologic Unit	Thickness (ft)	Physical character	Water-bearing characteristics
Sevier Shale	More than 1000	Shale, calcareous, dark-gray (fresh), thin layers of limestone near the base.	Yields water sufficient for domestic supply from cleavage planes at shallow depth. Water may have high sulphur and iron. In all east Tennessee, 2 out of 40 springs flow at least 450 gal/min.
Lenoir Limestone	0 - 200	Limestone, shaly, olive-gray, very fine grained, thin-bedded, Mosheim Member at base, cryptocrystalline limestone, medium- to thick-bedded. Calcite "eyes."	Very limited in areal extent. In east Tennessee, three of eight springs flow at least 450 gal/min.
Knox Group Mascot Dolomite of Bridge (1956)	350 - 600	Dolomite, siliceous and cherty, medium dark-gray, cryptocrystalline, thin- to medium-bedded; limestone, cryptocrystalline, medium- to thick-bedded. Sandstone at base.	In Knox Group, in general water occurs in joints and bedding-plane solution openings. Yields small to large supplies to wells. Water is of good quality. In east Tennessee, 11 of 37 springs in Mascot Dolomite flow at least 450 gal/min.
Knox Group Kingsport Formation of Bridge (1956)	250 - 400	Dolomite with chert nodules, light gray, either very fine or coarse crystalline, thin- to medium-bedded; limestone and laminated dolomite (in lower half of formation), cryptocrystalline, light-gray or brown, thick bedded with many clay partings, "dove limestone."	In east Tennessee, two out of eight springs in the Kingsport flow at least 450 gal/min.
Knox Group Longview Dolomite of Bridge (1956)	200 - 400	Dolomite, siliceous, very light gray, fine- or coarse-crystalline, with round quartz grains throughout; limestone (in upper half of formation) light bluish-gray, very fine or coarse crystalline.	Water occurs in solution openings. In 1979 no published data are available for large springs in this formation.

Table 2.--Geologic description and water-bearing characteristics of rock formations in Dandridge area--Continued

Geologic Unit	Thickness (ft)	Physical character	Water-bearing characteristics
Knox Group Chepultepec Dolomite	500 - 600	Limestone, dolomitic, cherty, olive-gray to brownish-black, cryptocrystalline, thick-bedded; dolomite, cherty, light-gray, fine-grained, thick-bedded; sandstone, fine- to medium-grained, beds up to 10 ft thick. More sinkholes than any other formation except the Copper Ridge Dolomite.	In east Tennessee, 2 out of 30 springs in the Chepultepec flow at least 450 gal/min.
Knox Group Copper Ridge Dolomite	900 - 1200	Dolomite, or dolomitic limestone in lower 3/4 of formation, dark purplish-gray, cryptocrystalline to saccharoidal, fetid or asphaltic odor; dolomite (in upper ¼), light-gray, very fine grained, with interbeds of chert, siliceous oolite and calcareous sandstones. The most sinkholes of any formation in area.	In east Tennessee, 16 out of 96 springs in the Copper Ridge flow at least 450 gal/min.
Maynardville Limestone	175 - 420	Dolomite or dolomitic limestone (in upper half), light-gray, cryptocrystalline to medium crystalline, thin-bedded, very little chert; limestone, (in lower ½), medium- to dark-gray, thick-bedded, chert-free. Calcite vugs.	Contact springs occur at shale-limestone contacts. In east Tennessee, three out of five springs in the Maynardville flow at least 450 gal/min.
Nolichucky Shale	200 - 400	Shale, calcareous, olive-gray, laminated to thin-bedded, some beds are cross laminated.	Yields are sufficient for domestic supply, 2-10 gal/min; water may have high sulfur and iron content.

COLLECTION AND INTERPRETATION OF HYDROLOGIC DATA

Well Data

In 1978 records of 89 wells in the Dandridge area were on file with the Division of Water Resources of the Tennessee Department of Conservation. Those records having map locations and most complete data were used to determine the success that area residents have had in obtaining a water supply for their home or farm. According to those records, no wells are shallower than 40 ft below land surface. As shown in figure 6, 52 percent of these wells range in depths between 80 and 200 ft, whereas a few wells are as deep as 500 or 600 ft. The median depth of wells in the area is 170 ft. Of the wells for which a value is given the average casing length is 50 ft.

Fifty percent of the wells for which there are records produce 10 gal/min or less (fig. 7). Forty percent of the wells listed produce between 10 and 50 gal/min, but only 10 percent produced more than 50 gal/min.

Discussion with Drillers

Some insight into water occurrence and typical well construction in the Dandridge area was obtained from two water-well drillers in Jefferson County. They have found that very little water, if any, is available from soil above limestone and dolomite bedrock. The depth of zones that yield more than 50 gal/min in limestone or dolomite bedrock is about 250 ft. If no water is produced from a well at depths shallower than 300 to 400 ft, there is only a very small chance that any water will be obtained below those depths. There are wells in the area that produce as much as 300 gal/min, but a discharge of this magnitude is very seldom measured because it is very much greater than most landowners need.

Water-bearing zones in limestone and dolomite are crevices or joints in the rock. Above the water surface, the crevices are filled with soil or mud. Below the water surface they are usually filled with mud or water, and usually the more mud blown from a well during drilling, the more water will be found in the water-bearing zones. By pumping and surging for approximately 4 hours the mud can be cleaned out of a well. It is not unusual for wells to be cased to depths between 100 and 110 ft to keep mud in the shallower crevices from contaminating water pumped from the well.

Local drilling contractors have found that the quality of water obtained from wells drilled in limestone or dolomite is much better than that obtained from shale, the third major rock type in the Dandridge area. Drillers have also found that in areas where limestone and shale are butted against each other, as along a fault, there are very good chances of obtaining large amounts of water from the limestone. Usually wells

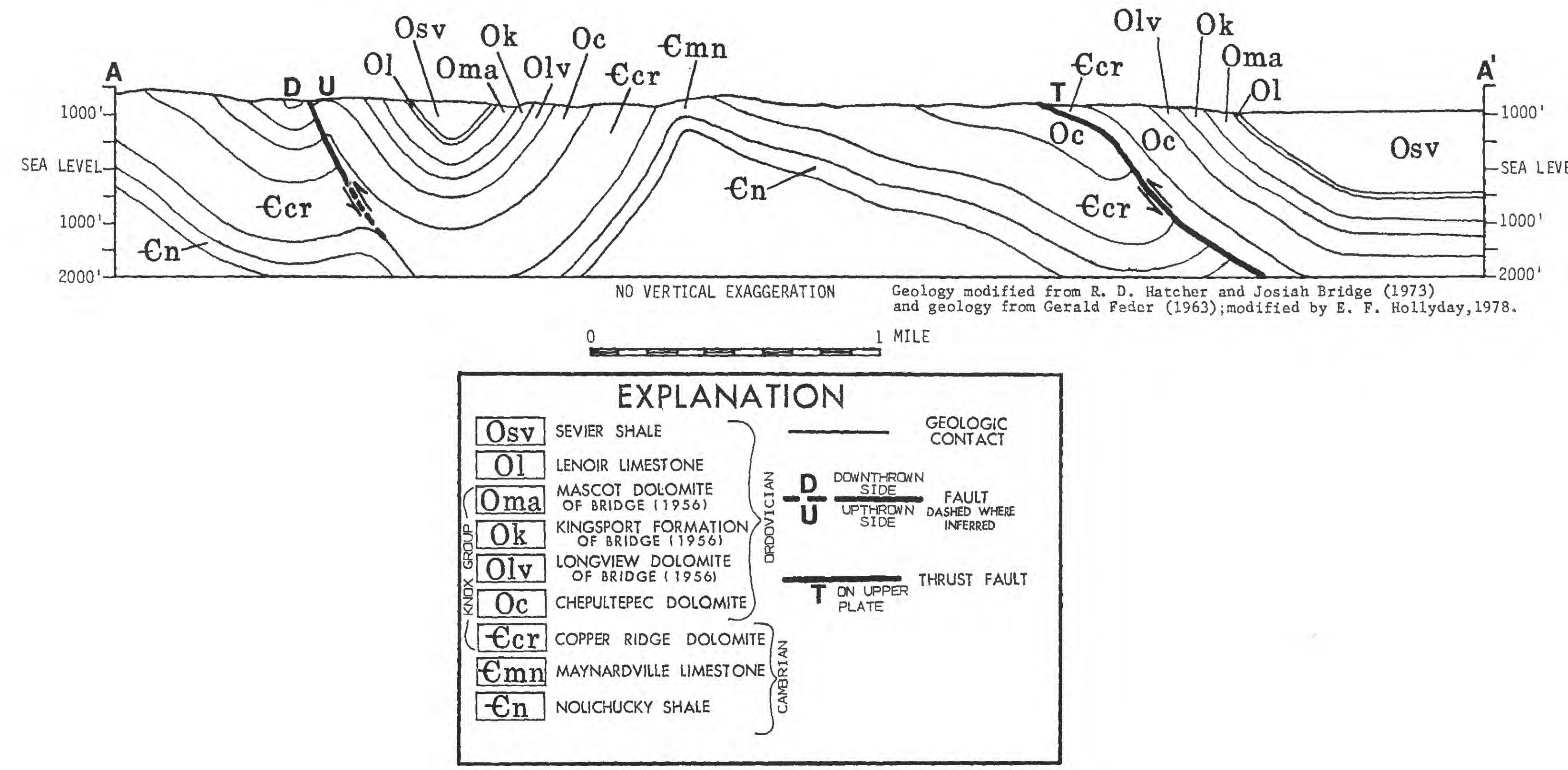


Figure 4.-- Geologic cross section of rocks in the Dandridge area.-

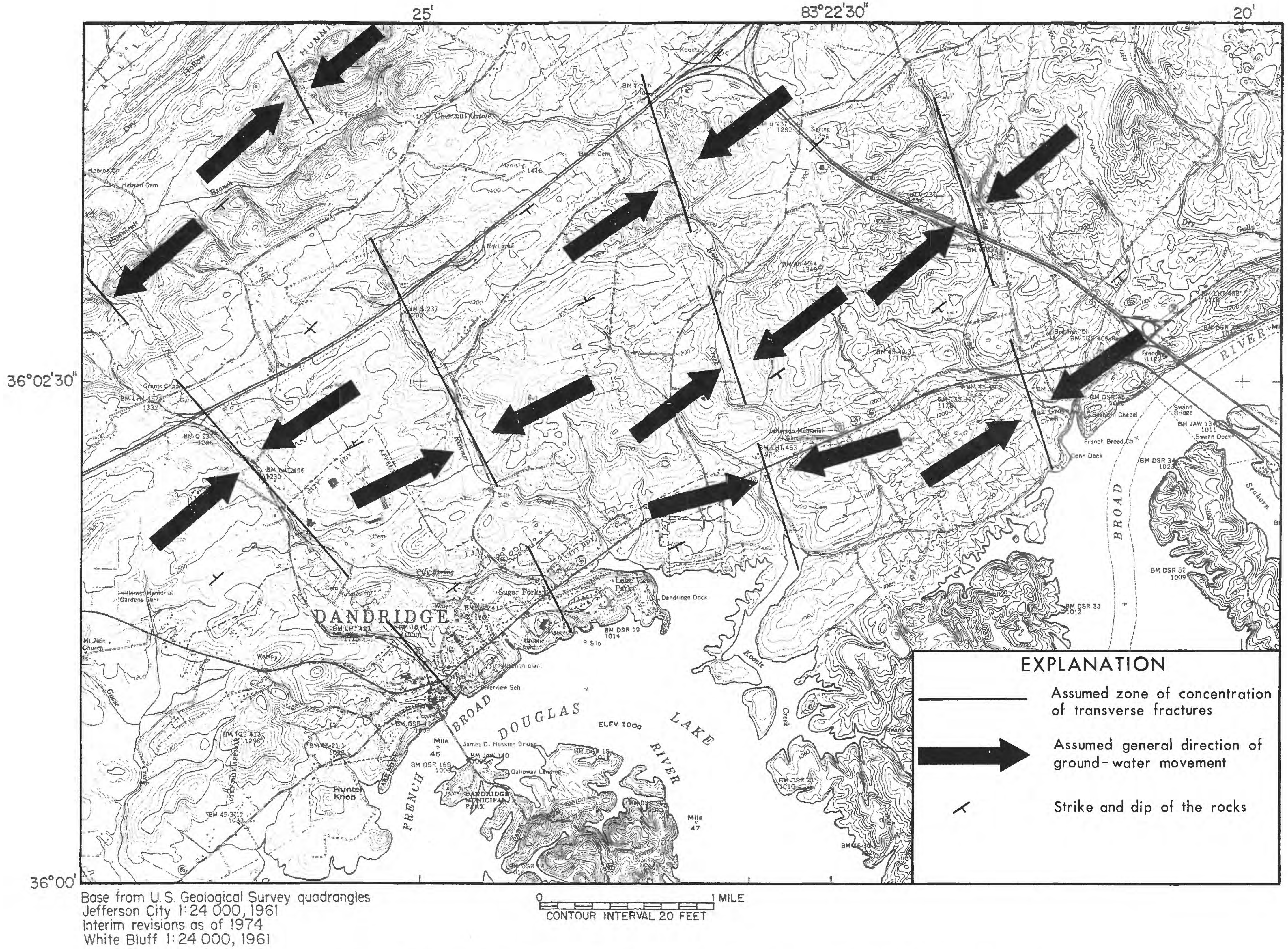


Figure 5.-- Initial concept of ground-water movement in the Dandridge area.

