Arkansas Water Resources Center

NORTHERN ARKANSAS GROUNDWATER INVENTORY

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GROUNDWATER INVENTORY

OBJECTIVES

The purpose of the FY 75 Groundwater Inventory Program is to evaluate the rock and hydrologic characteristics of the Roubidoux and Gasconade Formations. The overall objective was to define specific hydrologic and hydraulic parameters of the deeper groundwater aquifers. The objectives were to be accomplished through the following:

1) Construction of groundwater yield maps for estimating hydrogeologic parameters of the Roubidoux and Gasconade Formations.

2) Construction of regional lithofacies maps that depict the distribution of reservoir strata within the Gasconade and Roubidoux Formations.

3) Evaluation of recent and historical static water levels and the construction of piezometric maps for the deeper aquifers.

4) The evaluation of groundwater potential of the upper part of the Gasconade Formation.

To accomplish these objectives, the study area was expanded to encompass a large portion of Missouri. This area is believed to be the region of recharge for the deep aquifers of northern Arkansas, and is the outcrop region of the Roubidoux and Gasconade Formations.

BACKGROUND

Comprehensive surface and subsurface mapping of the Roubidoux and Gasconade Formations in Missouri was accomplished by McCracken and McCracken (1965), through the use of insoluble residue analysis. The complete Ordovician sequence to which the Roubidoux and Gasconade Formations belong, consists of cherty and siliceous dolomite and magnesian limestone, with erratic discontinuous sandstone units. Due to similarity of rock type in the sequence, no reliable regional subsurface markers are recognized. In the absence of well markers, McQueen (1931) and Grohskopf and McCracken (1949) established the use of insoluble residue analysis of well cuttings for correlation purposes in Missouri. By classifying types of residues, a definite pattern for the formations was established, and has been used successfully in Missouri. Some guide horizons are traceable into Arkansas, Kansas, Oklahoma, and Texas (McCracken, 1955).

Comprehensive subsurface mapping in northern Arkansas has not been feasible except in localized areas because of complex stratigraphy and inadequate well control. Previous subsurface investigations in Arkansas have utilized the analysis of lithic features of well cuttings in conjunction with electric logs; however, diagnostic marker beds were not easily defined (Caplin, 1960, and Lamonds, 1972). In view of the lack of diagnostic marker features in well cuttings from the Arkansas Ordovician sequence, the present study utilized available insoluble residue logs in conjunction with electric logs and a modified microscopic analysis of well cuttings based on recognition of insoluble constituents (Snyder, 1976). Isopachous and structural maps were constructed from these data for the Roubidoux and Gasconade Formations in northern Arkansas. These maps were tied into the maps for the Missouri area published by McCracken and McCracken (1965).

The basic hydrologic data for this study consist of a series of maps constructed from data obtained from various State, engineering, and Federal agencies in Missouri and Arkansas. The potentiometric, yield, and specific capacity maps were developed from pumping tests supplied by the Missouri Geological Survey and Water Resources, Arkansas Geological Commission, United States Geological Survey, and the private engineering firms of McGoodwin, Williams, and Yates, John Mahaffey and Associates, Taylor Engineering, Inc., and Max Mehlburger Engineers. The data are summarized in Appendix A.

Data on groundwater quality were supplied by the Missouri Geological Survey and Water Resources and the Arkansas State Health Department.

Data on static water levels were supplied by the Missouri Geological Survey and Water Resources which utilizes monitored wells with continuous recorders, and the United States Geological Survey which measures water levels once a year in northern Arkansas.

GEOLOGIC SETTING

Bedrock throughout most of Missouri and northern Arkansas is of Paleozoic age, with rocks of the Cambrian, Ordovician, Mississippian and Pennsylvanian Systems being most prominent (Plate 1). Igneous rocks of Precambrian age crop out in the St. Francois Mountains of southeastern Missouri and consist of felsitic volcanic rocks ranging from rhyolite to andesite, and granite and basic gabbroic intrusions. These Precambrian rocks form the center of the broad assymetrical Ozark dome. The structural attitude of the Paleozoic formations is controlled by the tectonic origin of this uplift, so that strata dip away in all directions from the periphery of the St. Francois Mountains into surrounding basins. These basins include the Forest City basin to the northwest, the Illinois basin to the northeast, the Anadarko basin to the southwest, the Arkoma basin to the south, and the Mississippian embayment to the southeast. Progressively younger Paleozoic formations are encountered at the surface toward the basins and attain their maximum thickness there.

STRATIGRAPHY

The generalized succession of stratigraphic units in Arkansas and Missouri is summarized in Figure 1.

Precambrian Rocks

The igneous rocks that are exposed in the St. Francois Mountains and the basement rocks of Missouri and Arkansas range in age from 1.2 to 1.45 billion years (Muelberger and others, 1967). The Precambrian rocks exposed in the St. Francois Mountains are felsitic volcanic rocks ranging from rhyolite to andesite, and granite and basic gabbroic intrusions. Rocks beneath the surrounding sedimentary cover range in lithologic type from granite, gneiss, and basic and intermediate plutonic rocks, to volcanic and metamorphosed volcanic rocks (Kisvarsanyi, 1974). These crystalline rocks

SYSTEM	SERIES	STAGE	FORMATION	MEMBER
PENNSYLVANIAN	UPPER	ATOKA	Atoka	GREENLAND SANDSTONE
PENNSYLVANIAN	UPPER	MORROW	BLOYD	TRACE CREEK SHALE, KESSLER LS. DYE SHALE BRENTWOOD LIMESTONE, WOOLSEY SH
PENNSYLVANIAN	UPPER	MORROW	HALE	PRAIRIE GROVE CANE HILL
MISSISSIPPIAN	UPPER	CHESTER	PITKIN	
MISSISSIPPIAN	UPPER	CHESTER	FAYETTEVILLE	WEDINGTON SANDSTONE
MISSISSIPPIAN	UPPER	CHESTER	BATESVILLE	HINDSVILLE LIMESTONE
MISSISSIPPIAN	LOWER & MIDDLE	OSAGE	BOONE	ST. JOE LIMESTONE
MISSISSIPPIAN / DEVONIAN	LOWER & MIDDLE / UPPER		CHATTANOOGA	SYLAMORE SANDSTONE
ORDOVICIAN	LOWER	UPPER CANADIAN	EVERTON	KINGS RIVER SANDSTONE
ORDOVICIAN	LOWER	UPPER CANADIAN	POWELL	
ORDOVICIAN	LOWER	UPPER CANADIAN	COTTER	
ORDOVICIAN	LOWER	UPPER CANADIAN	JEFFERSON CITY	
ORDOVICIAN	LOWER	UPPER CANADIAN	ROUBIDOUX	
ORDOVICIAN	LOWER	UPPER CANADIAN	GASCONADE	GUNTER SANDSTONE
CAMBRIAN	UPPER		EMINENCE	
CAMBRIAN	UPPER		POTOSI	
CAMBRIAN	UPPER		DERBY-DOERUN	
CAMBRIAN	UPPER		DAVIS	
CAMBRIAN	UPPER		BONNETERRE	
CAMBRIAN	UPPER		LAMOTTE	(After Mapes, 1968)
PRECAMBRIAN BASEMENT ROCKS				

Figure 1. Generalized stratigraphic column of northwestern Arkansas, southwestern Missouri, and northeastern Oklahoma.

formed prominent topographic and structural basement highs which had a profound influence on subsequent Paleozoic sedimentation.

Paleozoic Rocks

The Paleozoic Era is represented by sedimentary rock deposited throughout much of northern Arkansas and Missouri, when relatively shallow seas covered part and at times all of the area. Mild vertical movements modified the environment from time to time and uplift with local or regional emergence resulted in discontinuous sedimentation and unconformities. Downwarping favored the continuity but not necessarily increased thickness of sediments, and the section, therefore, varies in both thickness and character from place to place (Howe and others, 1967). Only minor igneous activity occurred in the area during the Paleozoic.

Cambrian System

Rocks of Cambrian age crop out along the periphery of the St. Francois Mountains Precambrian igneous complex in southeastern Missouri. These strata are regarded as late Cambrian in age, and lie unconformably on the irregular Precambrian basement. Outcrops of successively younger units occur in peripheral, annular patterns around this complex. The lower portion of the Cambrian succession consists of quartzose sandstone, and the upper part is composed of dolomite and shale (Howe and Koenig, 1961). These strata dip beneath younger Paleozoic formations away from the uplift. They are present in the subsurface throughout northern Arkansas and Missouri, except where they have been removed from Precambrian topographic highs by erosion. The upper Cambrian Series consists of the following formations in ascending order: the Lamotte, Bonneterre, Davis, Derby-Doerun, Potosi and Eminence Formations. The combined thickness of these formations in Missouri is 2,000 feet and in Arkansas averages 500 feet. The Davis and Derby-Doerun Formations have not been recognized in the subsurface of northern Arkansas (Caplin, 1960).

Lamotte Formation

The Lamotte Formation is the basal unit of the Cambrian in Missouri and Arkansas. It is predominantly a quartzose sandstone, which grades laterally into conglomerate and arkose where it lies on crystalline rock. The Lamotte attains its maximum thickness of 500 feet in the depressions between Precambrian ridges and knobs in Missouri (Howe and Koenig, 1961). In Arkansas the Lamotte has been encountered in only a few wells, with a maximum thickness of over 150 feet (Caplin, 1960).

Bonneterre Formation

The sandstone of the Lamotte Formation grades upward through a zone of arenaceous dolomite into the Bonneterre Formation. The Bonneterre is typically a light-gray dolomite, but locally, parts are shaly and glauconitic. The formation rests conformably on the Lamotte and attains a maximum thickness of 1,580 feet in the subsurface of Pemiscot County, Missouri (Howe and Koenig, 1961). The Bonneterre has been recognized in only a few wells in Arkansas and is generally around 70 feet thick (Caplin, 1960).

Davis and Derby-Doerun Formations

These units constitute the Elvins Group of Missouri but are not present in the Arkansas subsurface. Strata of the Elvins Group are composed of shale, siltstone, fine-grained sandstone, and carbonate rock. Dolomite predominates in the upper formations, whereas the lower parts are shaly and glauconitic (Howe and others, 1967). The combined thickness is about 150 feet near their type localities in Missouri (Grohskopf and McCracken, 1949). The Davis is the lower of the two formations and is conformable with the underlying Bonneterre Formation. The contact of the Derby-Doerun with the underlying Davis Formation is conformable.

Potosi Formation

The Potosi is a massive, thickly-bedded, medium to fine-grained dolomite, containing an abundance of chert and associated quartz druse (Howe and Koenig, 1961). The formation rests conformably on the Derby-Doerun Formation in Missouri and ranges in thickness from 75 to a maximum of 300 feet. In northern Arkansas the Potosi and overlying Eminence Formation are undifferentiated. The Potosi has not been recognized in wells in northern Arkansas and like the Davis and Derby-Doerun Formations may not be present

(Caplin, 1960).

Eminence Formation

The Eminence marks the top of the Cambrian section in northern Arkansas and Missouri. The formation is principally a medium to massively-bedded, light-gray, medium to coarse-grained dolomite (Howe and Koenig, 1961). Nodular chert is present in small amounts in the upper portions of the formation in Missouri, and very thin sandstone or sandy dolomite lenses have been observed in northern Arkansas (Caplin, 1960). The contact of the Eminence with the underlying Potosi is conformable.

Thickness of the Eminence ranges from 200 to 250 feet in Missouri, except where it is absent over local structural features. In northern Arkansas the undifferentiated Potosi-Eminence section ranges between 307 feet and 384 feet (Caplin, 1960).

Lower Ordovician System

Rocks of the Lower Ordovician or Canadian Series of Missouri and Arkansas are principally arenaceous and cherty dolomite and sandstone. They crop out in eastern, central, and southern Missouri and are present in the subsurface over large portions of that state and northern Arkansas. The series is bounded at the base and top by regional unconformities and contains the following succession in ascending order: Gasconade, Roubidoux, Jefferson City, Cotter, Powell, and Smithville Formations. A persistent sandstone unit designated the Gunter Member is present at the base of the Gasconade.

Gasconade Formation

Nason (1892) proposed the term Gasconade for the limestone series underlying the Roubidoux Formation along the Gasconade River in central Missouri. He thus established the upper boundary of the formation, leaving the base undefined. Ball and Smith (1903) established the base of the formation at the top of the Gunter Sandstone. Marbut (1907) included the Gunter Sandstone in the Gasconade Formation, making it the basal member. Bridge (1930) working in the Eminence and Cardareva quadrangles of Shannon, Reynolds and Carter Counties in Missouri, restricted the Gasconade by including the lower dolomite and the Gunter Sandstone in the Van Buren Formation. James (1948), and Grohskopf and McCracken (1949) demonstrated that precise boundaries between the Gasconade and Van Buren Formations could only be drawn in local areas. Grawe (1945) and Knight (1954) included the Gunter Sandstone in the Gasconade Formation, and this use has persisted to the present.

The Gasconade Formation includes a sandy dolomite or sandstone (Gunter Member) at the base, and an overlying dolomite which has been informally divided into lower and upper parts (McCracken, 1964). The lower portion of the dolomite unit contains large amounts of chert which often exceed 50 percent of the total volume of the rock (Howe and Koenig, 1961). The upper portion of the dolomite is finely crystalline and contains only small amounts of chert. Gasconade dolomite is typically light brownish-gray in color.

Gunter Member

The Gunter Member of the Gasconade Formation was first described by Swallow (1855) and later by Meek (1855). The term Gunter Sandstone was first used for the unit by Ball and Smith (1903). Knight (1954) discussed the stratigraphic relationships of the Gunter Member in southern Missouri. He also recognized facies of the Gunter from surface and subsurface data and produced a lithofacies map for the sand facies of the Gunter in Missouri. Subsurface study of the Gunter in northern Arkansas has been extremely limited by a lack of well data and analysis thereof. Prior to the initiation of this study, the work of Sheldon (1954), Caplin (1960), Lamonds and Stephens (1969), and Lamonds (1972) were the primary published sources of data.