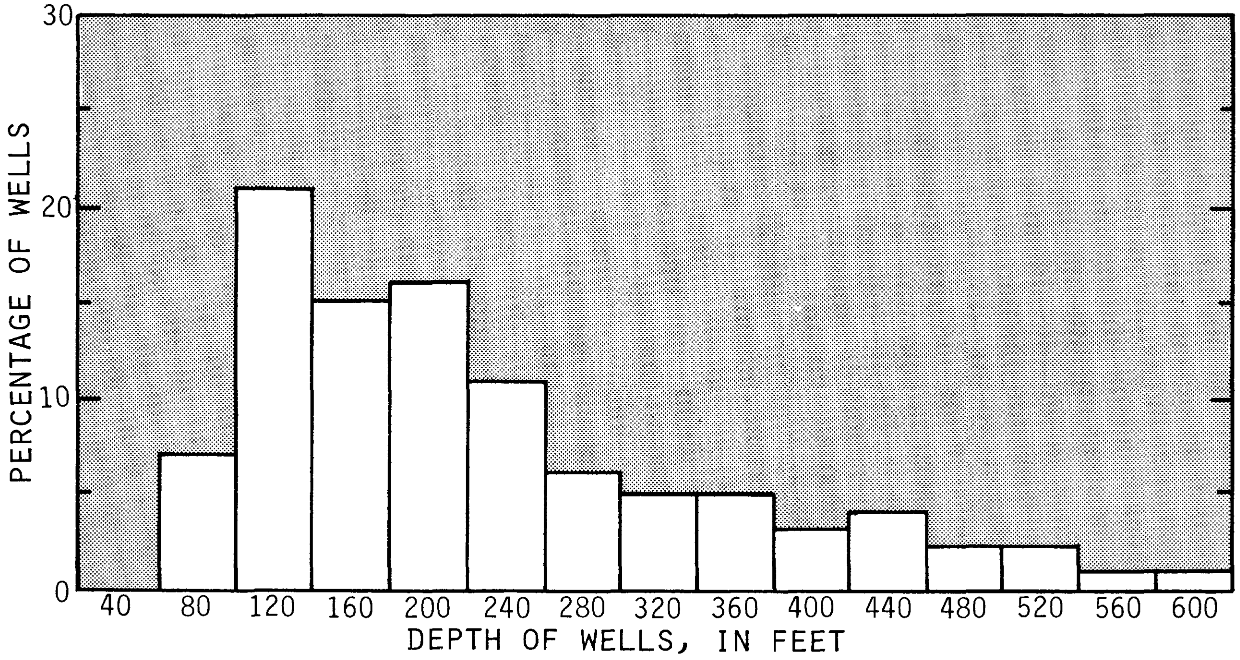


Figure 6.-- Frequency distribution of the depth of wells in carbonate rocks in the Dandridge area.

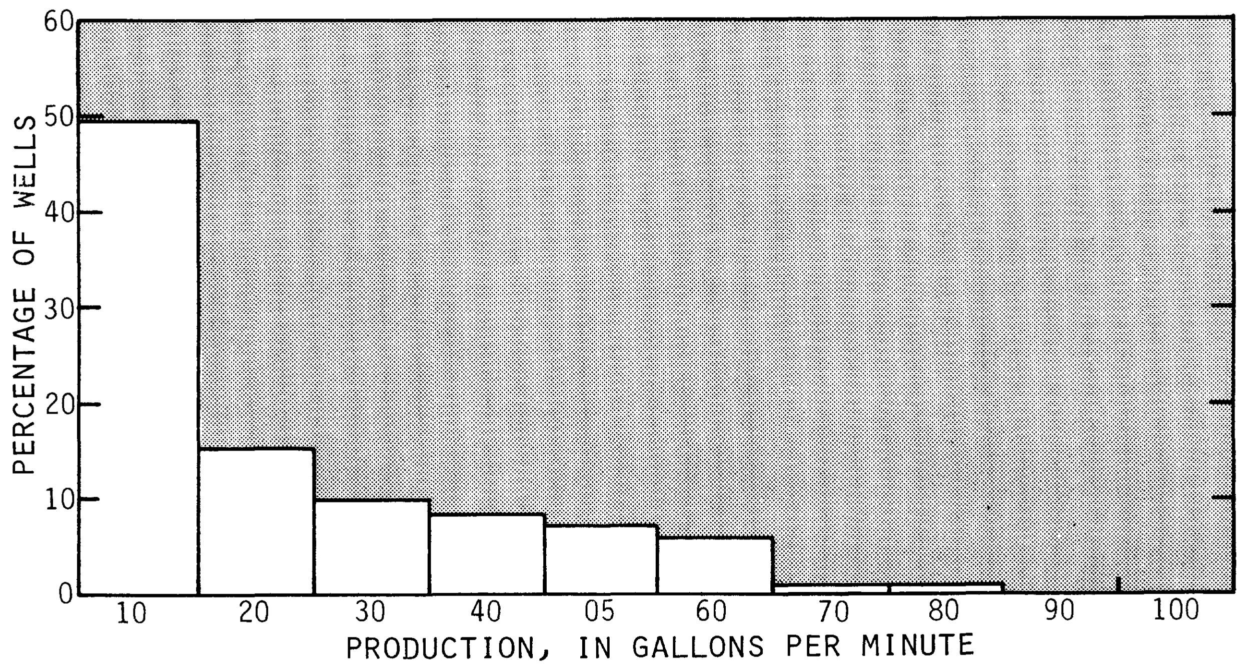


Figure 7.-- Frequency distribution of the production of domestic and farm wells in the Dandridge area.

penetrating flat-lying beds have greater yields than those in steeply dipping beds. Large amounts of water have been obtained from some wells located in the vicinity of large springs. Other wells close to springs have penetrated very tight rock below the ground elevation of the springs and have been drilled to unusual depths without producing usable amounts of water.

Stream and Spring Survey

Significance of Difference in Base Flow

Streamflow is maintained by discharge from ground-water sources after all water that is not retained in ponds or reservoirs has drained off the surface of the land following precipitation. This stream discharge is referred to as base flow. The source of this water is ground water in storage in the deep intersticial soils above bedrock, and in the solution openings in the bedrock. Discharge from the soils occurs at innumerable seeps. Discharge from the larger solution systems occurs at a few large springs.

During base flow, at any instant in time, streamflow varies considerably from place to place, even on streams that have drainage basins that are near identical in size. For any climatologically and physiographically homogeneous area as small as the study area, the determining factors governing these differences in flow are the balance between gains in streamflow from seeps and springs and losses in streamflow through solution openings in the bottom of the stream channel in the basin above the point of observation. The reason for a stream to be either deficient in flow or completely dry is that solution openings beneath the stream are large and extensive enough not only to transmit water from hills to valleys but also to divert streamflow underground and thus to drain the area by subsurface routes. This water is soon returned to the surface by a spring or springs either downstream from the area of water loss or in an adjacent watershed. In short, the large solution systems can be located by observing reaches of stream that are either dry or deficient in flow when compared with nearby basins of comparable area during conditions of base flow.

Field Survey of Streams and Springs

Color infrared aerial photography of the Dandridge area was interpreted for the occurrence of dry stream reaches and wet stream reaches. This photography, which is available from the Mapping Services Branch, Tennessee Valley Authority, was acquired by the National Aeronautics and Space Administration during a period of high base flow on April 18, 1972. A high-altitude U-2 aircraft and Zeiss mapping camera with a 12-inch focal length were used to derive a scale of photography of 1:60,000. At this scale and with this equipment, objects the size of tractor-trailer trucks are clearly visible. Clear water appears blue black; slightly turbid water is light blue to cream.

Figure 8 shows the distribution of dry reaches of stream, wet reaches of stream, ponds, and wet sinkholes that could be identified using this photography. All five of the small streams flowing southeast to the French Broad River that drain the study area are wet and, based upon topography, would appear to be flowing. However, there appear to be several places where there is interrupted flow in the tributaries to these streams. In these places a stream has flow in its headwaters, then becomes dry in the downstream direction, then becomes wet again further downstream. One such occurrence is in the headwaters of an unnamed left bank tributary to Spring Creek immediately north of Interstate 40 and Route 66A interchange. Presumably the flow which this tributary derives from seeps and springs in its headwaters is lost downstream to solution openings beneath the stream.

To determine where this water might reappear at land surface, the largest springs known at the time were added to figure 8. These are Swann Spring, Fain Spring, Riley Spring, and City Spring. A line of wet sinkholes with long axis trending northeast (fig. 8) extends in a northeast direction along the strike of the rocks from Swann Spring to and past the lower reaches of the dry left bank tributary of Spring Creek. It appeared possible that the water lost from this unnamed tributary to Spring Creek might resurge at Swann Spring.

Perhaps tributaries to the other main streams in the area are also losing water that is reappearing at other major springs. In this regard there appear to be at least four areas with dry reaches of stream, three of which are situated topographically above known springs (fig. 8). These areas are identified by unusually long dry reaches of streams without tributaries which are themselves tributary to the previously mentioned main streams. The first area is the land between Dry Gully and Spring Creek, northeast of Swann Spring. The next to the southwest is the land between Spring Creek and Koontz Creek. During the initial phase of the study no large spring was known to drain this area. The next area to the southwest is the land between Koontz Creek and Rimmer Creek, north of Riley Spring. The last area is the land between Rimmer Creek and City Spring Creek, north of City Spring. These four areas may be underlain by extensive solution systems, three of which may be draining to known springs.

Comparison of the location of Swann Spring, Riley Spring, and City Spring with the underlying geology (fig. 3) reveals that all three springs discharge from the Copper Ridge Dolomite, which has more sinkholes than any other formation in the area. Swann Spring, Riley Spring, and Fain Spring are located near the contact of the Copper Ridge Dolomite and the Chepultepec Dolomite. It was hypothesized that if a large spring drained the land between Spring Creek and Koontz Creek it probably would be located near this contact. Reexamination of the color infrared aerial photography revealed what appeared to be a short spring tributary on the right bank of Spring Creek in the outcrop belt of the Chepultepec Dolomite near its contact with the Copper Ridge Dolomite. Later field reconnaissance confirmed the existence of Raines Spring (fig. 8).

A reconnaissance of the watershed of Koontz Creek, Rimmer Creek, and City Spring Creek from low-flying aircraft on August 16, 1978, revealed little change in the stream drainage net compared to April 18, 1972. A few more streams without tributaries were dry and the first occurrence of water in the headwaters of the main streams was further downstream. Several additional springs were located, however, for later inspection on the ground.

To test the preliminary concept that ground water flow is collected by fractures and joints transverse to the strike of the rocks (that is, parallel to the dip of the rock) as in figure 5, two stream reaches were selected for detailed reconnaissance: Rimmer Creek between Route 66 and 66A as it passes Riley Spring, and the left bank tributary to Spring Creek northeast of Swann Spring. The authors walked these reaches estimating discharge, measuring conductance and temperature of the water and strike and dip of the rocks, and noting joints and fractures in the rocks every 500 ft. If the preliminary concept were true, the stream should gain flow from ground water at transverse breaks in the rock as revealed by increases in discharge, decreases in temperature, and increases in conductance.

The reach of Rimmer Creek revealed that in general there are many small springs with a discharge of about 5 to 10 gal/min, but the significant increases in streamflow are derived from a few large springs (table 3). Springs are not located at major cross joints or fractures. In fact, breaks parallel to the dip of the rock are rare. In addition, some of the abundant joints parallel with the strike intersect each other at acute angles and indicate compression parallel with the strike, that is, along a northeast-southwest axis. This compression presumably would seal any breaks parallel with the dip. One small bedding-plane fold with 1-foot amplitude was found. Its axis was parallel with the dip, again indicating compression parallel with the strike.

Inspection of Riley Spring, Swann Spring, springs supplementing City Spring, and several smaller springs reveals that most spring discharge is from either a bedding-plane solution opening or a solution-widened joint parallel with the strike of the rocks. It would appear that ground water is moving parallel to the strike of the rocks in the vicinity of these springs.

The other stream reach selected for detailed reconnaissance in August 1978, the left bank tributary to Spring Creek, was dry except for a few stagnant pools. The line of sinkholes that were wet in April 1972 were dry in August 1978. This dry reach of stream is characterized by many channel characteristics that are identical with characteristics of a stream in Lincoln County, Tenn. that was found to be underlain by an extensive solution system (E. F. Hollyday, written commun., 1979). These channel characteristics are compact gravel, sand, and clay in the channel bottom; flood trash piled against the base of trees growing in the channel bottom; short reaches where the banks are higher than the channel is wide; and, of course, no base flow. It is concluded that this reach of stream is probably losing water to an extensive solution system underneath the stream channel.

Table 3.--Discharge of large springs in the Dandridge area

Name	Date	Discharge (ft^3/s)	Temperature (°C)	Conductance (umho/cm at 25°C)
Swann Spring	Feb. 8, 1978	5.1	----	---
	Aug. 29, 1978	1.1	14.8	400
Raines Spring	Oct. 17, 1978	0.8*	----	---
Riley Spring	Feb. 8, 1978	1.4	----	---
	Aug. 18, 1978	0.5	14.4	400
	Nov. 20, 1978	0.4	----	---
Fain Spring	Feb. 8, 1978	1.3	----	---
City Spring	----	---	----	---

*Estimation.

Summary of Hydrologic Investigations

Drilling contractors report that wells for domestic or farm supply are commonly drilled to a depth of 170 ft below land surface and produce 10 gal/min on the average. At least 10 percent are reported to produce more than 50 gal/min. Water-bearing zones producing at least 50 gal/min are usually at depths as great as 250 ft. Wells may have to be cased to 110 ft to keep mud from shallower openings in the rock from contaminating water pumped from deeper openings.