The basal Gunter Sandstone Member is composed essentially of sandstone throughout a narrow belt that extends southward from central Missouri to the Arkansas border (Knight, 1954). East and west of this belt the unit is more dolomitic and in places consists of sandy dolomite (Figure 2). In northern Arkansas the Gunter maintains these trends but increases in thickness from an average of 30 feet to as much as 120 feet.

The contact of the Eminence Dolomite with the Gasconade Formation is unconformable throughout Arkansas and Missouri.

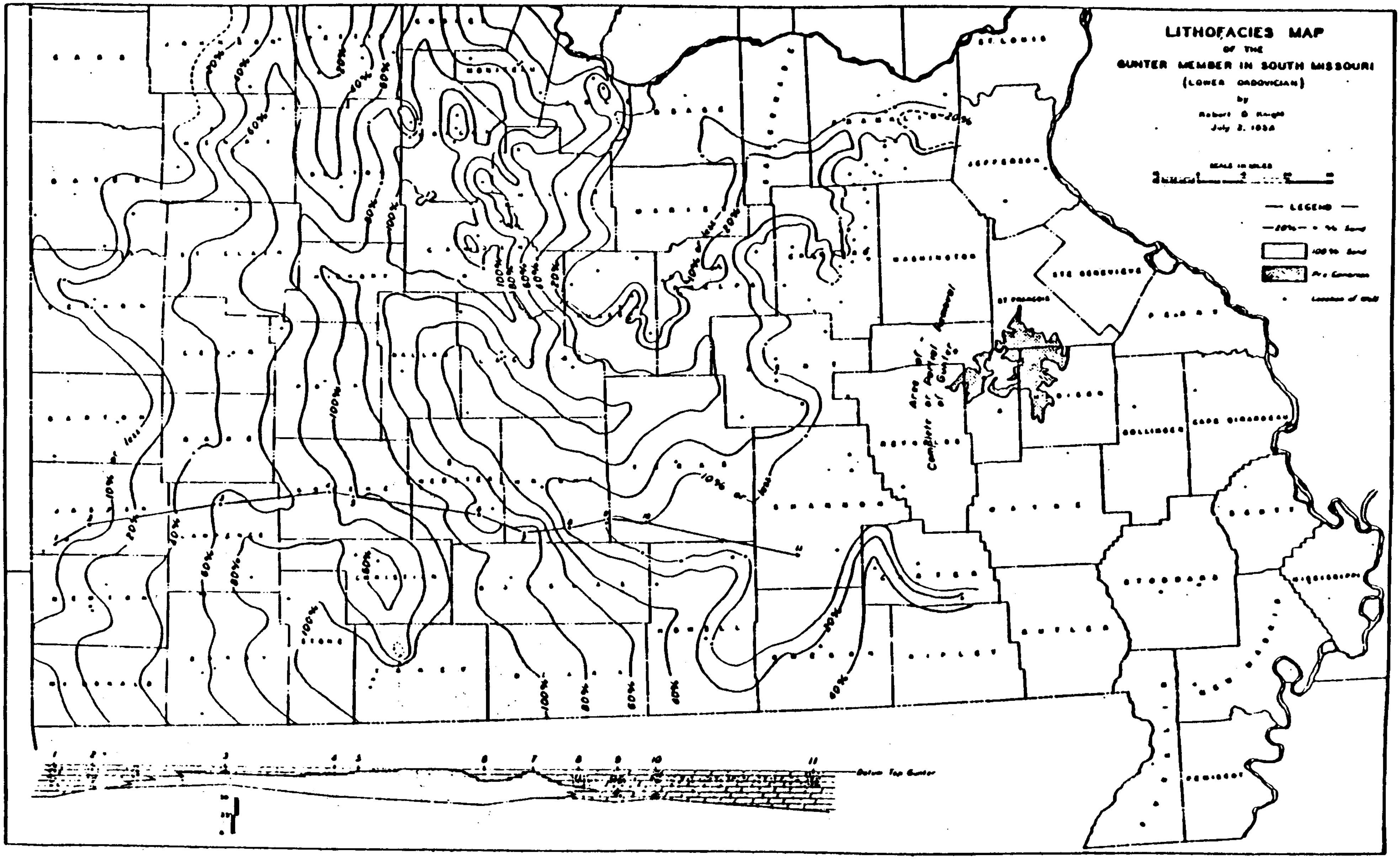

LITHOFACIES MAP
OF THE
GUNTER MEMBER IN SOUTH MISSOURI
(LOWER ORDOVICIAN)
by
— LEGEND —

Figure 2

The Gunter sand accumulated on an irregular surface of erosion developed on dolomite beds of the underlying Eminence Formation (Knight, 1954). The irregularity of the surface accounts for variations in thickness of this unit. The thickness of the Gasconade Formation averages 300 feet in central Missouri but may exceed 700 feet in the northern Arkansas subsurface. The contact with the overlying Roubidoux Formation is an unconformity.

Roubidoux Formation

Nason (1892) suggested the name Roubidoux for rocks described as "overspreading the Ozark region from Cabool to Gasconade City, and from Salem to Doniphan, Missouri". Bain and Ulrich (1905) defined the Roubidoux Formation and placed it stratigraphically below the Jefferson City Formation and above the Gasconade Formation. Heller (1954) described the Roubidoux as consisting of a complex of sandstone, chert, quartzite, dolomite and shale of uncertain thickness. He also recognized the need for further work and attempted to define both the fauna and faunal zones of the formation and where possible to correlate surface units with those of the subsurface. Unfortunately, Heller concluded that lithologic, stratigraphic and faunal character of the formation was extremely complex and inconsistent. One year later McCracken (1955) concluded that the fossil control was limited to a few localized areas and is almost absent in the subsurface.

At the same time paleontologists were attempting to identify the Roubidoux in the subsurface and because of the economic importance of groundwater associated with sandstone, McQueen (1931) developed the use of insoluble residues for subsurface stratigraphic recognition. Grohskopf and McCracken (1949) and McCracken (1952) established insoluble residue zones for some Paleozoic formations, including the Roubidoux and Gunter units. The zones are used almost exclusively by the Missouri Geological Survey for their subsurface hydrological studies; however, subsurface work on groundwater associated with the Roubidoux and Gunter Member in Arkansas has been limited.

Sheldon (1954) examined selected wells in northern Arkansas for the purpose of determining the areal extent and lithologic character of Paleozoic formations, particularly in the subsurface. Several of these wells penetrated the Roubidoux and Gunter; however, only tentative correlations were provided. Caplin (1960) examined the pre-Everton Cambro-Ordovician sequence in northern Arkansas in terms of the petroleum possibilities. This study was based largely on examination of well cuttings. Generalized structural and isopach maps were developed for the Roubidoux Formation. A structure map of the Gunter was also presented as a part of this study. Lamonds and Stephens (1969) developed water resource data for the Ozark Plateaus of Arkansas. The study includes a compilation of data on structural tops and thicknesses for the Roubidoux Formation and Gunter Member, along with some chemical analyses of water from wells penetrating these units. The most recent study was conducted by Lamonds (1972) who compiled structural and piezometric maps for the Roubidoux Formation and Gunter Member, and discussed the hydrologic characteristics of these and other water-bearing units of northern Arkansas.

The Roubidoux Formation unconformably overlies the Gasconade Formation and crops out extensively over a broad area in southeastern Missouri. The most southerly outcrop is approximately four miles north of the Arkansas-Missouri border (Heller, 1954). In Missouri the Roubidoux Formation ranges from 105 to 250 feet in thickness. Variations in thickness are in part attributed to the irregular nature of the unconformity at its base (Heller, 1954). The formation is conformably overlain by dolomite beds of the Jefferson City Formation.

The Roubidoux Formation consists of cherty dolomite, dolomitic sandstone, and well developed sandstone bodies in Missouri. The lithic characteristics in Arkansas are similar, but no persistent sandstone units have been observed in subsurface studies (Snyder, 1976). Dolomite in the Roubidoux is finely crystalline, light-gray to brown in color, and thinly to thickly bedded (Howe and Koenig, 1961).

Jefferson City and Cotter Formations

The Jefferson City Formation was described by McCracken (1964) as a cherty, somewhat silty dolomite with very few sand lenses. The formation is exposed around the periphery of the Ozark dome and is recognized in the subsurface by the characteristic type of oolitic chert it contains (Howe and

Koenig, 1961). The thickness of the Jefferson City Formation ranges from 100 to 500 feet and averages about 200 feet (Howe and Koenig, 1961). The Jefferson City rests conformably on the Roubidoux Formation and is overlain conformably by the Cotter Formation.

The Cotter Formation is similar to the Jefferson City Formation in that it is principally a light-gray to brown, cherty dolomite, but may locally contain thin beds of green shale and sandstone (Howe and Koenig, 1961). Because of the similarity of rock types the Cotter and Jefferson City Formations are often undifferentiated in subsurface studies (Caplin, 1960). The Cotter crops out along the northern and western edges of the Ozark uplift, and averages about 200 feet in thickness.

Powell and Smithville Formations

The Powell Formation rests conformably on the Cotter Formation, and because of similarities of lithology is often undifferentiated from the Cotter. The Powell crops out across southern Missouri and northern Arkansas and is composed of medium to fine-grained dolomite and thin beds of green shale and sandstone (Howe and Koenig, 1961). The thickness ranges from 150 to 175 feet.

The Smithville Formation is similar lithologically to the Powell in that it is composed of gray, finely-granular, dolomitic limestone, which may grade into dolomite locally (Caplin, 1960). The formation crops out in southeastern Missouri and northeastern Arkansas and reaches a maximum of 150 feet in thickness (Howe and Koenig, 1961). The contact of the Smithville with the underlying Powell Formation appears to be one of conformity. However, their stratigraphic relationship has not been defined adequately, especially in Arkansas sections (Caplin, 1960).

Black Rock Formation

The Black Rock Formation crops out in northeastern Arkansas but has not been recognized in southeastern Missouri (Caplin, 1960). The unit consists of fine-grained, dolomitic limestone, similar to that of the underlying Smithville Formation. The Black Rock may also contain dolomite beds and small amounts of sandstone (Caplin, 1960). The maximum thickness ranges from 55 to 200 feet in surface exposures, and the formation is reported to overly the Smithville unconformably (Caplin, 1960).

Everton Formation

The Everton Formation unconformably overlies the Black Rock Formation in northern Arkansas and rocks of the Canadian Series in Missouri and Arkansas. It consists of sandy dolomite and sandstone containing sub-angular to rounded, frosted quartz grains (Caplin, 1960). Complex stratigraphy and facies changes are common in the Everton as the result of local unconformities and fluctuating environmental systems (Shum, 1974).

Devonian System

Chattanooga Formation

The Chattanooga Formation is described by Frezon and Glick (1959) as a black, carbonaceous, fissile shale unit containing a thin basal sandstone member. The formation rests unconformably on rocks of the Ordovician System in southern Missouri and northern Arkansas. The thickness of the Chattanooga ranges from a few inches to a maximum of 85 feet, with an average thickness of 30 feet (Croneis, 1930).

Mississippian System

Rocks of the Mississippian System Crop out over large portions of southwestern Missouri and northwestern Arkansas. The sequence of rocks varies lithologically because of facies changes within given units (Howe and Koenig, 1961).

Kinderhookian-Osagean Series

In southwestern Missouri the Kinderhookian-Osagean Series is represented by the Bachelor, Compton, Northview, Pierson, Reeds Spring, Elsey, Burlington and Keokuck Formations. In Arkansas the Boone Formation and basal St. Joe Member are equivalent to this entire sequence. Rock types of the Kinderhookian Series range from crinoidal limestone to siltstone and green shale. Rocks of the Osagean Series are dominantly coarse crystalline, cherty, crinoidal limestone. The rocks form a fairly continuous outcrop band around the Ozark region (Howe and Koenig, 1961).

Upper Mississippian

Rocks of late Mississippian age consist of the Meramecian and Chesterian Series in southwestern Missouri and northern Arkansas. Lithic types of the Meramecian Series are predominantly limestone with some shale units present, while the Chesterian Formations consist of crudely rhythmic repetitions of sandstone, shale and limestone (Howe and Koenig, 1961). The Meramecian rests conformably on the Osagean Series, and is overlain unconformably by Chesterian Series strata (Howe and Koenig, 1961).

Pennsylvanian System

Rocks of Pennsylvanian age are present beneath surficial deposits over much of northern Arkansas and southern Missouri. Pennsylvanian strata are dominantly clastic, but there are also many important limestone and coal beds. Strata of Pennsylvanian age in southwestern Missouri and northern Arkansas include the Morrowan and Atokan Series.

Morrowan Series

South of the Missouri boundary in the northern part of the Boston Mountains of northern Arkansas, the Morrowan Series consists of the Hale and Bloyd Formations. North of the boundary the Morrowan is represented only by outliers of the Hale Formation (Howe and Koenig, 1961). The Hale in these areas of Missouri consists of massive, cross-bedded, quartzose sandstone, whereas in northern Arkansas it consists of a succession of shale, siltstone, and calcareous sandstone.

The Bloyd Formation of northern Arkansas is composed of shale and limestone beds with some small coal seams (Croneis, 1930). The formation exhibits facies changes eastward along the outcrop and southeastward in the subsurface. (Caplin, 1957).

Atokan Series

The Atokan Series overlies the Chesterian Series, and forms the higher elevations of the Boston Mountains. The series crops out in northern Arkansas where it is entirely represented by the Atoka Formation. This formation consists mainly of dark shale and sandstone units, with occasional fossiliferous, sandy limestone units (Caplin, 1957). Approximately seventy-five percent of the formation is composed of black shale (Croneis, 1930).