Several reaches of streams in the study area have interrupted flow, as revealed by examination of aerial photography. This loss in flow may be due to the presence of solution openings beneath the stream. The alignment of sinkholes, in some places, may indicate that this loss in flow is being diverted to a spring or springs. The geologic position and the topographic position of known large springs with respect to dry reaches of stream were used to discover a large spring heretofore known only to the adjacent landowners.

Detailed reconnaissance of a reach of Rimmer Creek revealed that fractures are rarely parallel to the dip of the rocks. Fractures are numerous parallel to the strike of the rocks. Inspection of springs revealed that most springs discharge from either a bedding-plane solution opening or a solution-widened joint that is parallel with the strike. Detailed reconnaissance of a reach of a left-bank tributary to Spring Creek near Swann Spring revealed that the tributary was dry and had channel characteristics that are identical with the characteristics of channels that are underlain by known extensive solution systems in other parts of the state.

The initial concept of the ground-water flow system envisioned that many small amounts of water flowing parallel with the strike of the rocks would be collected at many points by a few major fractures parallel with the dip, and hence the largest ground-water flows would be in these latter fractures. The results of the hydrologic investigations indicate that this initial concept is invalid, and in fact the largest ground-water flows are parallel with the strike, based upon the following four observations:

1. Sinkholes that are in line with major springs are lined up along the strike of the rocks,
2. Four out of five major springs occur near the contact between two formations where these formations are dipping at least 30°, and hence the contact follows the strike,
3. Fractures parallel with the dip are rare,
4. Many springs discharge from orifices which appear to be lined up with the strike.

The Revised Hydrologic Concept

The presence of many unusually long, dry reaches of first-order streams in areas lying between the southeast-flowing main streams (fig. 8) indicates that ground water is receiving direct recharge in these areas. Rather than discharging into the local small streams, a significant part of this ground water is moving to topographically lower elevations to the southeast apparently by moving down bedding planes that dip 30° to the southeast and up the joints that dip 60° to the northwest and strike parallel to the northeasterly strike of the rocks (fig. 9). According to regional well records, this stair-step movement may reach depths on the average of 250 ft below land surface.

This regional diffuse flow to the southeast continues until it intersects a bed or series of beds with unusually large secondary permeability as compared to the rest of the rock section. The fact that four out of five large springs are located near the contact between the Copper Ridge Dolomite and the Chepultepec Dolomite indicates that the beds near this contact have unusually large secondary permeability openings compared to the rest of the rock section. In addition, although it was not specifically investigated, it is believed to be likely that faults could have broken the rocks and produced large secondary permeability openings similar to these beds.

In effect, the diffuse ground-water flow toward topographically lower areas to the southeast is intercepted by high permeability beds adjacent to the Copper Ridge Dolomite-Chepultepec Dolomite contact and is routed along the strike to a large spring (fig. 10). This high permeability conduit or solution opening may pass under a stream of large drainage area and keep it dry during base-flow conditions as in the case of the opening that probably passes under the unnamed left bank tributary to Spring Creek along the line of wet sinkholes to Swann Spring (fig. 8).

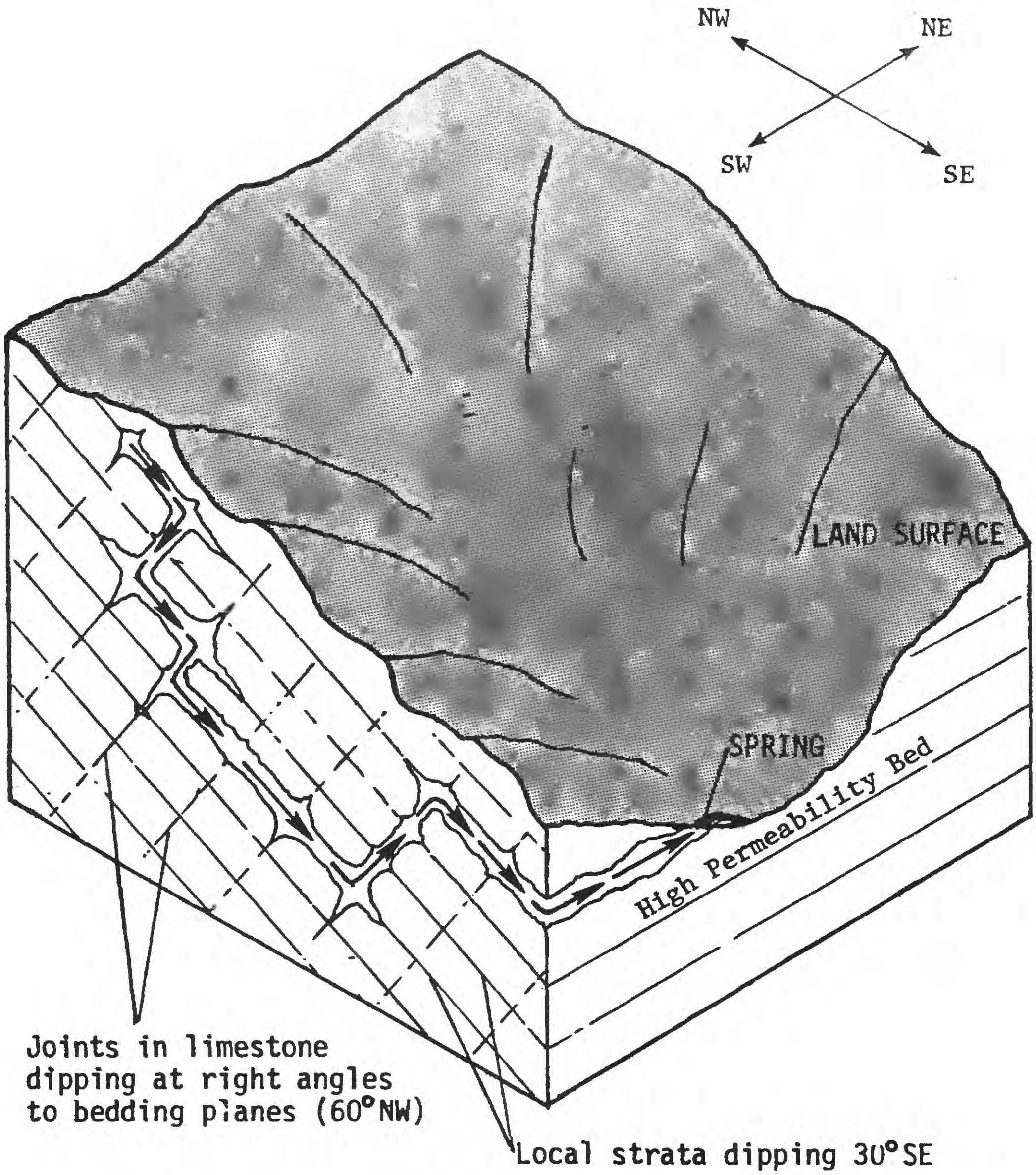


Figure 9.-- Hypothetical solution channel system showing path of ground-water movement in revised hydrologic concept.

SITE SELECTION FOR EXPLORATORY WELLS

Criteria

C.V. Theis (1940) states "all water discharged by wells is balanced by a loss of water somewhere." The water discharged by wells "must be balanced by an increase in the recharge of the aquifer, or by a decrease in the old natural discharge, or by loss of storage in the aquifer, or by a combination of these. This loss is always to some extent and in many cases largely from storage in the aquifer" as indicated by the lowering of water levels during pumping. In the Dandridge area there are very few areas of perennial wet ground, and hence it is doubtful that there are any significantly large areas of rejected recharge. For this reason the loss due to pumping must come from either storage in the aquifer or from the spring at which it discharges, if one exists.

Again, C.V. Theis (1940) states "the ideal development of an aquifer from the standpoint of the maximum utilization of the supply would be (to locate wells) as close as economically possible to areas of rejected recharge or natural discharge. By so doing this lost water would be utilized by the pumps with a minimum lowering of the water level in the aquifer."

On the basis of these statements and the revised hydrologic concept, the following physiographic, geologic, and hydrologic criteria may be used to locate wells with a large production: (1) near a large spring, (2) up flow and on the strike of the rocks discharging to the spring, (3) along an alignment of sinkholes, (4) in or near a dry creek, (5) on or near the contact between the Copper Ridge Dolomite and the Chepultepec Dolomite, (6) on or near a fault.

These six criteria are listed in table 4 for the five sites selected for exploratory drilling in the Dandridge area. Figure 11 shows the location of the five sites. Sites were picked where as many of these criteria as possible were satisfied. Table 4 also indicates which sites were actually tested with exploratory wells.

Criteria Evaluation

It is difficult to evaluate the six criteria because only two out of the five test drilling sites were tested. We can only speculate that the difference in criteria used to select these sites may account in part for their success or lack thereof. Based upon the occurrence of exploratory wells that produced more than 50 gal/min as listed in table 4, site 3, Riley Spring, is an unqualified success. On the same basis, site 5, Moore Spring, is a qualified failure.

The site selection criteria present at site 5, Moore Spring site, were as follows: (1) it is near a small spring; (2) there is a large sinkhole in line with the exploratory wells; and (3) it is near a mapped

Table 4.--Criteria for the selection of sites for exploratory wells in the Dandridge area

CRITERIA	SITE 1 Swann Spring	2 Raines Spring	3 Riley Spring	4 Fain Spring	5 Moore Spring
1. Near large spring	X	X	X	X	
2. Upflow and on strike	X		X		X
3. Alignment of sinkholes	X				X
4. Dry Creek	X	X	X		
5. On or near contact	X	X	X	X	
6. On or near fault			X		X
SITES TESTED WITH WELLS	-	-	X[1]	-	X[2]

1 Each of the four wells produced more than 50 gal/min when blown with air

2 One of three wells estimated to produce about 40 gal/min of muddy water before mud sealed water out

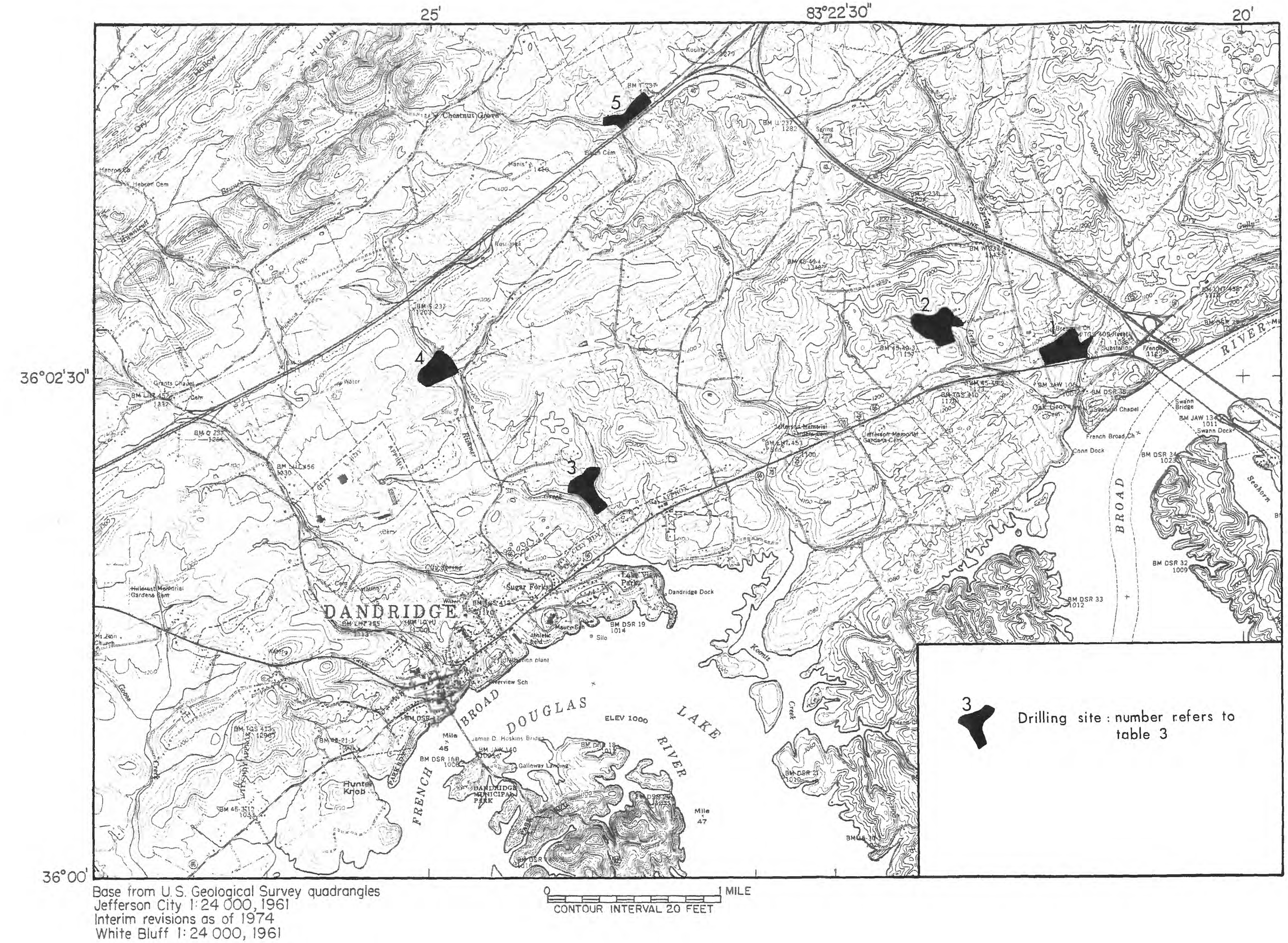
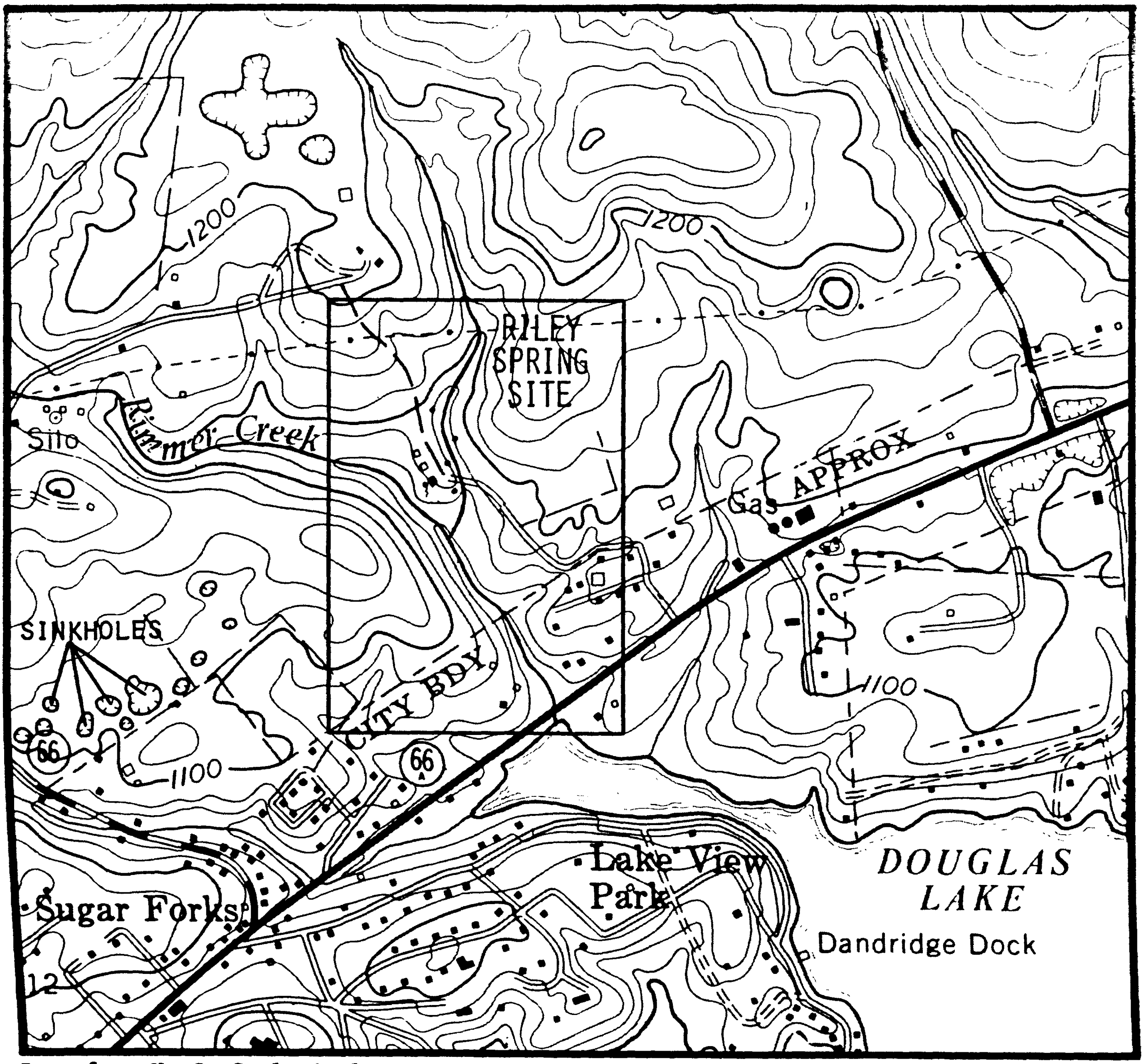


Figure 11.-- Five sites selected for drilling exploratory wells based upon criteria developed from hydrologic concept.



Base from U. S. Geological Survey
Jefferson City 1:24 000, 1961
Interim revisions as of 1974

0 ½ MILE
CONTOUR INTERVAL 20 FEET

Figure 12.--Riley Spring site, northeast of Dandridge.

fault. Site 3, Riley Spring met all site selection criteria that were derived from the revised concept of the hydrologic system. The criteria present at Riley Spring site that were absent from Moore Spring site are the following: (1) presence of a comparatively large perennial spring; (2) presence of a dry stream reach; and (3) location near the contact of the Copper Ridge Dolomite with the Chepultepec Dolomite.

Presence of a comparatively large spring is believed to be a criteria for locating a high-yielding well, although an aquifer test performed at Riley Spring site showed no hydraulic communication between the well and spring. This is because the presence of a large perennial spring is obviously a point of major ground-water discharge and indicative of extensive solutioning in the area and a large collection system necessary for an extensive underground reservoir. As such it is a good guide or starting point for locating a large underground reservoir. Lack of communication between the spring and test wells may be accounted for by the discontinuity of the carbonate aquifers in the Dandridge area.

RESULTS OF EXPLORATORY DRILLING

The seven exploratory wells were drilled between October 16, 1978 and November 2, 1978. Initially, all wells were drilled to bedrock with an 8-in. bit and cased with $6\frac{1}{4}$-in. ID pipe. The wells were then deepened with 6-in. bit to their final depth. In mid-November, two wells were reamed from 6 in. to 8 in. all the way to the original depth. The upper part of these wells was reamed to 12 in. and cased with 10-in. ID pipe. All wells were drilled with an air rotary rig having one compressor assisted by a separate auxiliary compressor. During drilling a detailed record was kept of the following: (1) materials penetrated in every 5 ft of hole; (2) soft zones; (3) water-bearing crevices; (4) water discharge; (5) general water quality; and (6) water levels in nearby wells.

Four of the seven wells were drilled at site 3, Riley Spring, and three wells were drilled at site 5, Moore Spring (fig. 11).

Riley Spring Site

The Riley Spring site is in an area of rolling hills covered with pasture and hardwood forest located northeast of Dandridge (fig. 12). The small valley where the wells are located is at an elevation of 1,080 ft or about 80 ft above mean high water in Douglas Lake, which is 0.3 mi to the southeast. Local relief is about 100 ft. A belt of sinkholes 0.5 mi southwest of the site trends toward the site. At the well sites, the small valley is drained by a stream that is a tributary to Rimmer Creek, a major stream in the area. The tributary is believed to be dry except during floods as evidenced by the presence of grass, trees, and flood trash in the center of its channel and by short reaches where banks are steep and are higher than the channel is wide. The mouth of the dry tributary is less than 300 ft below Riley Spring on the left bank of Rimmer Creek (fig. 13).

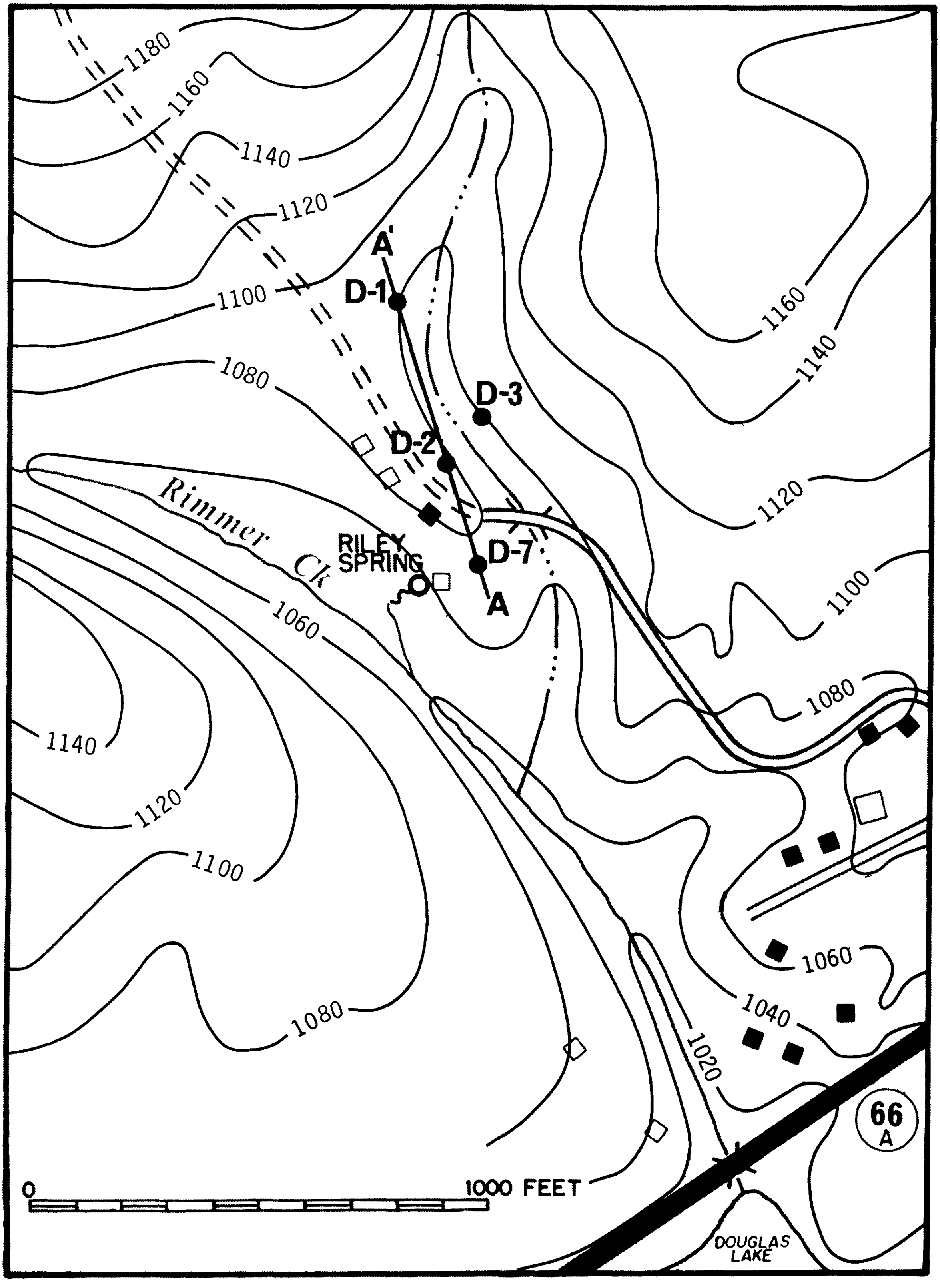


Figure 13.--Riley Spring site showing topography, location of four wells, Rimmer Creek, Riley Spring, and location of section in figure 14.

The four wells, D-1, D-2, D-3, and D-7, are situated approximately in a line almost parallel to the axis of the dry tributary and northeast of Riley Spring. The rocks at the site strike approximately parallel with Route 66A and dip about 30° to the southeast. A section is drawn along the line of wells from D-1 to D-7, approximately parallel to the dip of the rocks as shown in figure 14. The wells were drilled to depths between 290 and 408 ft and penetrated approximately 550 ft of rock section.

The site is underlain by the Copper Ridge Dolomite and Chepultepec Dolomite, of the Knox Group. They are covered by 6 to 20 ft of clay soil. These formations are composed of limestone and dolomite with subordinate amounts of claystone, quartz siltstone, and sandstone, and with very minor amounts of silicified oolite, chert, and black shale. Limestone comprises greater than one-half the section of the site (fig. 14). It is either cryptocrystalline, showing primary sedimentary structures, or has been recrystallized to fine sand-sized crystals and is typically brownish black on a fresh, wet surface. Much of it is either pelletal or oolitic. The remainder of the section is chiefly dolomite with some siltstone and sandstone. The dolomite varies from one well to another within the same stratigraphic horizon. A small part of the limestone has been silicified, particularly the oolitic facies.

The 300 ft of section immediately beneath the contact between the Copper Ridge Dolomite and the Chepultepec Dolomite is characterized by the occurrence in the section of thin beds of dolomite-cemented quartz sandstones and siltstones. It is the only part of the 3,000 ft of section in the Knox Group that is so characterized (Bridge, 1956; Hatcher and Bridge, 1973). Therefore, siltstone may be an indicator of greater solution development potential than other lithologies in the Knox Group. At this site, siltstone is more abundant than sandstone. Individual beds are usually only 5 ft thick but may occur interbedded with limestone or dolomite in zones as much as 30 ft thick (fig. 14).

Silicified limestone, chert, and black shale form a very small part of the section drilled.

Water-bearing solution openings occur in the wells almost from top to bottom as shown in figure 14 and in table 5. Figure 15 indicates that the distribution of a total of 35 openings in the four wells is almost uniform with depth. For this reason, it is likely that the exploratory wells were not drilled deep enough to tap all water-bearing openings at the site.