STRUCTURAL CONFIGURATION AND THICKNESS OF THE ROUBIDOUX AND GASCONADE FORMATIONS

Subsurface isopachous and structure maps of the Roubidoux and Gasconade Formations in Missouri and northern Arkansas have been published by McCracken (1964), McCracken (1965), Caplin (1960), and Lamonds (1972). The present study utilizes McCracken's maps for the Missouri portion of the study area. Caplin and Lamonds data, which consisted of 28 control points, were expanded by the addition of data from 20 wells in northern Arkansas not previously used for correlation studies (Table 1). Structure and isopachous

Table 1

Well Data for Isopachs and Structural Maps

Well Log Source

1. Missouri Geologic Survey - Rolla, Missouri
2. United States Geological Survey - Little Rock, Arkansas
3. Arkansas Western Gas Company - Fayetteville, Arkansas
4. Pan American Petroleum Co.

Formation Symbols

Ce Cambrian - Eminence Formation
Clm Cambrian - Lamotte Formation
Og Ordovician - Gasconade Formation
Or Ordovician - Roubidoux Formation

Well Ref. Number	Location Twp. Rge. Sec.	County	Owner or Driller	Year Completed	T.D. Below Land Surface	Elev. Feet Above MSL	FM. at T.D.	Penetration of Basal	Well Log Source	Roubidoux Fm. Elev. Base	Roubidoux Fm. Thickness	Gasconade Fm. Elev. Base	Gasconade Fm. Thickness	Log Type
1	21N 33W 22	Benton	Sibley Engr & Mfg Co	1955	900	900	Og	30	1	30	165			Insol Residue
2	21N 26W 15baal	Carroll	Holiday Island #2	1970	1,222	1,102	Og	184	2	64	186			Electric-gamma
3	21N 26W 17bccl	Carroll	Holiday Island #1	1970	1,058	1,010	Og	81	2	33	182			Electric-gamma
4	21N 26W 27ada	Carroll	Holiday Island #4	1972	1,800	1,520	Ce	10	2 1	375	185	-30	405	Electric-gamma temp-ins residue
5	21N 18W 29bdcl	Boone	Lead Hill Ark	1973	703	750	Og	13	2	60	274			Electric, gamma
6	21N 15W 9dddl	Ozark, MO	Corps of Engr Pontiac, Mo	1973	506	700	Og	8	2	202	244			Electric, gamma
7	21N 15W 6	Marion	Oakland Rec Area Bull Shoals	1968	1,081	771	Og	276	1	-34	255			Insol Residue
8	21N 13W 33	Baxter	R. Wilson/P. Schick	1949	800	945	Og	40	1	185	245			Insol Residue
9	20N 33W 11	Benton	City of Gravette #2	1954	1,603	1,199	Ce	23	1	-51	185	-386	335	Insol Residue
10	20N 33W 14	Benton	City of Gravette #3	-	1,611	1,275	Ce	1	1	10	185	-335	325	Insol Residue
11	20N 28W 13bdl	Benton	Lost Bridge Village	1973	1,626	1,380	Ce	77	2	190	204	-159	349	Electric
12	20N 26W 16cdl	Carroll	Eureka Springs P.S.	1972	1,418	1,250	Ce	54	2	240	214	-114	354	Gamma-elec-

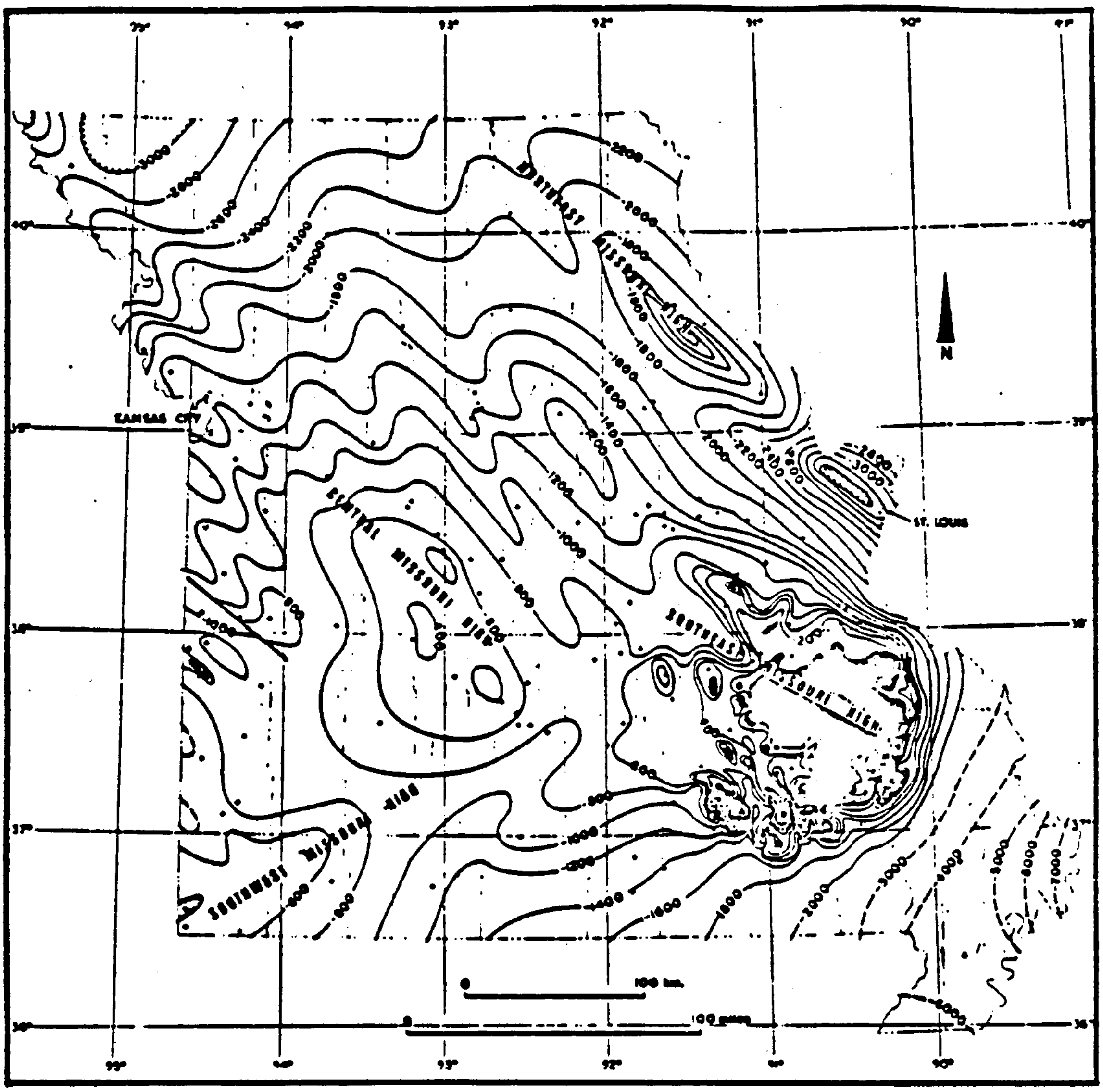
Well Ref. Number	Location Twp. Rge. Sec.	County	Owner or Driller	Year Completed	T.D. Below Land Surface	Elev. Feet Above MSL	FM. at T.D.	Penetration of Basal	Well Log Source	Rouhidoux FM. Elev. Base	Rouhidoux FM. Thickness	Gasconade FM. Elev. Base	Gasconade FM. Thickness	Log Type
13	20N 13W 33	Baxter	Baxter Lab		1,865	780	Ce	270	2	-295	-	-815	520	
14	20N 12W 1ccal	Baxter	Gamaliel Pub Use Area Corps.of Engr	1973	606	705	Og	21	2	240	191	-	-	Electric-gamma
15	20N 9W 18	Fulton	City of Viola	1964	1,600	800	Ce	30	1	-290	255	-770	490	Insol Residue
16	20N 8W 27	Fulton	Salem	1956	1,283	660	Og	613	2	-10	255	-	-	
17	19N 33W 11cda	Benton	Peterson Proc #2	1971	1,723	1,235	Ce	88	1 2	-95	190	-400	305	Electric, gamma Insol Residue
18	19N 33W 13	Benton	City of Decater	-	1,430	1,250	Ce	10	1	170	-	-170	340	Insol Residue
19	19N 31W 12	Benton	Millsap-Grady Jones #1		2,338			25		-67	210	-412	345	
20	19N 29W 18	Benton	City of Rogers	1954	1,660	1,375	Og	355	1	105	210	-	-	Insol Residue
21	19N 29W 25ca	Benton	Horseshoe Bend Rec Area	1971	1,165	1,175	Og	105	2	115	200	-	-	Electric
22	19N 23W 4	Carroll	City of Green Forest	1963	1,587	1,349	Og	7	1	-231	215	-	-	Insol Residue
23	19N 23W 15c	Carroll	Starke/Werdeman	1971	1,575	1,575	Og	16	2	-261	229	-	-	Electric
24	19N 19W 8	Boone	City of Bergman	1971	1,725	1,285	Og	205	1	-235	230	-	-	Insol Residue
25	19N 16W 32adal	Marion	City of Summit	1970	1,520	950	Ce	82	1	16	170	-488	472	Electric-ins residue
26	19N 14W 28	Baxter	Gassville		1,503	670	Og	548		-285	230	-	-	
27	19N 14W 29dbcl	Baxter	Town of Cotter	1972	1,625	720	Ce	177	2	-204	236	-728	524	Electric
28	19N 14W 31	Baxter	City of Cotter	-	-	666	Og	-	1	-274	215	-	-	Insol Residue
29	19N 13W 9	Baxter	Mt Home #2	1946	1,505	740	Og	555	1	-210	210	-	-	Insol Residue
30	19N 6W 23adal	Fulton	Cherokee Village-Cooper	1972	1,630	682	Ce	350	2	-141	267	-698	557	Electric

Well Ref. Number	Location Twp. Rge. Sec.	County	Owner or Driller	Year Com-pleted	T.D. Below Land Surface	Elev. Feet Above MSL	FM. at T.D.	Penetra-tion of Basal	Well Log Source	Roubidoux FM. Elev. Base	Roubidoux FM. Thick-ness	Gasconade FM. Elev. Base	Gasconade FM. Thick-ness	Log Type
31	19N 5W 21	Sharp	Cherokee Village	1972	1,555	750	Ce		1	0	230	-585	527	Insol Residue
32	18N 33W 14	Benton	Ozarks-Products #1	-	2,222	1,190	Elm	62	1	-210	205	-590	350	Insol Residue
33	18N 12W 3	Benton	Allen Canning	-	1,828	1,150	Ce	163	1	-180	180	-515	335	Insol Residue
34	18N 22W 24	Boone	AWG Bray #2	1958	2,805	2,172	Ce	1	3	-199	256	632	435	Gamma
35	18N 22W 25	Boone	AWG R. Roberts #1	1966	2,320	2,087	Og		3	-133	220			Gamma, Insol
36	19N 21W 18	Boone	Ark West Gas Ladd #2	-	2,260	1,848	Ce	33	1 3	3	285	-379	381	Formation density Insol Residue
37	18N 19W 19	Boone	Ark Hi Dept	1967	2,000	1,050	Og	400	1	-550	235	-	-	Insol Residue
38	18N 19W 33	Boone	Valley Springs		205	1,375	Ce	1		-145	230	-675	542	
39	18N 12W 2	Baxter	Norfolk Dam U.S. Forest Service	-	1,450	500	Og	300	1	-650	200			Insol Residue
40	18N 6W 10	Sharp	City of Ash Flat	-	1,545	555	Og	615	1	-375	220			Insol Residue
41	17N 33W 6	Benton	Plus Poultry Co	1966	1,515	1,150	Og	90	1	-275	215			Insol Residue
42	17N 29W 9abd1	Washington	White River Rural Dev Co	1973	2,071	1,481	Og		2	-220	220			Electric, gamma
43	17N 20W 21	Newton	Marble Falls	1972	2,576	1,344	Ce	43		-376	180	-1,116	560	
44	16N 32W 9abd1	Washington	Lake Wedington Park	1973	1,815	1,135	Ce	45	2	-280	210	-635	355	Electric
45	16N 27W 6	Madison	Independent Oil & #1 Banks	-	-	1,400	Ce	10	1	-335	249	-700	365	Insol Residue
46	15N 31W 17bbc1	Washington	D. Holcomb	1973	2,097	1,228	Og		2	-558	223			Electric
47	15N 16W 25	Searcey	Marshall	-	2,415	1,100	Og	75	1	-1,265	235			Insol Residue
48.	13N 22W 28	Newton	Pan Am Petroleum Co USA B #1	1964	4,996	1,682			4	-2,418	230	-2,938	520	Induction elec

maps were constructed for the northern Arkansas portion of the study area from this expanded data base. These maps were then correlated with those published by McCracken.

Structural Configuration of the Roubidoux and Gasconade Formations

Structural development of the Cambrian and Ordovician Formations of Missouri and northern Arkansas appears to have been greatly influenced by the structural grain of the Precambrian basement. These rocks in Missouri and northern Arkansas form a structurally high area of the mid-continent region flanked by basins on the east, south, and northwest (Kisuarsanyi, 1974). The area has been subjected to repeated uplifts during and after Precambrian time, with the Ozark dome being the most dominant structural uplift feature. In addition to these epeirogenic movements, a considerable amount of faulting has taken place. This faulting gives the Ozark area the pattern of a ruptured dome near the center of the structural high (McCracken, 1967). The pattern of Precambrian faulting follows predominant northwest-southeast trends with secondary northeast-southwest and east-west trending faults (McCracken, 1971). Repeated movement along some of these structures has been reflected in the overlying rocks. Figure 3 shows the topography of the buried Precambrian surface in Missouri. The Southwest Missouri High, Central Missouri High and Southeast Missouri High appear to have exerted a strong influence on deposition



(After Kisvarsanyi, 1974)

Figure 3. Topography of buried Precambrian surface in Missouri.

and structural development during Gasconade and Roubidoux sedimentation. Examination of the structural map contoured on the base of the Roubidoux Formation (Plate 2) shows strong correlation between structural highs present at the beginning of Roubidoux deposition and those of the Precambrian basement. The dominant trends of faults and of anticlinal and synclinal axes in these sediments are norhtwest, northeast, and east, which are similar to the Precambrian trends discussed above. Except in the vicinity of faults the regional dip of Plaeozoic strata in Missouri is only a few degrees. The Paleozoic strata of northern Arkansas rest on a broad structural platform that extends into the state from Missouri. The Roubidoux and Gasconade Formations regionally dip from 18 to 36 feet per mile southward across this platform toward the Arkhoma basin in central Arkansas. Near the margin of the basin the dip steepens along a hinge that extends westward from central Searcy County to northern Crawford County and attains values that range from 80 to 100 feet per mile to the south. North of this hinge the southerly dip of the platform has been modified by several broad, poorly defined structural highs and intervening lows that trend generally to the southeast.

Thickness Trends of the Roubidoux and Gasconade Formations

The thickness of the Gasconade and Roubidoux Formations is depicted on the isopachous maps accompanying this report (Plates 3 and 4).

Gasconade Formation

The thickness of the Gasconade Formation ranges from 160 feet in Bates County, Missouri, to over 660 feet in Searcy, Stone, Izard, Sharp, and Randolph Counties, Arkansas. The direction of regional thickening of the Gasconade follows a pattern of increasing from northwest to southeast toward the Arkhoma basin of central Arkansas. This trend follows the regional gradient of the Precambrian topography (Figure 3) and is reflective of the strong influence that the Precambrian structural grain exerted on subsequent sedimentation. Thinning of the Gasconade corresponds with the Southwest Missouri High, Central Missouri High and Southeast Missouri High. Thickenings follow elongate troughs trending northwest, and are associated with recurrent basement faults of the same trend.

The northwest to southeast thickening and thinning of the Gasconade appears to extend across the structural platform in the Arkansas subsurface, with a regional increase in thickness to the southeast.

Gunter Sandstone Member

The basal Gunter Sandstone Member of the Gasconade Formation has been included in the isopachous map of the Gasconade Formation (Plate 3). In general the Gunter Member is a sandy dolomite unit averaging 30 feet in thickness in Missouri and increasing in thickness from the northwest to the southeast. Subsurface and outcrop studies of the Gunter Member in Missouri by Knight (1954) show that the Gunter is represented in different areas by a sandstone and a dolomite facies (Figure 2). The Gunter Member is largely sandstone in an area trending southward from Miller County through Greene and Webster Counties to Taney and Ozark Counties, Missouri (Knight, 1954). East and west of this belt it increases in dolomite content to a maximum of over 90 percent dolomite. Subsurface work by Snyder (1976) in Arkansas indicates a continuation of Knight's sandstone facies from Taney and Ozark Counties, Missouri through Carroll and Boone Counties, Arkansas. East and west of this area dolomite content increases to a maximum of approximately 70 percent.

The thickness of the Gunter Member is quite variable due to the uneven surface on which it was deposited (Knight, 1954). The thickness ranges from zero over Precambrian highs to 120 feet in northern Arkansas. The thickening of the Gunter is similar to that of the overlying Gasconade, having a northwest to southeast trend. This trend and the increase in sand content toward the south suggests that the Gunter may have a source south of the Ouachita Mountain province (McCracken, 1964).

Roubidoux Formation

Thickness trends of the Roubidoux Formation are shown on Plate 3 of this report. The Roubidoux ranges from 100 feet thick in Hickory and Benton Counties, Missouri, to over 280 feet thick in Benton County, Arkansas. The regional trend is one of thickening of the Roubidoux Formation from northwest to southeast. The thickness of the Roubidoux Formation is remarkably regular from central Missouri to northeastern Oklahoma (McCracken, 1964). The unit is approximately 190 to 200 feet thick throughout a belt that extends southwest from southern Baxter County through southern Marion, central Newton and northern Franklin Counties, Arkansas. Regionally the Roubidoux thickens southeast of this belt.

The Roubidoux Formation of south central Missouri normally contains several lenticular sand bodies which occur near the top, middle, and base of the formation (McCracken, 1964). The development of these sand lenses has not been observed in the subsurface of northern Arkansas.

GROUNDWATER IN THE OZARK PLATEAUS PROVINCE

Occurrence

Groundwater in the Ozark Plateaus is derived from shallow and deep aquifers, with the total reservoir section consisting of over 2,000 feet. Similar to physiography, the Ozark Plateaus area may also be divided into three units in terms of groundwater availability; the Salem Plateau, Springfield Plateau, and Boston Mountains. Groundwater in the Salem Plateau is derived from aquifers of Cambrian and Ordovician age, which are at or near the surface throughout the area. Groundwater in the Springfield Plateau and Boston Mountain areas is obtained from shallow aquifers of Mississippian and Pennsylvanian age and deeper aquifers of Cambrian and Ordovician age. Water from the shallow aquifers occurs under water table conditions and generally supplies enough water for domestic use. Groundwater from the deep aquifers is generally under artesian pressure and yields are usually considerably higher than those of the shallow aquifers. The most dependable water supplies for industrial, municipal and agricultural uses are derived from the deep aquifer section.

Deep Aquifers

Groundwater from the deep aquifers of the Ozark area is derived from Cambrian and Ordovician sandstone and dolomite. The deep aquifer section encompasses the following principal fresh water formations: the Lamotte Sandstone, Potosi

Dolomite, Gasconade Dolomite and Gunter Sandstone Member, and the Roubidoux Formation. The position of these units in the geologic column and their relationship to other geologic units is shown in Figure 1. All of the principal aquifer units crop out in concentric belts surrounding the St. Francois Mountains but are confined to the subsurface in southwestern Missouri and northern Arkansas (Plate 1).

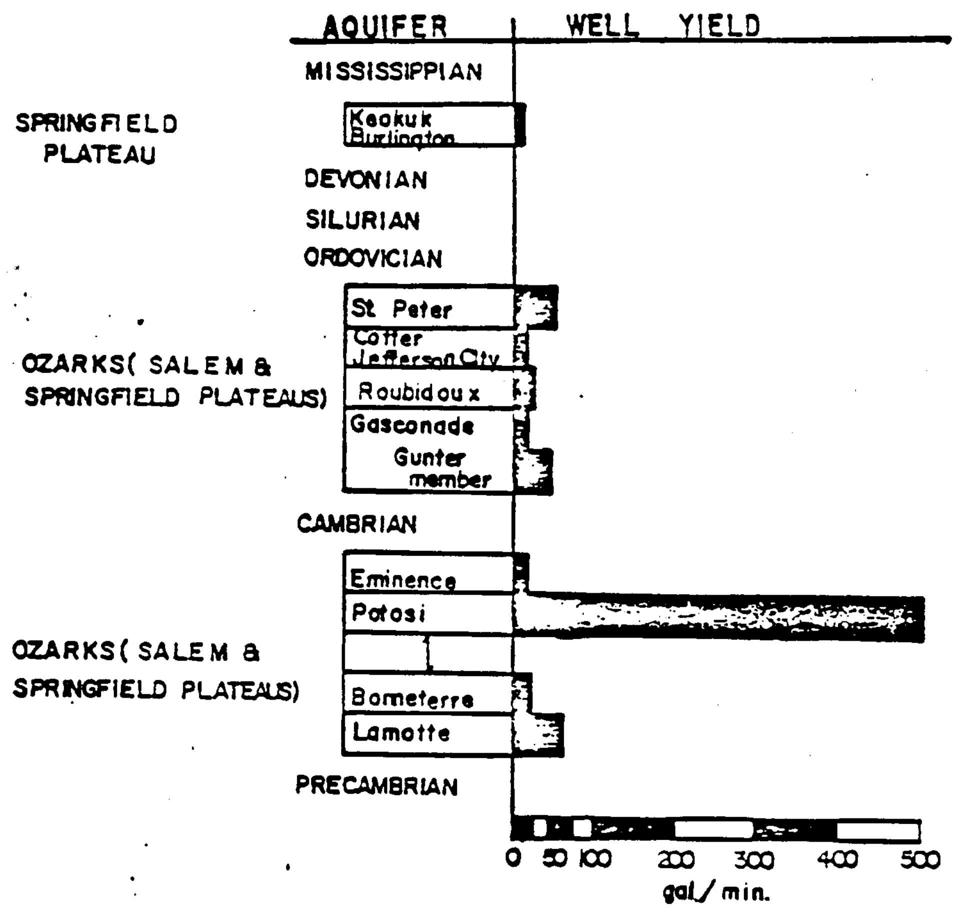
Recharge to the principal aquifers is by vertical movement of water through overlying younger formations (Fuller and Knight, 1967). Recharge and water yields are dependent upon the permeability of the formations. Yields often show large variations because of low permeability associated with the carbonate lithologies of the formations. Relative yields of the principal aquifers in southern Missouri are shown in Figure 4.

General Hydrologic Character of the Principal Aquifers

Lamotte Sandstone

The Lamotte Formation is the oldest aquifer in the Ozark Area and is the basal unit of the Cambrian system. The Lamotte crops out in the St. Francois Mountain area but is confined to the subsurface throughout southern Missouri and northern Arkansas. Depths to the Lamotte range from 1,200 feet in southern Missouri to over 2,500 feet in northern Arkansas.

The Lamotte Sandstone in Missouri is generally a low yield aquifer (average 75 gpm) due to the void-filling



(After Knight, 1962)

Figure 4. Typical yields of wells in principal aquifers of the Ozark Plateaus.

cementation of the sand grains (Fuller and Knight, 1967); however, little is known about water yields from the Lamotte in northern Arkansas. No wells have been reported that produce from the Lamotte. The only penetration of the formation resulted from the drilling of oil wells which were not tested for fresh water yield.

Potosi Dolomite

The Potosi Dolomite is exposed on the flanks of the St. Francois Mountains and as the Lamotte is confined to the subsurface in southern Missouri and northern Arkansas. The Potosi of Missouri is generally a coarsely crystalline dolomite, and in most of the area it is drusy and vuggy (Fuller and Knight, 1967). The vugs are interconnected and water is able to flow freely (Fuller and Knight, 1967). This characteristic makes the Potosi one of the highest yielding formations of Missouri, and it is the primary source of water for municipal and industrial use in the area. Yields average 500 gpm (Knight, 1962) from the Potosi. Depths to the Potosi in Missouri average 1,200 feet.

As is true of the Lamotte, little is known about the yield potential of the Potosi in northern Arkansas. Only a few wells have penetrated the formation and are producing from it. A well drilled near Rogers, in Benton County, Arkansas is reported to be producing from the Potosi. The well is located in Sec. 13, T. 20 N., R. 29 W., and has a total depth of 1,968 feet, with a surface elevation of 1,460 feet. The well has a yield of 230 gpm with a drawdown of 49 feet (Taylor Engineering Co., Springdale, Arkansas, Personal Communication, 1975). The water from this well is of good chemical quality.

A well located in Sec. 17, T. 15 N., R. 13 W., in Washington County, Arkansas is reported by the United States Geological Survey at Little Rock to be in the Potosi at a total depth of 2,097 feet. This is an old oil test well by the Camden Oil Company. The well is reported to have yielded 50 to 60 gpm and had an unusually high total dissolved solid content of 928 ppm. The chloride content was 290 ppm.

Water from the Potosi may be considered as a future potential source in northern Arkansas. As the need for water increases in the area deeper wells may have to be drilled. Also, in areas where the Gunter Member and Roubidoux Formation are not good producers, the Potosi may be a logical alternative.

Eminence Dolomite

The Eminence Dolomite is medium to coarsely-crystalline and locally very siliceous (Fuller and Knight, 1967). In Missouri only small quantities of water are produced from the upper 100 feet of the formation. Moderate quantities are obtained from the lower portion of the formation, down dip from the outcrop area. The water is being produced from openings and fractures in the dolomite in yields sufficient for municipalities and small industries (Fuller and Knight, 1967). Yields from the Eminence average 25 gpm in Missouri (Knight, 1962).

In northern Arkansas the Eminence does not appear to be a significant aquifer. Many wells penetrate the first 50 feet of the formation, but no major increases in yield are apparent over those encountered in the penetration of overlying formations.

<u>The Gasconade Formation and Gunter Sandstone Member</u>

The Gasconade Formation is the earliest Ordovician unit in Missouri and northern Arkansas. The formation consists of an upper cherty dolomite unit averaging over 300 feet in thickness, and a lower basal sandstone and sandy dolomite member termed the Gunter Sandstone Member.

The Gunter Member crops out in the Lake of the Ozarks area of south central Missouri. It is generally a well developed sandstone averaging 30 feet in thickness throughout most of south central Missouri and north central Arkansas but becomes increasingly more dolomitic east and west of this area. Yields from the Gunter Member throughout most of southern Missouri to the Arkansas border average 40 to 50 gpm, and locally as much as 1,000 gpm (Fuller and Knight, 1967). Yields from the Gunter in northern Arkansas average greater than 100 gpm, with local yields as high as 581 gpm.

The dolomite beds of the Gasconade Formation above the Gunter Member contain several dense zones in the upper 150 feet of the formation. These zones apparently do not yield water and may form an aquiclude to water from over-

Regional Hydrologic Character of the Roubidoux and Gasconade Formations

Domestic supplies of groundwater outside of the outcrop area of the five principal deep aquifers in the Ozark Plateaus region are generally obtained from relatively shallow wells in formations of Pennsylvanian and Mississippian age. Water for municipal and industrial utilization is generally not available in sufficient quantities from these shallow aquifers, and must be obtained from the deep aquifer units (Feder and others, 1969). The Roubidoux and Gasconade Formations are being utilized extensively throughout Missouri as reliable aquifers for industrial and municipal needs. In northern Arkansas extensive development of these aquifers has been restricted by high drilling costs and relatively sparse population. At present, only a limited number of wells penetrate the Roubidoux and Gasconade Formations in the area; however, future development of large groundwater supplies in northern Arkansas appears to depend primarily on the water-bearing properties of the Roubidoux and Gasconade units.