The water-bearing openings are shown in figure 14 as following bedding planes; however, only 2 major openings out of the 15 shown occur at precisely the same stratigraphic horizon in more than one well, specifically wells D-7 and D-2. Either the bedding-plane openings have very small lateral extent or many of the openings that are shown actually follow

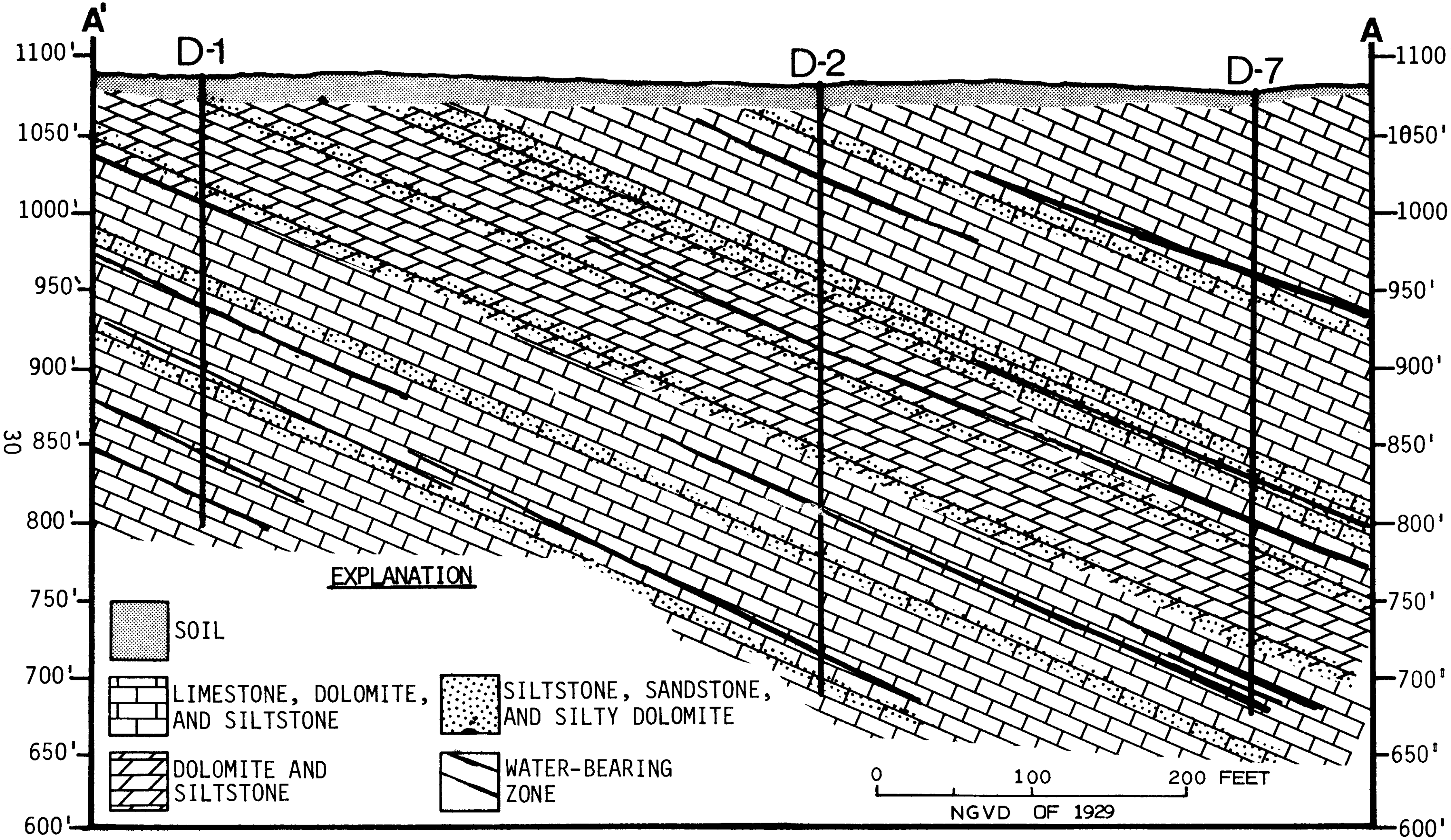


Figure 14.--Cross section from north to south through Riley Spring site showing location of wells, dip of rocks, and occurrence of water-bearing solution openings along bedding planes in the predominantly limestone lithology adjacent to the Copper Ridge Dolomite-Chepultepec Dolomite contact. Note possible solution openings following strike joints perpindicular to bedding.

Table 5.--Yield of water-bearing openings and wells (Datum for elevation of top of casing is National Geodetic Vertical Datum of 1929).

Well no. and depth (ft)	Casing			Major water-bearing openings		Rock at opening	Well	
	Diameter (in)	Depth (ft)	Elevation (ft)	Depth (ft)	Yield (gal/min)		Final yield with air (gal/min)	Specific capacity for 1 hour [(gal/min)/ft]
D-1 290	6¼	20.5	1088.52	19	1	Dolomite	76	0.67
				146	35	Limestone		
				184	20	---do---		
				201-203	16	Limestone and claystone.		
				270	20	Limestone and dolomite.		
D-2 390	10	61.5	1080.35	34	1	Oolite	76	0.68
				44	8	Limestone		
				57	20	---do---		
				271	16	Dolomite and siltstone.		
				280	15	Dolomite		
				362	44	Dolomite in crystal aggregates.		
D-3 408	6¼	19.5	1078.64	116	20	Dolomite and siltstone.	51	0.30
				173	4	Dolomite		
				228	4	Limestone		
				238	8	Limestone and dolomite.		
				276	7	Dolomite		
D-7 400	10	128	1075.59	18	1	Dolomite and limestone.	170	2.08
				112-116	50	Silicified oolite and chert		
				246-255	36	Sandstone		
				274	60	Siltstone		
				377	21	Dolomite		
				381	10	---do---		
				388	35	---do---		

joints parallel with the strike rather than bedding planes. The more numerous the openings along joints, the easier it would be for water to move to the southeast by alternately following bedding planes and joint planes. The wider openings appear to be more numerous toward the southeast at the site.

As shown in figure 14, the water-bearing openings are far more abundant in the interbedded limestone, dolomite, and siltstone part of the section than in the part with only dolomite and siltstone. Weathered material blown from the openings is most commonly light brown or yellow silty limestone, silty dolomite, or chert oolite from which the calcite or dolomite has been partly leached (table 5).

The yield of each major water-bearing zone as well as the final production of each well is given in table 5. Yields of the zones ranged from about 1 gal/min to as much as 60 gal/min. The production of each well when blown with air ranged from 51 gal/min for D-3 to 170 gal/min for D-7. Mean production was about 93 gal/min.

Temperature, specific conductance, and hardness of the water were measured during drilling usually after penetrating a water zone. The measurements showed that the water quality is similar throughout the aquifer underlying the Riley Spring site. Median values for a well from this site are: specific conductance, 480 μmho; hardness, 325 mg/L; and temperature, 16.5°C. A summary of all temperature, hardness, and specific conductance measurements appears in table 6. Throughout the drilling of each well at this site water-level measurements were taken at the other wells. In every case the water levels dropped as a nearby well was drilled. For example, as D-3 was drilled the water level in D-2 dropped as much as 8.5 ft from its initial depth below land surface. Similar drops in water level occurred in nearby wells as each well was drilled. A summary of water-level measurements appears in table 7.

Measurements of infiltration of precipitation, as well as streamflow losses are not available for the study area. However, it was believed that the solution openings are recharged directly by precipitation that percolates through the soil zone on the site and on areas topographically above and to the north of the site as well as by seepage through the bottom of the smaller stream channels during runoff events. It was also believed that the general ground-water flow to the southeast (fig. 16) to topographically lower areas was intercepted by relatively higher permeability solution openings, associated with the interbedded siltstone, limestone, and dolomite in the 300 ft thick zone immediately beneath the contact between the Copper Ridge Dolomite and Chepultepec Dolomite. In effect this higher permeability zone diverted flow along strike to large springs such as Riley Spring and effectively reduced any flow past this zone further toward the southeast. A conceptual flow net is shown in figure 17.

The upper water-bearing openings were largely mud-filled, and were cased-off in the large diameter wells. In effect, the top of the active zone of circulation is somewhere about 100 ft below land surface. The bottom of the zone is unknown, but exceeds 400 ft below land surface.

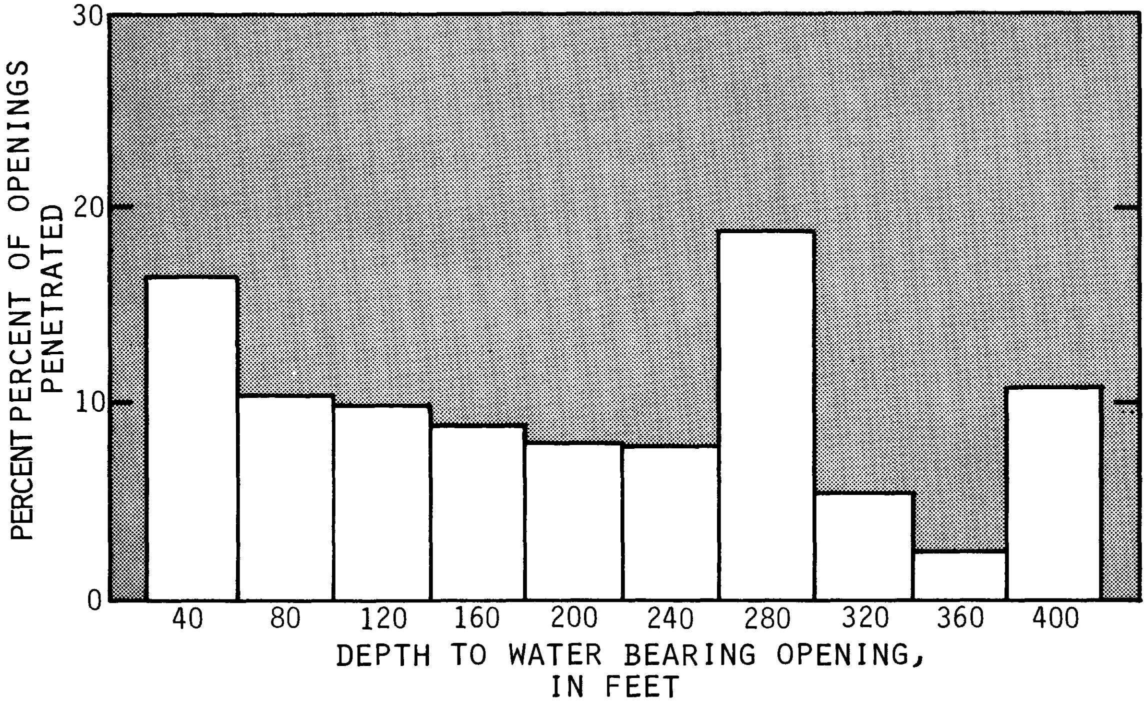


Figure 15.-- Frequency distribution of depth of water-bearing openings in exploratory wells at Riley Spring site.

Table 6.--Water quality data collected during exploratory drilling

Well no.	Depth (ft)	Water Quality Measurements: Specific Conductance (µmho/cm at 25°C)	Hardness as $CaCO_3$ (mg/L)	Temperature (°C)
D-1	105	450	---	26
	125	500	---	21
	146	480	357	16
	162	490	357	20
	185	470	---	16
	203	450	290	16
	250	480	323	16
	255	440	272	16
	290	470	---	16
D-2	210	480	---	15
	325	540	390	16
	362	480	---	16.5
	365	495	---	17
	370	520	391	16.5
	390	480	323	16
D-3	116	480	270	25
	245	560	320	22
	290	580	391	18
	345	565	390	17.5
	405	570	---	16
D-7	210	400	240	21
	260	480	340	17.5
	310	480	---	16
	395	500	359	17
Median value	---	480	325	16.5

Table 7.--Water-level decline in wells due to drilling or developing nearby wells with air

Well pumped	Approximate pumping rate (gal/min)	Pumping duration (hr)	Observation well	Drawdown (ft)
D-2	80	1	D-1	0.38
D-3	51	1	D-2	8.53
D-7	145	8*	D-2	12.53
			D-3	9.01

*Measurements taken at the end of 8 hours of intermittent drilling in D-7.

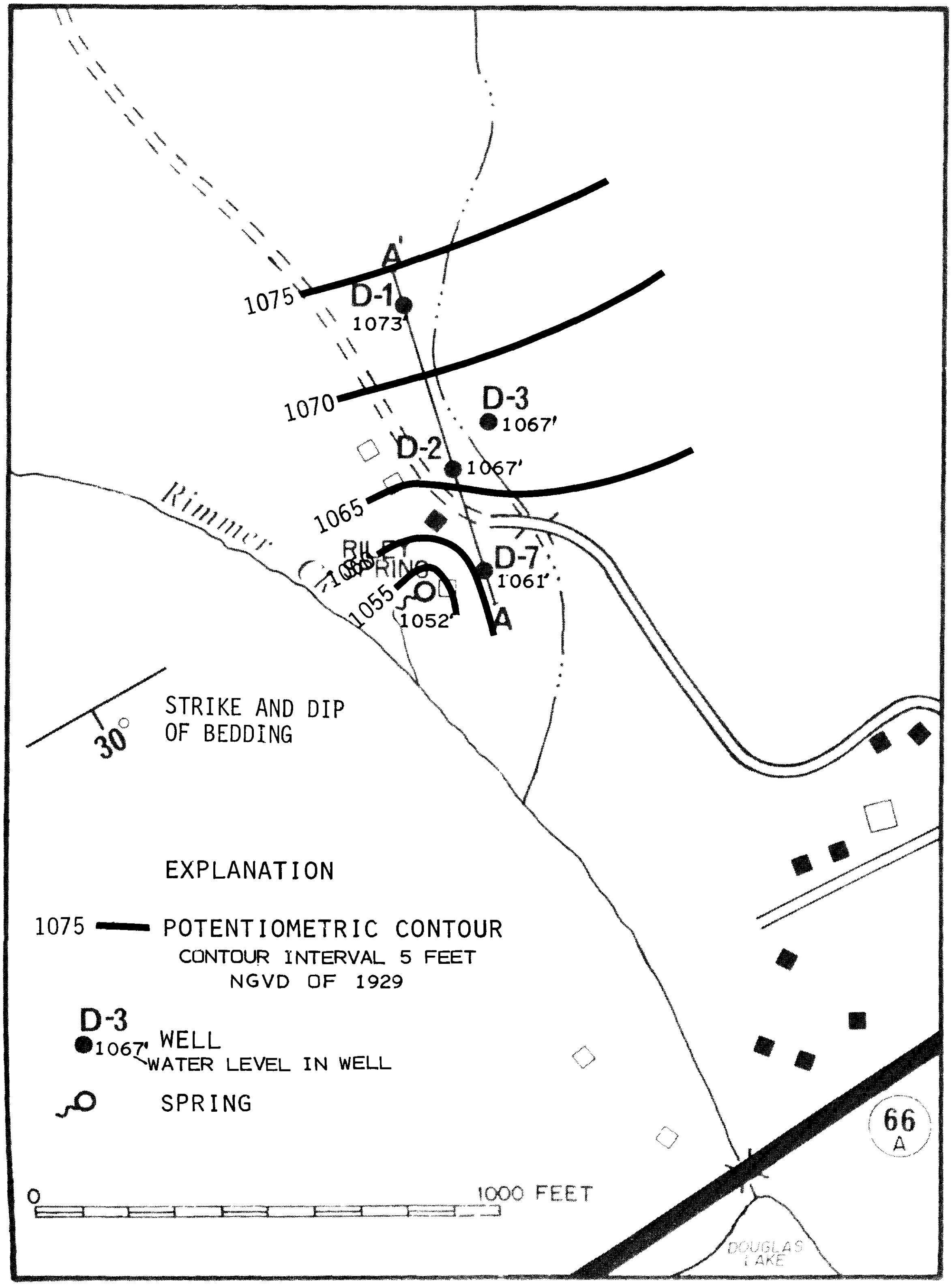


Figure 16.-- Water-level elevations in wells at Riley Spring site prior to pumping indicate that ground water flows to the south toward the spring. It was assumed that the wells tap the system that feeds the spring.