Water Availability

To determine the general availability of water supplies from the Roubidoux and Gasconade Formations, groundwater yield and specific capacity maps were constructed. Data for the maps (Plates 5, 6, 7, and 8) were collected from the Missouri Geological Survey, the Arkansas Geological Commission, the U. S. Geological Survey and from consulting lying formations. The next 100 feet to 150 feet below these dense zones contain up to 50 percent chert and yield water sufficient for farm and domestic use in Missouri. The availability of water from this zone in northern Arkansas has not been determined. Wells which penetrate only the upper Gasconade are not numerous enough at this time to permit proper evaluation of the aquifer's potential.

Roubidoux Formation

The Roubidoux Formation crops out extensively in southern Missouri, and is the most reliable shallow aquifer for farm wells in this area (Fuller and Knight, 1967). The Roubidoux is confined to the subsurface for the most part in southwestern Missouri and northern Arkansas. It consists of sandy, cherty dolomite, with distinct sandstone units appearing at the base, middle, and top of the formation in western Missouri.

Yields from the Roubidoux throughout Missouri average 15 to 20 gpm with some local production as high as 300 gpm (Fuller and Knight, 1967). Yields in northern Arkansas average 60 gpm with local variations as high as 600 gpm. The formation is the shallowest of the principal aquifers in the Ozark Region, and produces adequate yields for small industrial and municipal use.

engineers who have directed the drilling of wells in the area. In some cases data were obtained from individual owners of wells. In total, data from 257 wells throughout Missouri and northern Arkansas have been tabulated (Appendix A).

Estimated Yields

Most wells drilled into the Roubidoux and Gasconade Formations are open below a certain casing depth. This casing depth is determined by the presence of surface contaminants, the degree of weathering, and economics. Estimated yields from these wells, therefore, represent the total contribution from all open aquifers in the section. Yields from wells are dependent on the diameter and total depth of the bore hole, formations penetrated, geographic location, structural attitude of the rocks, and permeability of the aquifers tapped. The probability of interformational movement of water also makes it difficult to define parameters which describe the yield capabilities of the individual aquifers. It should be noted that the wells used to establish the yield and specific capacity zones shown in Plates 5, 6, 7, and 8 reflect these conditions. There is generally, however, a substantial increase in the collective yield of a well when either the Roubidoux or Gasconade Formations are penetrated. It is therefore possible to arrive at conclusions about the water-yielding properties of the Roubidoux and Gasconade Formations by using data from wells penetrating various aquifer combinations.

Analysis of the Roubidoux yield data presented in Plate 5 can be summarized as follows:

1. Yields range from 4 gpm to a maximum of 600 gpm, with an average yield of 50-60 gpm throughout the study area.
2. Yields are generally low (0-50 gpm) in the outcrop area of the Roubidoux Formation, but generally increase to the south and west of this area.
3. Yields appear to decrease significantly from the northern Arkansas structural platform toward the Arkhoma basin.
4. High yield areas (greater than 150 gpm) are not uniform throughout any portion of the study area. This observation would suggest that either the rock characteristics which dictate water production are not constant in their subsurface distribution, or that yields are affected by structure, faulting, or solutioning more than by lithic character.
5. Yields of 50 to 150 gpm are available from a belt beginning in the southwestern corner of Missouri and extending southeast across northern Arkansas.

Analysis of the Gasconade yield data (Plate 6) can be summarized as follows:

1. Yields are generally higher than for wells penetrating the Roubidoux Formation. Yields range from 4 gpm to a maximum of 732 gpm, with the average being approximately 170 gpm.
2. Yields are low (0-50 gpm) in the outcrop area of the

Gasconade Formation, and increase to the south and west of this area.

3. Yields appear to decrease toward the Arkhoma basin.

4. High yield zones (greater than 250 gpm) are more uniform and continuous than those of wells penetrating the Roubidoux Formation. These yield zones appear as elongate belts localized in southwest Missouri and extreme northwest Arkansas.

5. Yields of from 50 to 250 gpm are available over a large portion of the study area extending from southwest Missouri, south and east into northern Arkansas to the border of the structural platform.

Specific Capacities

Yield data alone are not an indicator of the performance of the aquifers because the size of the pump, size of the drill hole, and other variables can also influence water output. A more significant and reliable measure of the performance of an aquifer or well is its specific capacity. The specific capacity of a well is its yield per unit of drawdown, usually expressed as gallons per minute per foot of drawdown (Johnson Division UOP, 1972). Dividing the yield by the drawdown, each measured at the same time during a pump test, gives the value of the specific capacity. The drawdown in a well is the amount the water level is lowered during pumping (Anderson, 1973). If the aquifer is very permeable or contains well developed interconnected fractures or solution channels, the drawdown will be relatively small for any pumping rate, resulting in large specific capacity values. In contrast, aquifers having low permeabilities in the vicinity of the pumping well will produce large drawdowns and consequently low specific capacity values. Therefore, specific capacity can be a fairly reliable indicator of the water-bearing character of the aquifer.

Plates 7 and 8 show generalized specific capacity zones for wells penetrating the Roubidoux and Gasconade Formations. Analysis of these maps indicates the following for the Roubidoux Formation:

1. Specific capacities are less than 1 throughout most of the study area.
2. High specific capacities (greater than 5) are localized in portions of Dade, Barton, Vernon and Cedar Counties, Missouri, Newton County, Missouri, and portions of Carroll and Boone Counties, Arkansas. These zones appear to be related to localized fracturing or karst development.
3. Spedific capacities appear to decrease toward the Arkhoma basin.

Analysis of Plate 8, Gasconade specific capacity data, can be summarized as follows:

1. Specific capacities for wells penetrating the Gasconade Formation are greater than those for Roubidoux wells, but they are less uniform in distribution.
2. Specific capacities are less than 2 over much of the

outcrop area of the Gasconade Formation.

3. Specific capacities average about 3 outside the outcrop area, and regionally decrease toward the Arkhoma basin.

4. A prominent high specific capacity zone extends from Vernon and St. Clair Counties, Missouri, southeast to extreme northern Taney County, Missouri.

Geologic Factors Influencing Water Availability In the Roubidoux and Gasconade Formations

Groundwater in carbonate aquifers such as the dolomite which comprises the Roubidoux and Gasconade Formations moves quite differently than in granular rocks such as sandstone. In dolomite for example, porosity and permeability depend upon the presence or absence of discrete openings, whereas in granular rocks they are a function of intergranular pores. Although the ability of carbonate rocks to transmit groundwater can sometimes be attributed to original rock texture, secondary parameters such as faults, fractures, joints, bedding planes, and intercrystalline and solution passages are more important by far. Most workers in carbonate hydrogeology agree that the capacity of dense dolomite aquifers to transmit groundwater to wells and springs largely depends upon the size and number of these water-yielding secondary parameters. Nearly all aquifers composed of limestone, dolomite and siliceous rocks have at least some fracture porosity. The fracture planes combine with whatever porosity already exists to form an interconnecting system that greatly increases the permeability of the rock. Thus two systems of permeability are involved in many dense, fractured aquifers; (1) the low-permeability blocks between fractures where the water moves slowly through short distances, (2) the high permeability fractures that eventually lead to the well bore. No matter how dense and compact the rock formation may appear at the outcrop or in well cuttings, these same rocks may become a suitable aquifer at depth as the result of fracturing, fissuring, and shattering.

Examination of data presented in a recent study completed in northwest Arkansas which concerns relatively shallow carbonate aquifers, establishes that a significant correlation exists between high yield wells and springs and their proximity to zones of rock fracture (Hanson, 1973). The assumption that these secondary openings can extend into the subsurface for several thousands of feet has been supported by numerous fractured petroleum reservoirs which have produced millions of barrels of oil in the United States alone.

Wells which penetrate the Roubidoux or Gasconade Formations to depths in excess of 1,000 feet in portions of Missouri and northern Arkansas show some correlation with large surface linear or fault systems; however, more detailed research is necessary to document this observation. The high yield and specific capacity zones of the Roubidoux and Gasconade Formations located in Vernon, Cedar, Barton, Dade, Lawrence, Greene, and Christian Counties in Missouri are associated with prominent northwest trending fault systems (Plates 2 and 8). These are the Chesapeake and Bolivar-Mansfield fault zones. These faults are reported to extend to great depths (McCracken, 1971), possibly to the Precambrian basement. In the area of the high yield, high specific capacity zones the Chesapeake fault is upthrown to the southwest and downthrown to the northeast, with a maximum displacement of approximately 250 feet. The Bolivar-Mansfield fault is upthrown to the northeast and downthrown to the southwest, with about the same amount of displacement. This pattern of faulting describes a large northwest trending horst and graben system, with higher yields and specific capacities localized within the graben block. Southeast of Greene County, Missouri the fault-block displacement changes, with the Chesapeake fault becoming upthrown to the northeast and downthrown to the southwest, and the Bolivar-Mansfield fault becoming upthrown to the southwest and downthrown to the northeast. The central block of the system, therefore, becomes a horst southeast of Greene County. Yields and specific capacities show a marked decrease from northwest to southeast throughout this horst block. The total effect of this faulting activity is to produce an elongated high-recharge trough trending northwest from Greene Counto to the Kansas-Missouri border. Increases in permeability associated with the faulting activity are believed to be responsible for the high yields throughout this zone; however, one might assume that some increase in water availability within the zone may be due to lithologic controls. Examination of well logs supplied by the Missouri Geologic Survey shows that this is not the situation because no major lithologic changes can be found within the aquifer section. The lithologic nature of the Roubidoux and Gasconade Formations in not dissimilar to that observed in wells from low yield zones. Structural setting, therefore, appears to be the major control over water availability in the highest yielding zone of the Ozarks.

Increased permeability related to secondary solutioning along zones of fracture and faulting has an important effect on water availability and movement in the Roubidoux and Gasconade Formations. Solution phenomena such as springs, caves, and sinks are common in the outcrop area of the formations on the west flank of the Ozark uplift (Skelton, 1966). Water-well drilling and temperature data show that water may circulate through interconnected solution openings to depths of 800 feet in some areas of the Salem Plateau (Harvey and Vineyard, 1967). These openings may extend to greater depths down dip from the outcrop area. Drillers in northern Arkansas have periodically reported the occurrence of cavities at depths exceeding 1,000 feet (Lee Taylor, Personal Communication), and water yields generally increase where subsurface solution channels are encountered. For example, the high specific capacity zone of the Roubidoux Formation beginning in Texas and Wright Counties, Missouri and extending southward to Fulton County, Arkansas appears to be related to the development of an extensive subsurface drainage system (Plate 7). This zone is also associated with the Spring River drainage basin and Mammoth Spring. Mammoth Spring is the second largest spring in the Ozark Plateau Province. In 1966 fluorescein dye was traced from Grand Gulf, a large surface karst feature located in Oregon County, Missouri to Mammoth Spring (Vineyard and Feder, 1974).

Lateral changes in lithology or facies do not appear to be a major factor controlling water availability from the Roubidoux or Gasconade Formations in Missouri or northern Arkansas. Snyder (1976) has provided lithofacies data for these formations in northern Arkansas on the basis of sand, dolomite, and chert percentages. Snyder's facies in the Roubidoux and Gasconade Formations having high sand percentages show no apparent correlation with the yield zones presented by this investigation on Plates 5, 6, 7, and 8.

A somewhat different situation appears to exist in the Gunter Sandstone Member of the Gasconade Formation. Work by Knight (1954) in Missouri, and Snyder (1976) in northern Arkansas has provided facies of sand versus dolomite percentages for this unit. The Gunter consists of 100 percent sand in an area trending southward from Miller County, Missouri to Boone County in northern Arkansas.

East and west of this belt the member becomes increasingly more dolomitic reaching a maximum of over 90 percent. These facies appear on a regional scale to exert some control over water yields. Water yields generally increase over those available from the dolomite of the upper Gasconade and Roubidoux Formations when the Gunter Member is penetrated in Missouri and northern Arkansas. Westward into northern Oklahoma the Gunter is primarily dolomite, and yields are negligible (Reed and others, 1955). In contrast to these broad regional trends, sand facies of the Gunter Member show no specific correlation with the high yield-high specific capacity zones established in this study (Plates 5, 6, 7, and 8). The zones fall within the 10 to 40 percent sand facies rather than the 80 to 100 percent belt established by Knight and Snyder. The lack of increase in yield from the high sand percent facies may be due in large part to reduction in permeability by dolomite and silica cementation (Snyder, 1976). The high yields appear to be the result of complex faulting and structural control rather than lithic character.

Recharge, Movement, and Discharge of Groundwater

Recharge

The Roubidoux and Gasconade Formations receive recharge primarily from precipitation falling throughout the study area. The amount and rate of recharge depends upon the general configuration and physical character of the land surface, the distribution and quantity of precipitation, the geologic framework of the area, the permeability and porosity of the soil and bedrock, and surface runoff and stream flow. Movement of water from the soil to the bedrock occurs along fractures and solution openings in the rock. The principal area of recharge to the formations falls within the Salem Plateau section of the Ozark Plateaus province. Throughout this area the Roubidoux and Gasconade Formations are at or near the surface. Recharge to wells penetrating the aquifers is in direct response to rapid infiltration of precipitation. The process of this recharge is illustrated by hydrograph data from monitored wells in the Salem Plateau provided by the Missouri Geologic Survey. Figures 5 and 6 show the relationship of water levels to precipitation in a well penetrating the Gasconade and Eminence Formations at West Plains in Howell County, Missouri. Figure 5 is a hydrograph with a nine year base (1965-1973). Figure 6 shows water level and precipitation fluctuations for the year 1973. Figures 7 and 8 are for a well penetrating the Gasconade Formation at Willow Springs in Howell County, and figures 9 and 10 are hydrographs of a well penetrating the Gasconade Formation at Bradleyville in Taney County, Missouri. In each case the period of record is a nine year base and the year 1973. These wells are largely representative of the correlation between precipitation and water levels characteristic of the Salem Plateau for both long and short term events.

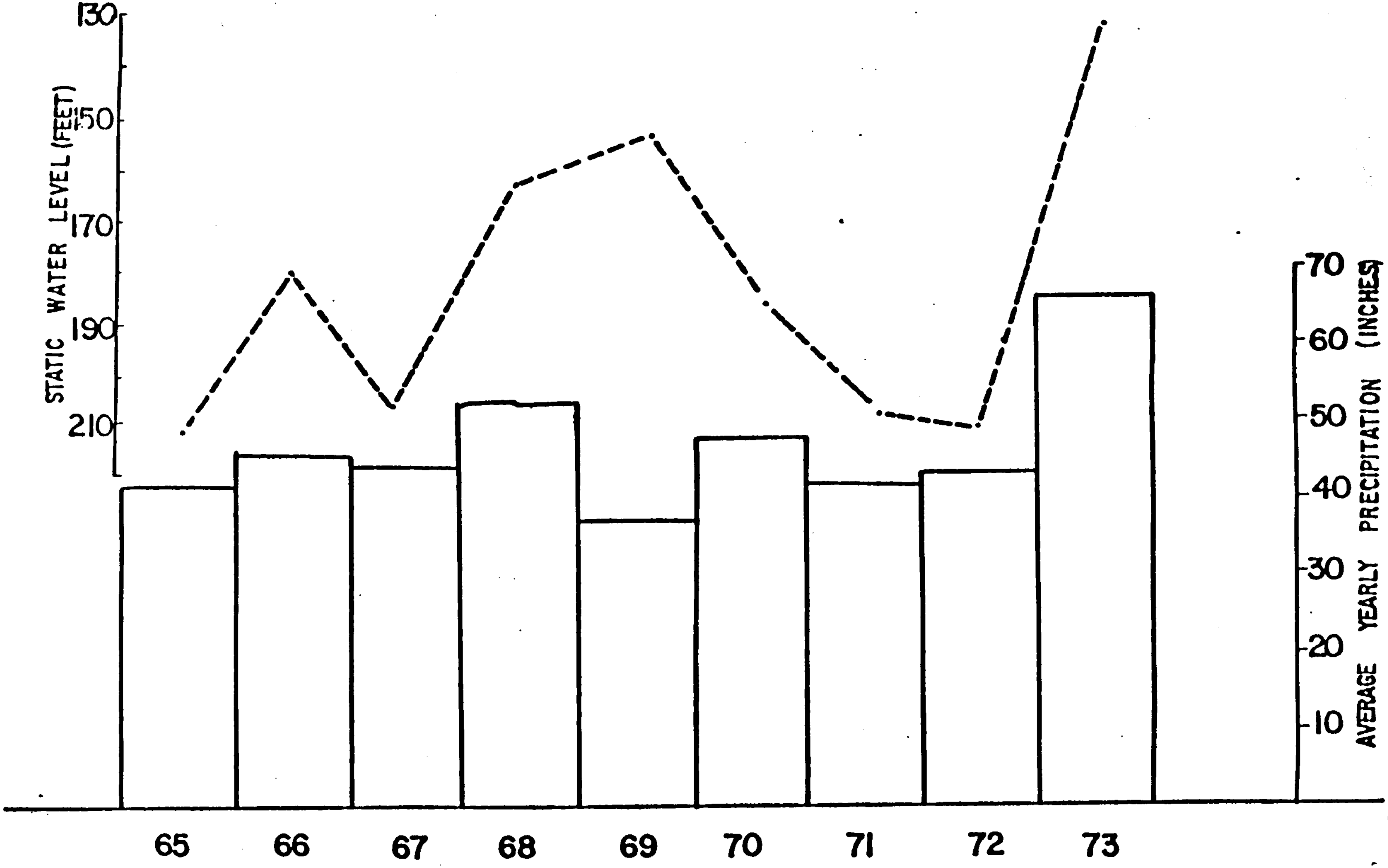


Figure 5. Hydrograph of water level fluctuation in well at West Plains, Howell County, Missouri.

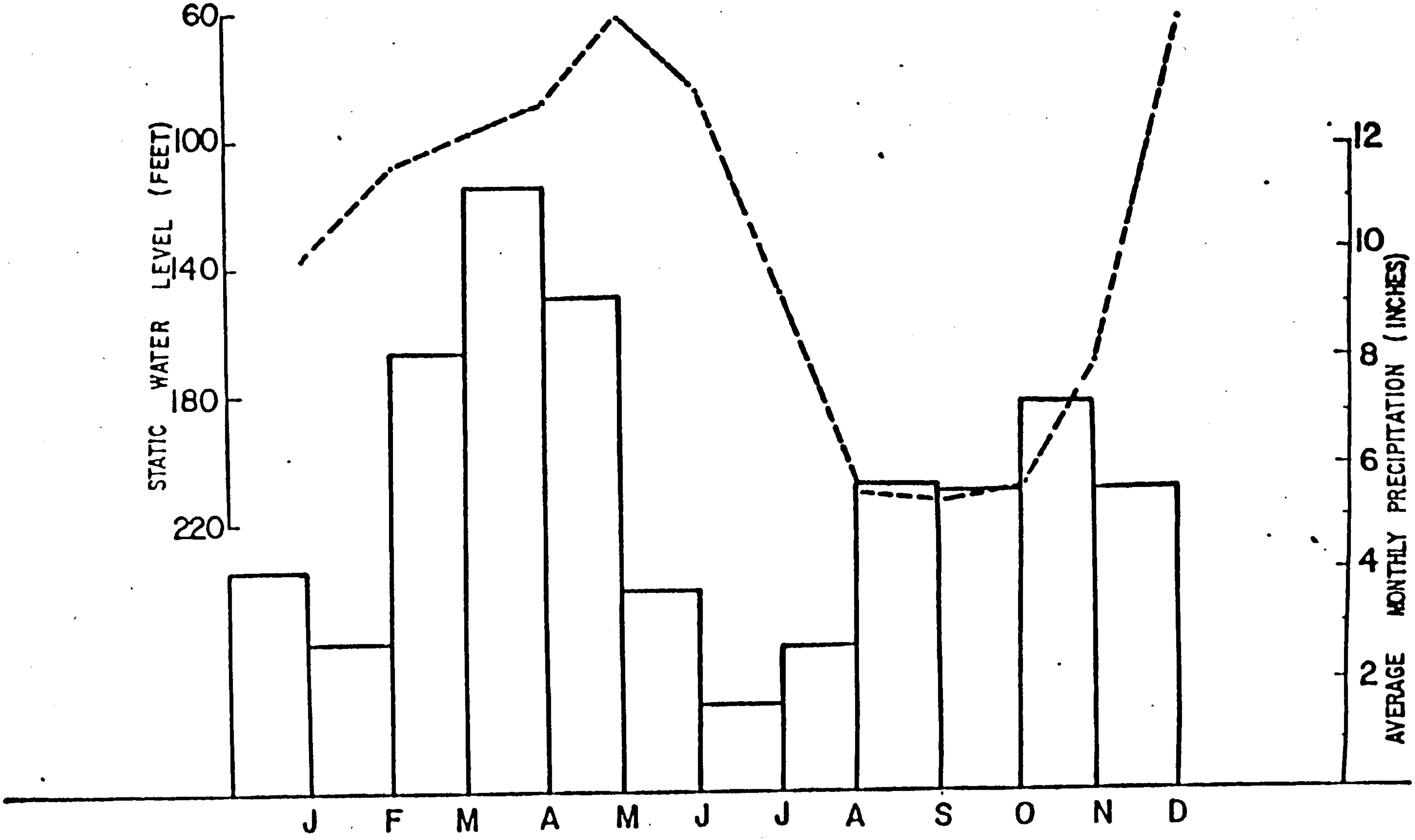


Figure 6. Hydrograph of water level fluctuation in well at West Plains, Howell County, Missouri during 1973.

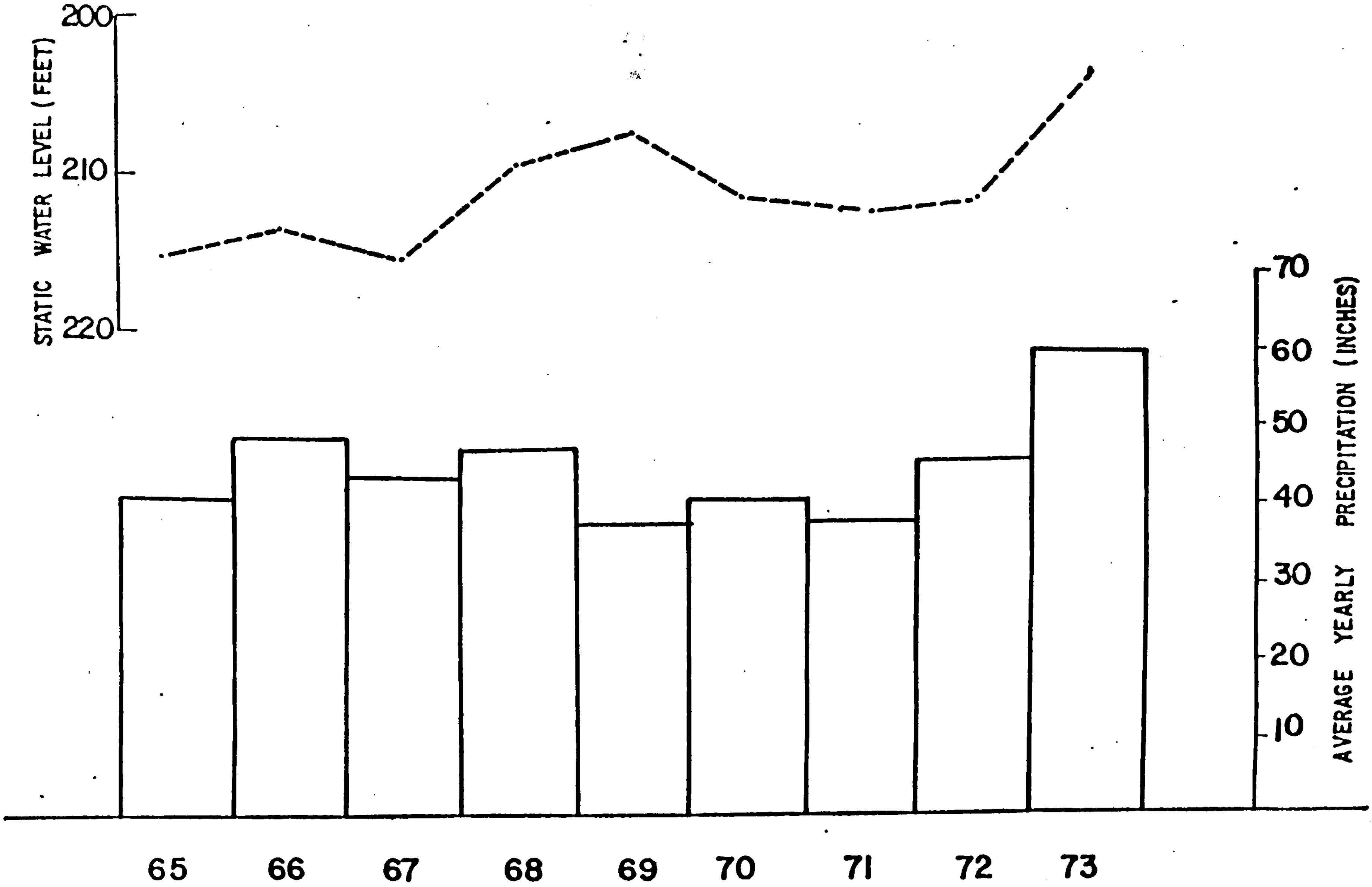


Figure 7. Hydrograph of water level fluctuations in well at Willow Springs, Howell County, Missouri.

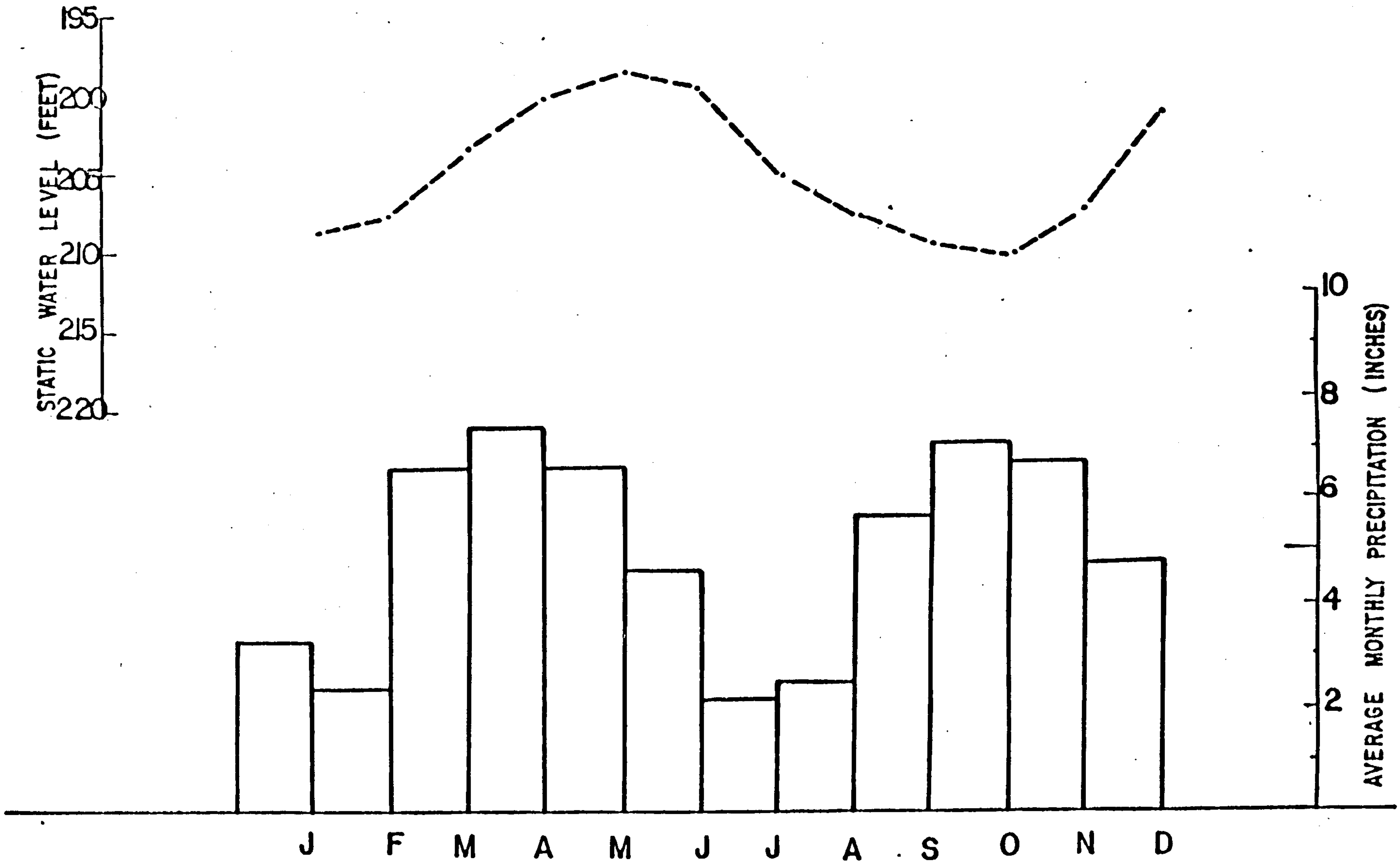


Figure 8. Hydrograph of water level fluctuations in well at Willow Springs, Howell County, Missouri during 1973.