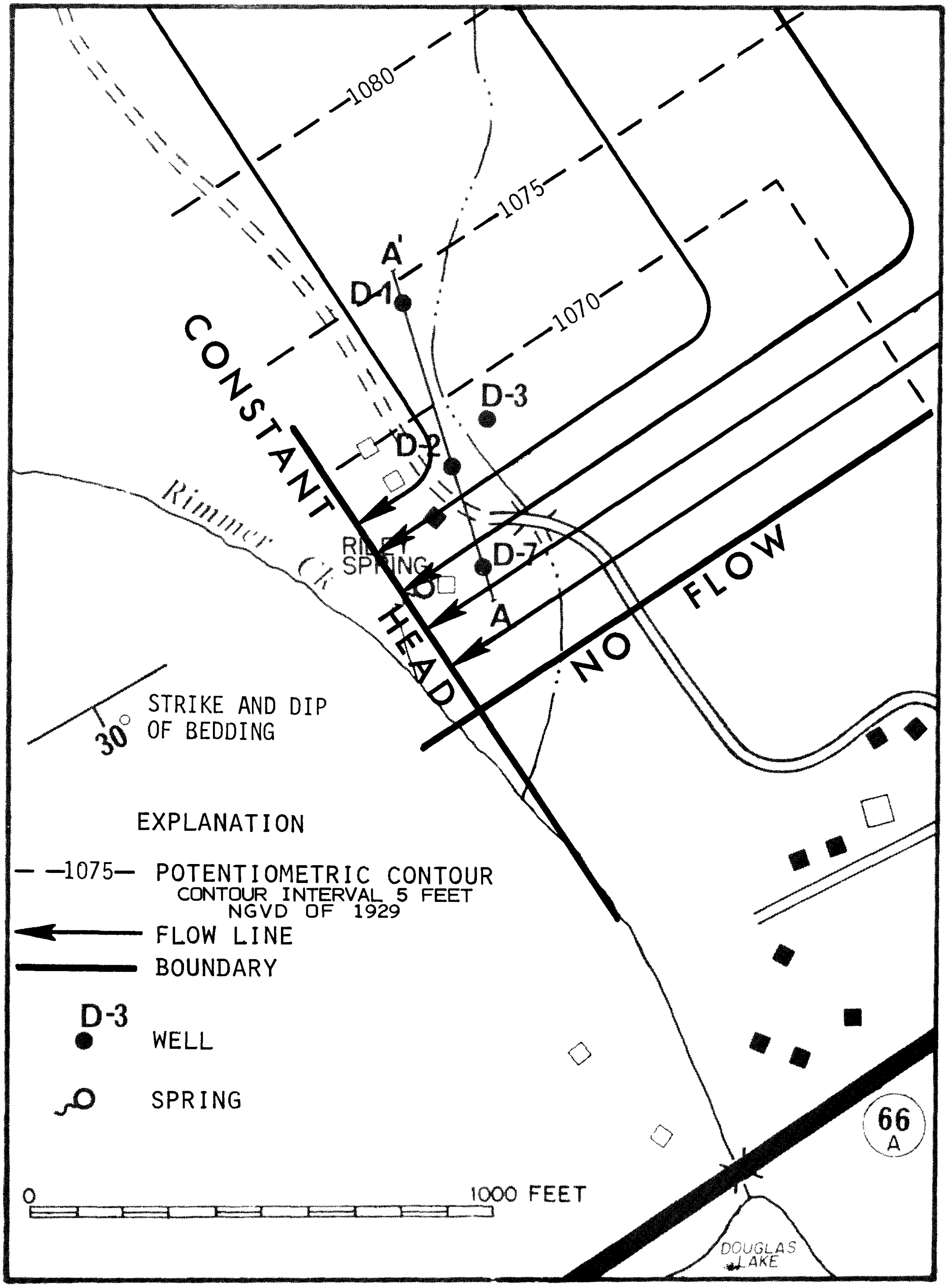


Figure 17.-- Concept of the flow net under natural conditions and hydraulic boundaries anticipated in aquifer test.

Based upon drill data and upon the concept of the hydrologic system, we anticipated the following external boundaries to the aquifer:

(1) An upper boundary at the top of the active zone of circulation (or bottom of the mud-filled solution openings) at about 100 ft below land surface,

(2) a lower boundary at the base of the zone of active solutioning presumed to be somewhere below 400 ft or at about 500 ft for estimation purposes,

(3) a constant-head boundary 150 ft southwest of D-7, at Riley Spring and along Rimmer Creek,

(4) a no-flow boundary southeast of the site and parallel with the strike of the rocks, and

(5) an areally extensive aquifer to the north and east.

It was anticipated that the aquifer would respond to pumping as if it were under artesian pressure because the static water level (potentiometric surface) is shown between 5 and 15 ft below land surface and the top of the active zone of circulation was about 100 ft below land surface.

The aquifer test was started at 8:30 a.m., Monday, November 20, 1978. Well D-7 was pumped continuously for 24 hours. During this period the pumping rate was stepped-up twice:

Step	Duration (hr)	Discharge (gal/min)	Specific capacity of D-7 at end of step [(gal/min)/ft]
1	8	60	1.42
2	8	120	1.24
3	8	180	1.02

Water-level declines were recorded in the three other wells whose distances from the pumped well and total drawdown at the end of the 24 hours of pumping are the following:

Well	Distance from pumped well (ft)	Decline by end of test (ft)
D-1	527	5.99
D-2	185	29.04
D-3	250	28.08

Discharge of Riley Spring varied less than 5 percent from 195 gal/min from the time that flumes were installed on November 17 through the beginning of water-level recovery in the wells on the morning of November 21, 1978.

The step-test data followed G. K. Moore's empirical type curve for estimating maximum production (written commun., 1978). Based upon this method and depth to the first water-bearing opening (246 ft), it is estimated that maximum production is 250 gal/min for 0.5 hour and 210 gal/min for 8 hours of continuous pumping. Based upon these figures, it is estimated that 200 gal/min is a limiting rate for periods of continuous pumping of about 1 day.

Riley Spring was unaffected by pumping during the 24-hour test period. This combined with the fact that none of the observation wells sensed a constant-head ("recharging") boundary during the test would imply that the constant-head boundary anticipated at Riley Spring and along Rimmer Creek does not exist. It seems, rather, that the spring may be discharging from a shallow or perched aquifer. A boundary between the shallow aquifer discharging to the spring and the deep aquifer discharging to the wells would most likely be horizontal. This type of boundary would be imperceptible by an aquifer test which may be why it is not evident in the drawdown data obtained from the 24-hour test. The lack of connection between the wells and spring made it necessary to revise the concept of the flow net under pre-pumping conditions (fig. 18).

Drawdown data for observation wells D-2 and D-3 for the three steps indicate the presence of a no-flow ("discharging") boundary about 600 ft from these two wells, either to the northwest or the southeast (fig. 19). Drawdown data for observation well D-1 indicates that this well may not be in the same aquifer system as D-2, D-3, and D-7. However, the occurrence of some drawdown during early times and significant drawdown after 16 hours elapsed would indicate that the water-bearing openings at D-1 are leaking to the openings in the other wells and may actually be interconnected by some long and circuitous (not radial) route.

It is concluded that the aquifer at Riley Spring site is not isotropic. In the neighborhood of wells D-2 and D-3, however, it responded in a manner similar to an ideal aquifer with an estimated transmissivity of 600 ft^2/day and an estimated storage of 2×10^{-4} on both drawdown and recovery during the 1-day test. In addition, at least one no-flow boundary is present.

Table 8 lists the physical properties and concentration of chemical and microbiological constituents found in a water sample collected from well D-7 just prior to the end of the 24-hour test. These constituents are useful in interpreting the geochemistry of the water and in evaluating its suitability for various uses. Comparison of the concentrations with maximum concentrations recommended for constituents in water intended for human consumption (U.S. Environmental Protection Agency, 1975) indicates that none of the constituents analyzed for would be harmful to human health.

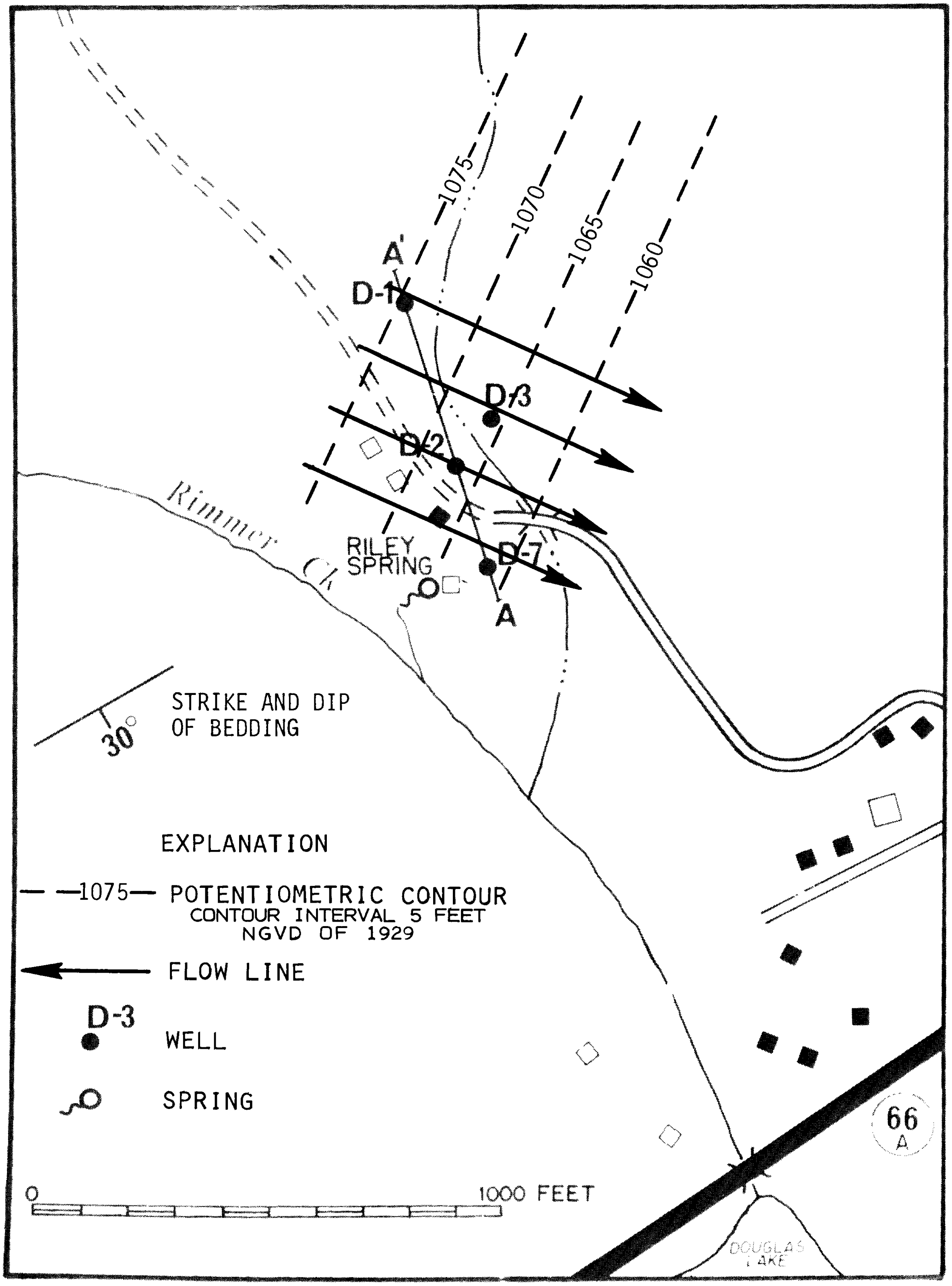


Figure 18.-- Revised concept of flow net under natural conditions at Riley Spring.