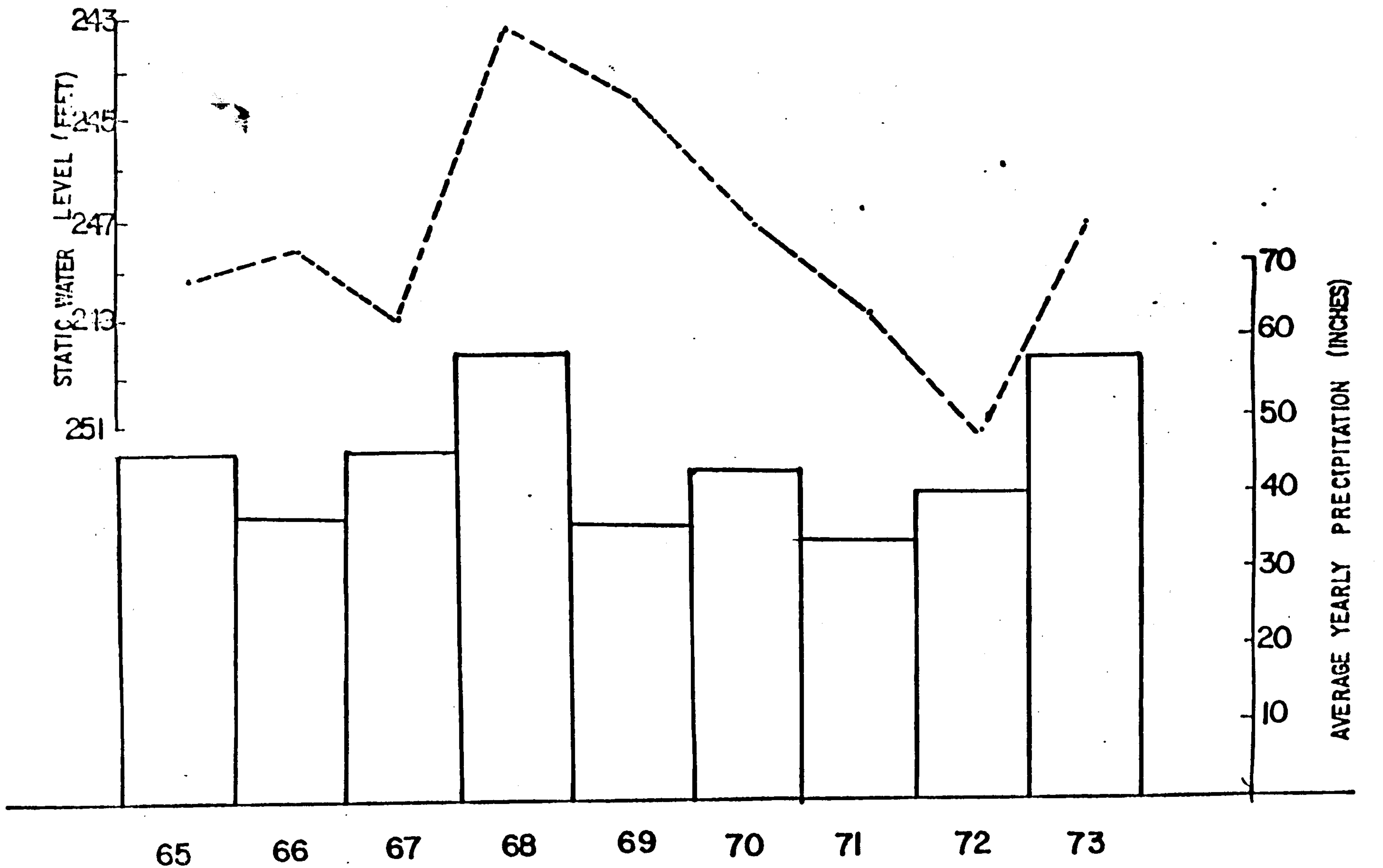


Figure 9. Hydrograph of water level fluctuations in well at Bradleyville, Taney County, Missouri.

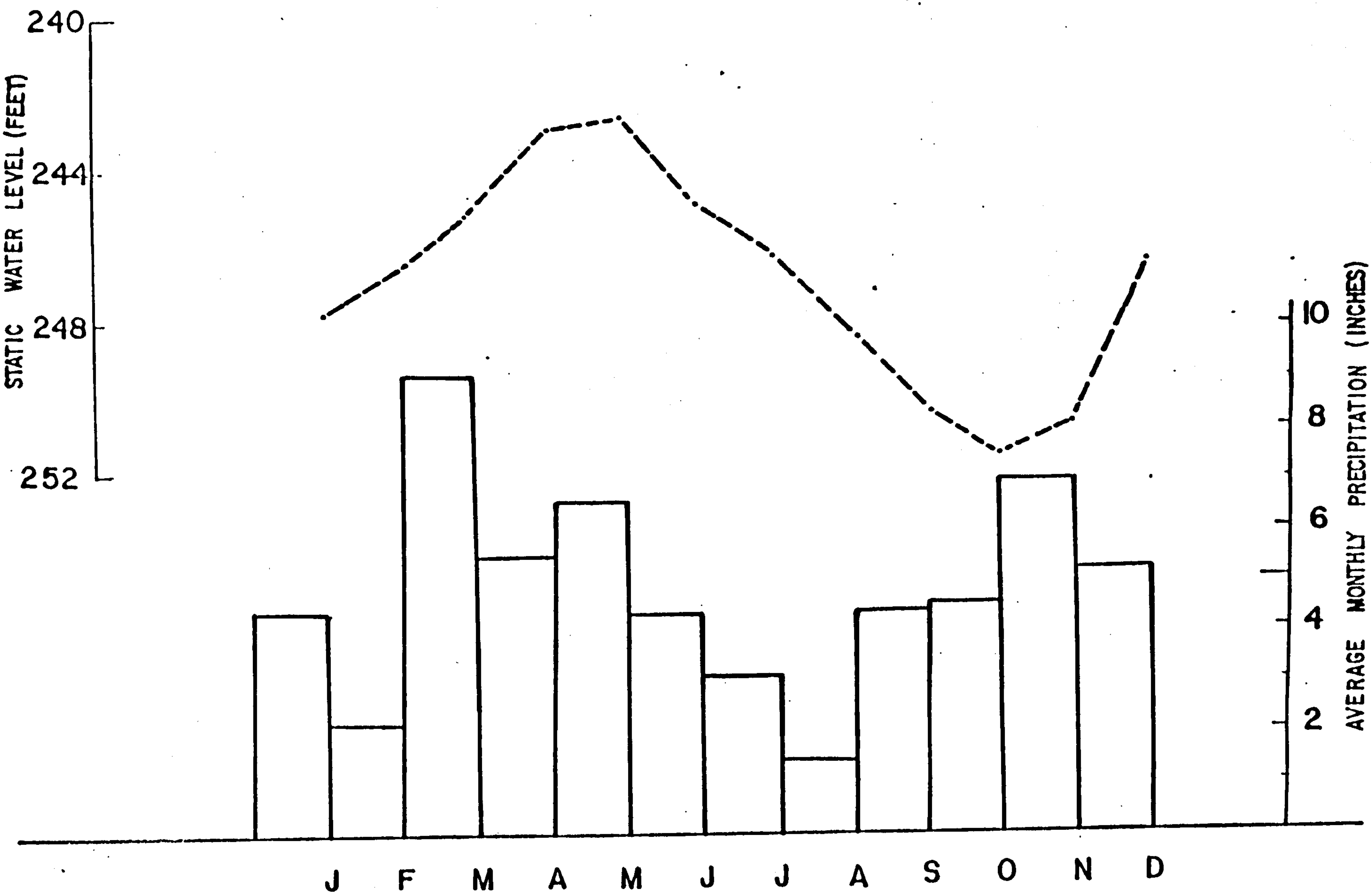


Figure 10. Hydrograph of water level fluctuations in well at Bradleyville, Taney County, Missouri during 1973.

Recharge to the aquifers outside the Salem Plateau is not in direct response to variations in precipitation. This area of low response corresponds to the Springfield Plateau section of the Ozark Plateau province. In this region the Roubidoux and Gasconade Formations are confined to the subsurface, and are generally overlain by thick sequences of upper Ordovician, Mississippian and Pennsylvanian rocks. Local variations in precipitation do not directly affect the supplies available from the deep aquifers (Feder and others, 1969). Well hydrographs (Figures 11, 12, 13, and 14) from wells penetrating the aquifers at Noel in McDonald County, Missouri, Rogers in Benton County, Arkansas and Flippin in Marion County, Arkansas illustrate the lack of response of wells to precipitation events and are characteristic of deep wells in the Springfield Plateau. Primary recharge to the aquifers in this area results from the slow migration of groundwater along bedding planes, faults, fractures, and solution channels down dip from the outcrop area in the Salem Plateau. Determination of the rate of this movement is not possible at this time; however, examination of existing data suggests that movement is extremely slow and non-uniform.

Some areas of the Springfield Plateau appear to have significant aquifer recharge by vertical infiltration along faults and from overlying shallow aquifers rather than by lateral migration from the outcrop area (Feder and others, 1969). The effect of this recharge is responsible

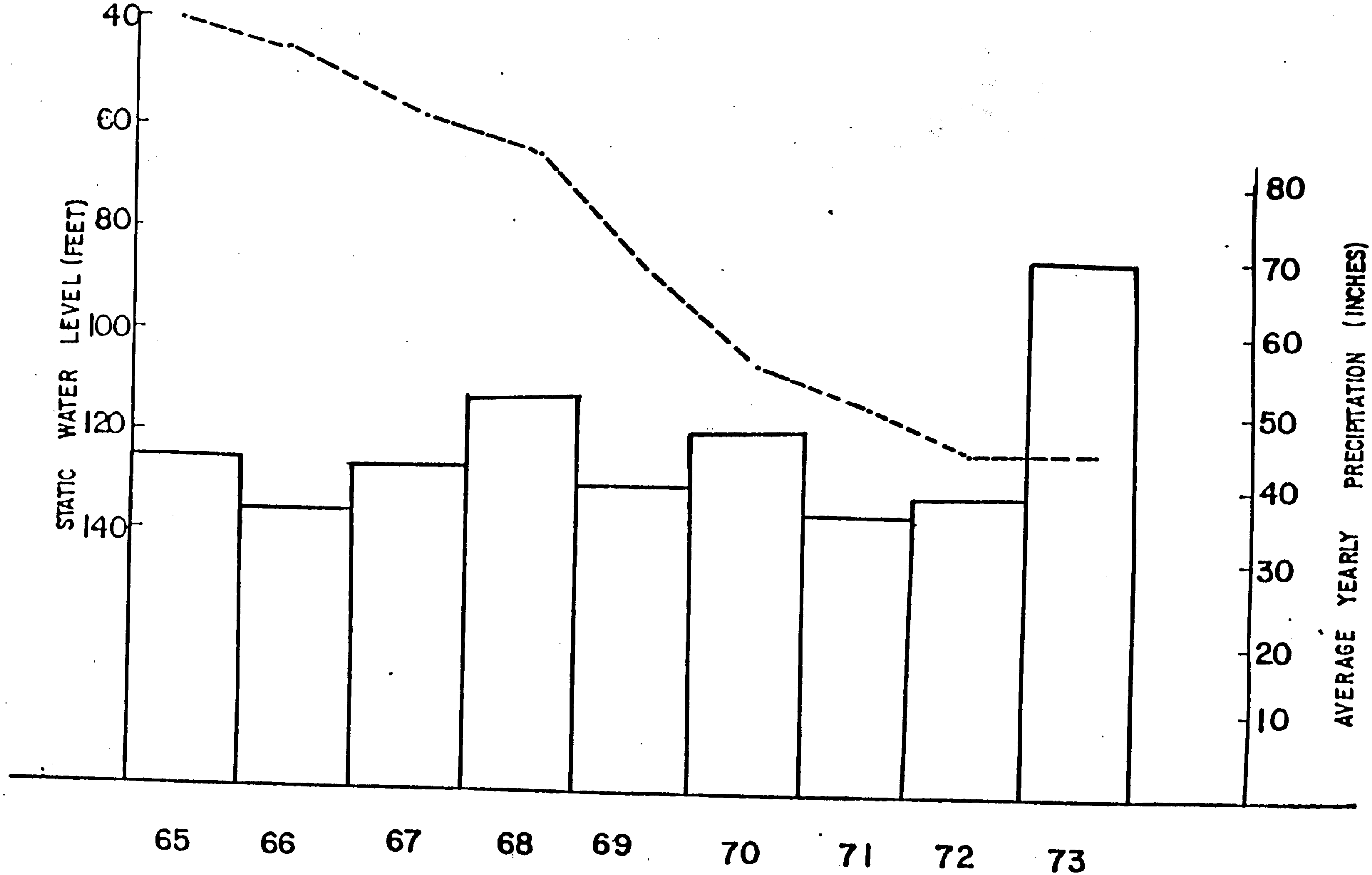


Figure 11. Hydrograph of water level fluctuations in well at Noel, McDonald County, Missouri.