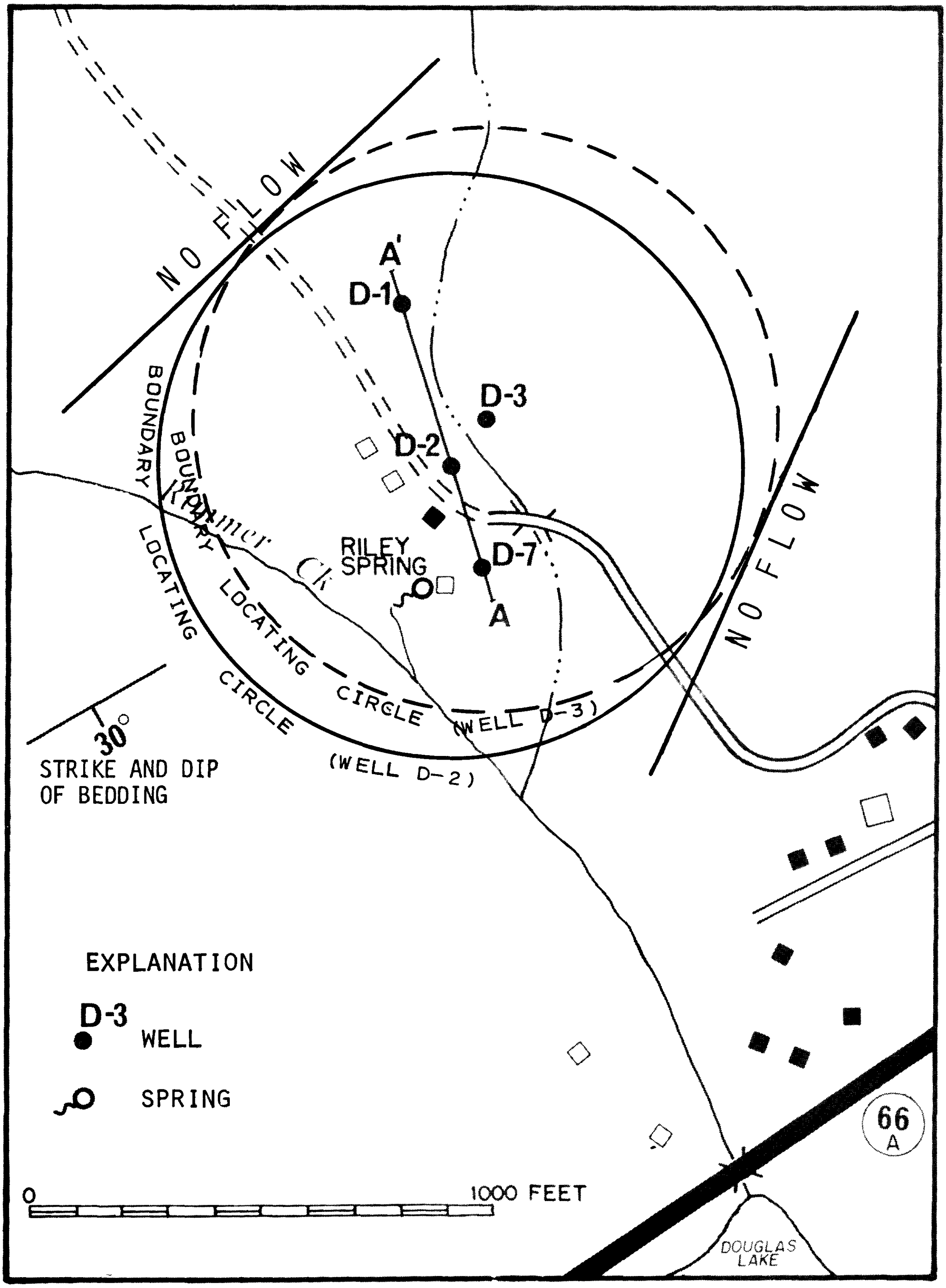


Figure 19.-- Two possible locations for a no-flow boundary whose effect was observed in water-level data.

Table 8.--Physical properties and concentration of microbiological and chemical constituents in a sample of water from well D-7 collected during aquifer test. Measurements are in milligrams per liter unless otherwise specified in parentheses.

Constituent	Concentration
Alkalinity, total, as $CaCO_3$	280
Arsenic, total	0.001
Bacteria (colonies/100 mL)	
Coliform, fecal	<1
Coliform, streptococcal	<1
Coliform, total	2*
Barium, total	0.2
Bicarbonate	340
Cadmium, total	0.001
Calcium, dissolved	69
Carbon dioxide, dissolved	27
Carbon, total organic	1.2
Carbonate	0
Chloride, dissolved	2.5
Chromium, hexavalent	0.000
Color (platinum cobalt units)	10
Copper, total	0.000
Cyanide, total	0.00
Dissolved solids, sum of constituents	292
Dissolved solids (tons/acre-foot)	0.39
Dissolved solids, residue at 180°C	286
Fluoride, dissolved	0.2
Hardness as $CaCO_3$, noncarbonate	33
Hardness as $CaCO_3$, total	310
Iron, dissolved	0.010
Iron, total	0.060
Lead, total	0.009
Magnesium, dissolved	34
Manganese, dissolved	0.000
Manganese, total	0.000
Mercury, total	0.0006
Methylene Blue, active substance	0.00
Nitrate, as N, total	1.1
Nitrite, as N, total	0.00
Nitrite plus nitrate, as N, total	1.1
pH, field	7.3
Phenols	0.000
Phosphorus, as P, total	0.00
Phosphorus, as PO_4	0.00
Potassium, dissolved	1.7

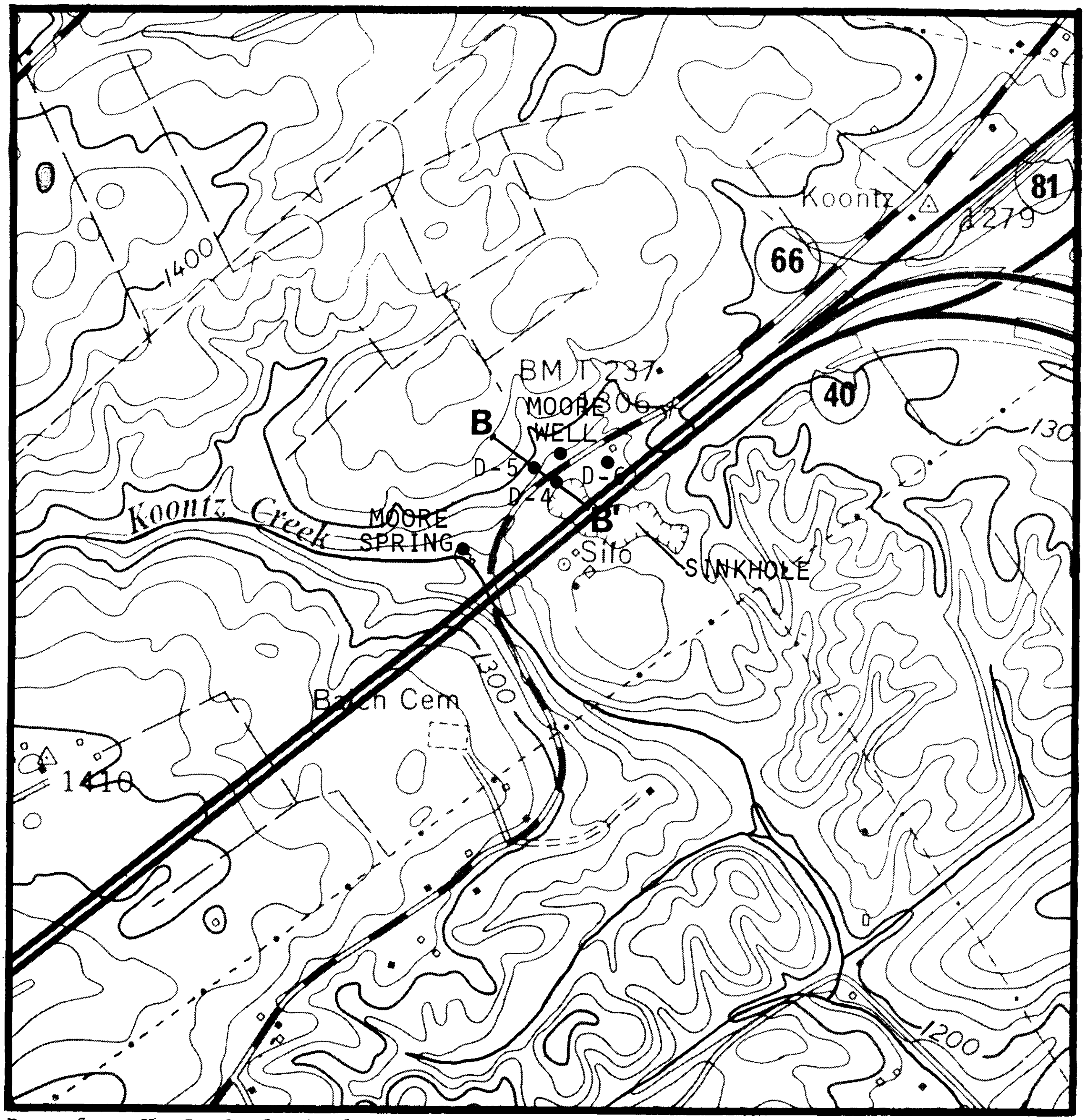
Table 8.--Continued.

Constituent	Concentration
Selenium, total	0.000
Silica, dissolved	8.7
Silver, total	0.000
Sodium, dissolved	1.0
Sodium (percent)	1
Sodium (adsorption ratio)	0.0
Specific conductance, field (µmho/cm at 25°C)	510
Sulfate, dissolved	6.9
Turbidity (Jackson turbidity units)	0
Water temperature (°C)	16.0
Zinc, total	0.000

*A nonideal plate count.

Table 9.--Openings in wells at Moore Spring Site.

Well	Depth (ft)	Diameter (in)	Casing Depth (ft)	Major Openings Depth (ft)	Major Openings Yield (gal/min)	Remarks
D-4	248	6¼	pulled	50-82	0	Mud
				96-133	0	Mud Abandoned well.
D-5	105	6¼	pulled	57	40±	Eventually sealed out by mud.
				59-96	0	Mud
D-6	149	6¼	22.9	None	0	Only solid rock penetrated.



Base from U. S. Geological Survey
Jefferson City 1:24 000, 1961
Interim revisions as of 1974

0 ½ MILE
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Figure 20.--Moore Spring site at Route 66 and Interstate 40/ Interstate 81 overpass, showing location of section in figure 20.

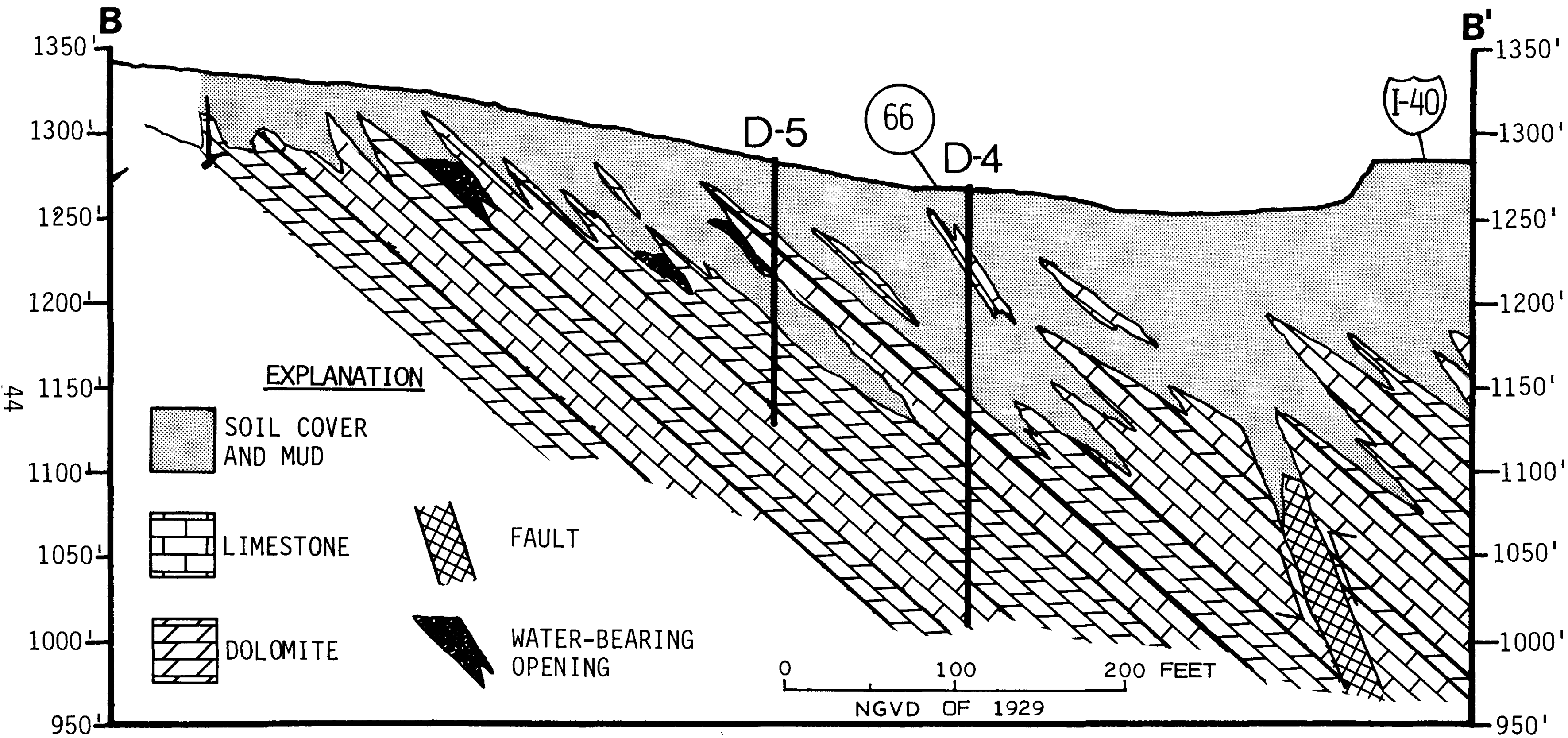


Figure 21.--Cross section from northwest to southeast through Moore Spring site showing occurrence of mud-filled openings at northwest end of sinkhole.

Like most ground water from carbonate rocks, however, the calcium-magnesium hardness is very high. It may be helpful, though expensive, to soften the water for some uses.

Moore Spring Site

The second site chosen for test drilling is located on Route 66 at the Interstate 40/Interstate 81 overpass. As shown in figure 20, this site lies on the north edge of a large sinkhole. The site has gently rolling hills with elevations ranging from 1260 to 1360 ft above mean sea level. The spring at this site is situated in a small drainage way which is tributary to Koontz Creek, a major southeasterly flowing stream, and is near the headwaters of the stream. Moore Spring, the sinkhole, and a high yielding domestic well, Moore well, indicate that a sizable underground reservoir may be present.

The site is underlain by the Kingsport Formation of Bridge (1956) and Mascot Dolomite of Bridge (1956) at the top of the Knox Group and by a part of the overlying Lenoir Limestone (table 1). Based upon previous geologic mapping (Hatcher and Bridge, 1973), the rocks at the site lie within the northwest or downthrown block of a steep reverse fault (figs. 3 and 4). These rocks at wells D-4 and D-5 dip about 40° southeast into the fault and toward the sinkhole (fig. 21). The rocks at D-6 are more nearly horizontal with only a slight dip toward the sinkhole.

The rocks at the site are typically limestone, about a third of which has been replaced with dolomite in silt-size crystals. The limestone commonly is dusky yellowish brown, either cryptocrystalline limestone showing primary depositional textures or recrystallized limestone. The dolomite is usually slightly brownish medium gray. Pyritic black shale partings or laminae are common. The rocks are only rarely olive in color. In several places in the drilled section as well as in outcrops near Moore Spring, the rock is minutely fractured to brecciated. The fractures are tightly sealed with coarse-crystalline calcite or dolomite. The mud-filled openings, in addition to orange, silty clay, often contain light-olive gray claystone, coarse-grained quartz sandstone with iron and clay cement, and cauliflower chert masses that appear to be a variety of cave filling. These same materials can be found in outcrop filling the spaces between rock ledges.

Three wells were drilled at this site, D-4, D-5, and D-6 (fig. 20). The three wells ranged in depth from 105 to 248 ft (table 9). Overburden depths ranged from 3 ft at D-6 to 55 ft at D-5. The only well that produced water was D-5, which yeilded approximately 40 gal/min from an opening at 57 ft below land surface.

Solid rock and mud, with just one water-bearing opening, was virtually the only material encountered in all wells drilled. Mud seams at 50 to 82 ft and 96 to 133 ft below land surface were encountered in D-4. In D-5 a mud-filled cavity between 59 and 96 ft below land surface was penetrated (fig. 21). Casing in both these wells was pulled and the holes abandoned. Only solid rock was encountered throughout the entire depth of D-6 (table 9).

It was believed before drilling commenced at this site that extensive bedrock solutioning had caused the sinkhole in which these three wells were drilled and therefore water-bearing openings would be present. However, after drilling three wells without penetrating any major water-bearing openings, this concept was revised. Revision of the regional underground flow concept at Moore Spring site accounts for lack of success in penetrating any major water-bearing openings. It is now hypothesized that clay soil from the surface subsided causing the large sinkhole and filling the water-bearing solution openings. This impervious clay soil apparently diverted ground-water flow away from the center of the sinkhole toward its flanks thereby accounting for the nearby high-yielding well up flow from the sinkhole and the spring down flow from the sinkhole (fig. 22). Attempts at finding this diverted flow by drilling wells D-5 and D-6 were unsuccessful.

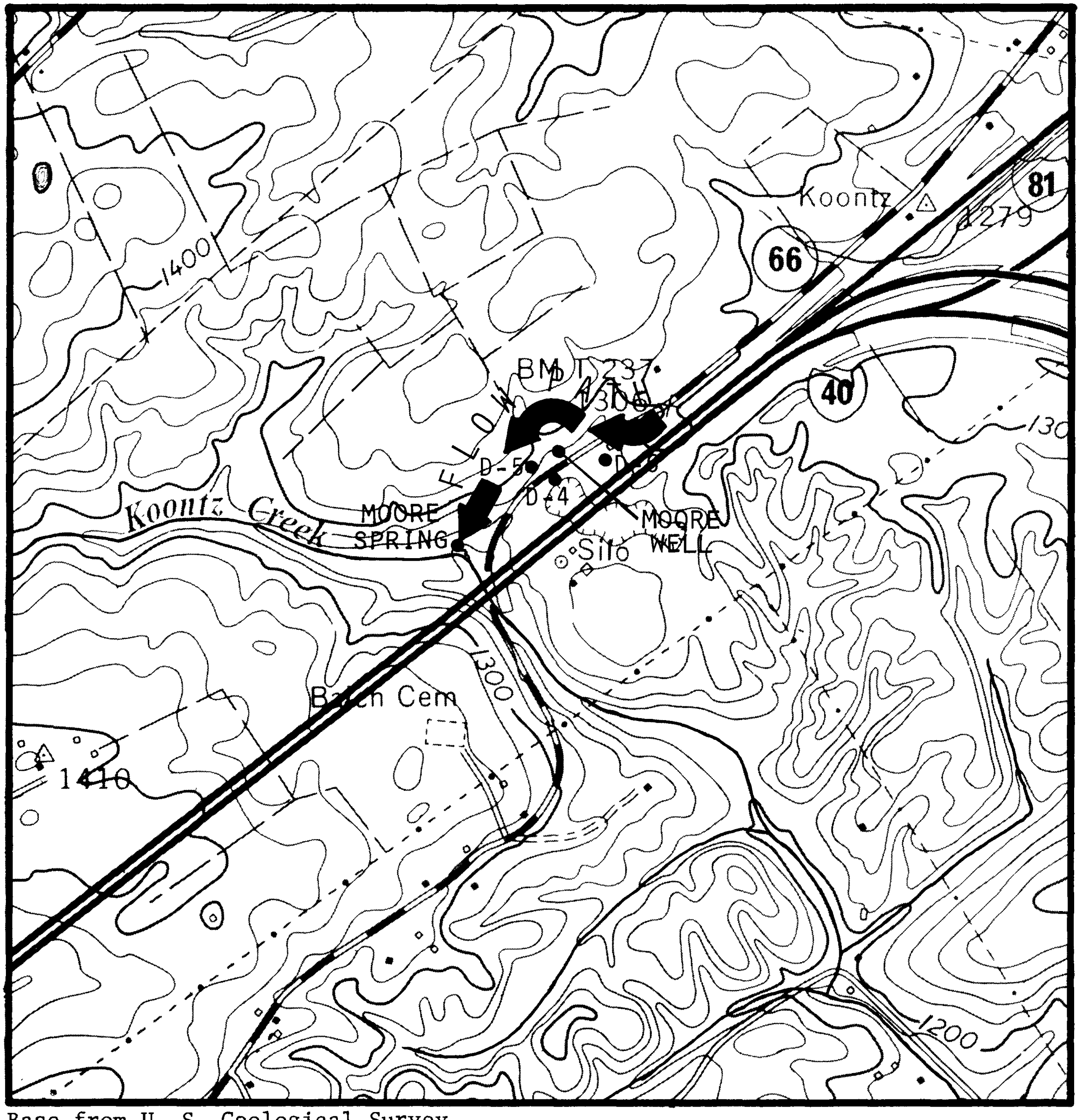
SUMMARY AND CONCLUSIONS

The purposes of this report were to (1) describe the development of concepts of the physiographic and geologic occurrence of large solution openings in the folded and faulted carbonate rocks in the Dandridge area, and (2) test the concepts with data from exploratory wells and aquifer tests.

The area is adjacent to the northwest shore of Douglas Lake in the Valley and Ridge physiographic region of east Tennessee. This rolling valley area southeast of Bays Mountain is drained to the southeast by five streams, each having drainage areas of about 3 mi^2. The area is underlain by a folded and faulted sequence of 5,000 ft of limestone and dolomite, mostly in the Knox Group. These rocks are highly soluble and as a result sinkholes are many and outcrops are few. Water occurs underground in solution openings rather than in primary pore spaces which are essentially nonexistent in these dense rocks. Drilling contractors report that most domestic wells are drilled to at least 170 ft below land surface, but water-bearing zones that occasionally yield at least 50 gal/min or more are usually as deep as 250 ft.

Aerial photography of the study area shows several reaches of stream with interrupted flow where loss in flow might be due to the presence of a solution opening beneath the stream. Sinkhole alignment, in some places, suggests that this loss in flow is being diverted to a large spring.

The original concept of the ground-water flow system envisioned that most ground water was moving parallel to strike along the more soluble beds in the sequence, and this flow was being collected by major systems of fractures and joints transverse to the strike of the rocks. Field reconnaissance revealed that major transverse fractures and joints do not exist. Instead, most springs, which are the discharge points for major underground collection systems, discharge from either a bedding-plane solution opening or a solution-widened joint parallel with the



Base from U. S. Geological Survey
Jefferson City 1:24 000, 1961
Interim revisions as of 1974

0 ½ MILE
CONTOUR INTERVAL 20 FEET

Figure 22.--Revised concept of occurrence of water-bearing openings at Moore Spring site showing diversion of flow to the spring around the mud-filled sinkhole.

strike. Alignment of sinkholes indicates that the majority of ground-water movement in the vicinity of large springs is parallel to the strike of the rocks. Dry reaches of stream look like reaches in other study areas that are underlain by known extensive solution systems.

The concept of the ground-water flow system, revised on the basis of the aerial photography and the field reconnaissance, proposes that there is regional, diffuse flow across the strike of the beds towards topographically lower areas to the southeast. This flow may be intercepted by high permeability beds adjacent to the Copper Ridge Dolomite-Chepultepec Dolomite contact and is routed along the strike to a spring or springs.

Five sites were selected for drilling exploratory wells based upon six site-selection criteria that were developed from the revised concept of the ground-water flow system. The difference in criteria used to select the successful Riley Spring site and the unsuccessful Moore Spring site suggests that those criteria which must be satisfied are (1) near a large spring, (2) in or near a dry creek, (3) on or near the contact between the Copper Ridge Dolomite and the Chepultepec Dolomite.

Four wells were drilled at the Riley Spring site where these three criteria were satisfied. They range in depth between 290 and 408 ft. Each of the wells penetrated at least five major water-bearing zones, and the frequency of occurrence with depth suggests that there are more water-bearing zones below the maximum depth drilled. The mean production of each of the four wells when blown with air is about 93 gal/min.

Drilling revealed that the 550 ft of section near the contact between the Copper Ridge Dolomite and the Chepultepec Dolomite is more than half limestone. This section, compared to the rest of the Knox Group, is characterized by the occurrence of dolomite-cemented quartz sandstones and siltstones, comprising about 10 percent of the section.

Prior to the aquifer test, the aquifer was anticipated to respond to pumping like an infinite artesian aquifer with a constant-head boundary at Riley Spring and a no-flow boundary along the strike at a location southeast of the site where the high permeability beds dip to depths greater than 500 ft below land surface. The aquifer test revealed that the pumped well D-7 could be pumped continuously at about 200 gal/min for one day, that the wells are not open to the aquifer zone that is discharging to Riley Spring, and that there is a no-flow boundary tending to increase water-level decline compared to what would be expected in an infinite aquifer.

Analysis of a water sample collected during the test indicates that although hardness may be troublesome to some users, none of the constituents present in the analysis would be harmful to human health.

Three wells were drilled at the Moore Spring site where none of the three most critical site selection criteria were satisfied. They ranged in depth between 105 and 248 ft. Two of the wells penetrated mud-filled solution openings, one of which yielded an unsustained flow of about 40 gal/min. The third well was drilled through essentially solid rock near the top of the Knox Group. The rocks are predominantly limestone and dolomite with minor black, pyritic shale partings. Before drilling commenced, it was believed that the large sinkhole at the site was indicative of extensive underground solutioning and the presence of water-bearing openings. Drilling revealed that virtually all openings had been filled with mud, some coming from the land surface. The revised concept proposes that clay soil has filled the original water-bearing openings and is diverting ground-water flow away from the center of the sinkhole towards its flanks, past Moore well and to Moore Spring.

It was concluded that ground water in the Dandridge area occurs most abundantly in solution openings in interbedded limestone and dolomite whose section may be characterized as having at least 10 percent of dolomite-cemented sandstone and siltstone. This water may be located and utilized most easily at the discharge end of the ground-water flow system near large springs. The aquifer test at Riley Spring revealed that the aquifer feeding Riley Spring has yet to be tapped. In addition, the hydraulic properties determined for the aquifer that is open to the existing exploratory wells cannot be extended much more than 600 ft from the center of the site without giving consideration to boundaries and leakage from either overlying (downdip) or underlying (updip) solution-system aquifers.

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