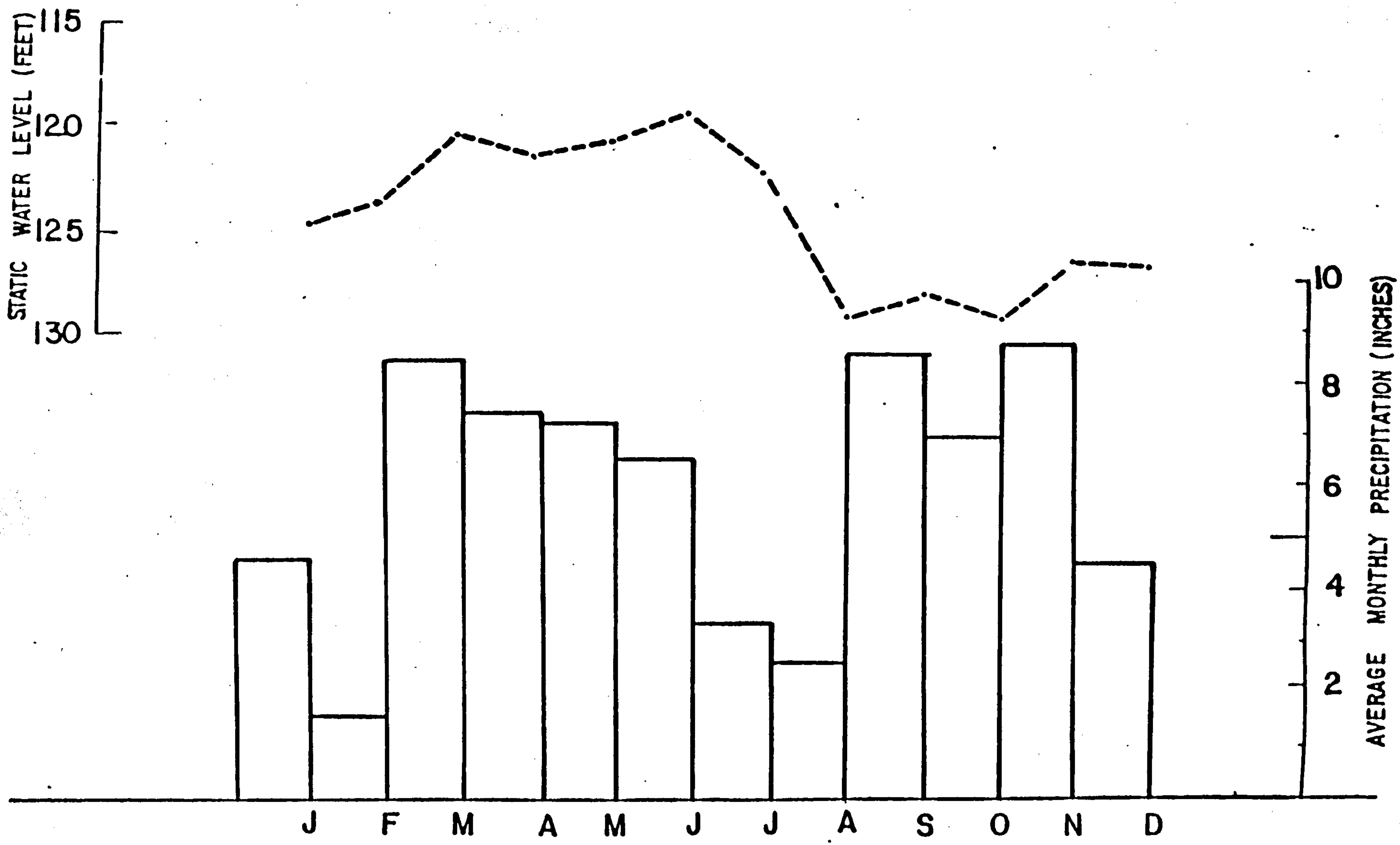


Figure 12. Hydrograph of water level fluctuations in well at Noel, McDonald County, Missouri during 1973.

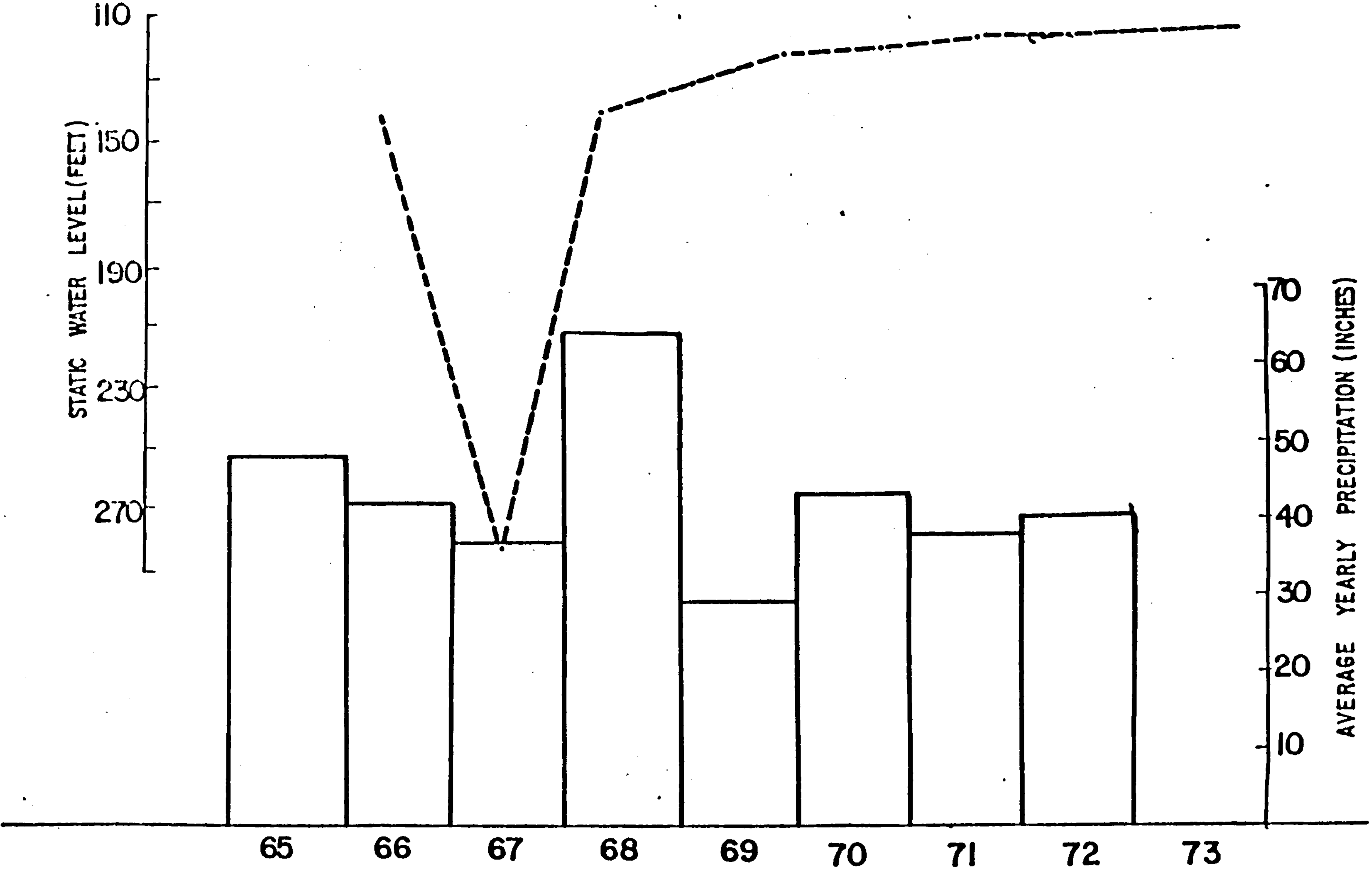


Figure 13. Hydrograph of water level fluctuations in well at Rogers, Benton County, Arkansas.

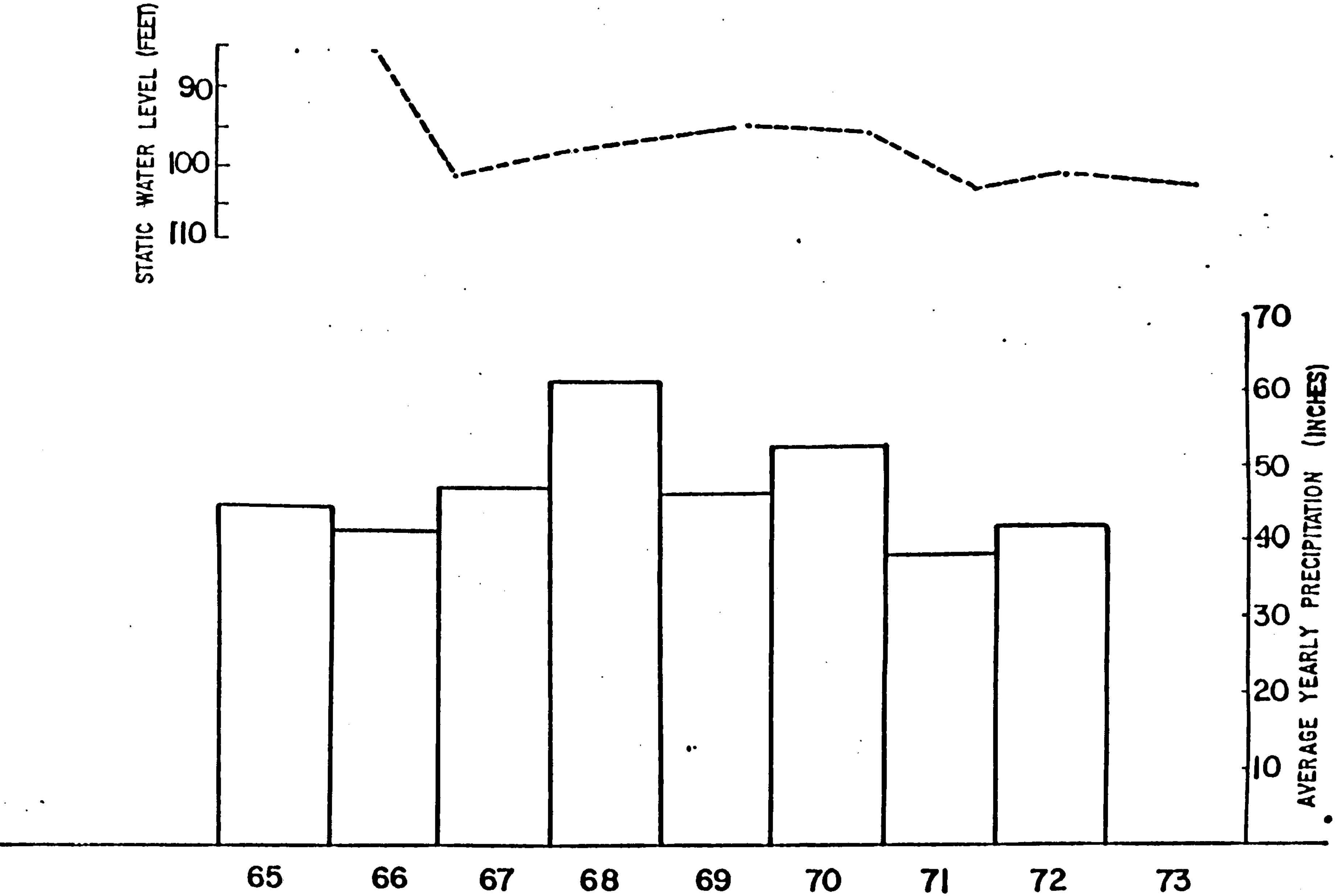


Figure 14. Hydrograph of water level fluctuations in well at Yellville, Marion County, Arkansas.

for most of the high-yield, high-specific capacity wells in the Springfield Plateau. The influence of local recharge of this nature on these wells can be illustrated by graphs of drawdown versus time plotted on semilog graph paper. Data for the graphs are derived from pumping tests supplied by drillers and engineering consultants in the area. When water is pumped from a well the quantity discharged initially is obtained from aquifer storage immediately surrounding the well. As pumping continues more water must be derived from greater distances away from the bore hole. This produces a circular-shaped cone of depression which expands and deepens as pumping progresses so that water can move from greater distances toward the well. The radius of influence and drawdown of the well will continue to increase as the cone expands and deepens until aquifer recharge starts to equal the pumpage. Figure 15 is a graph of drawdown versus time for a pump test of the Arkansas Highway Department well at Harrison, Arkansas, which penetrates the Gasconade Formation (Well #245, Appendix A). The graph indicates an increase in drawdown with an increase in time of pumping, thus suggesting that the well in not receiving significant recharge, and consequently drawing water from storage. The pumping rate for this test was varied from 170 gpm to 88 gpm in an attempt to establish an equilibrium between discharge and recharge. However, the lack of significant recharge to the well prevents the establishment of equilibrium at any of these pumping rates. If pumping was continuous at these rates the water level would be in danger of falling below the level of the pump. Through the use of intermittent pumping, however, the well is allowed to recover during periods when the pump is off. Some recharge reaches the well, but the rate of movement is too slow to equalize the rate of withdrawal during pumping. Over a matter of hours or days of non-pumping the water level in the well will rise. This rise in water level is probably a measure of the lateral movement of water from the outcrop area to the well. The drawdown versus time graph may, therefore, be used as an indicator of the permeability of the aquifers penetrated. The graph for the Arkansas Highway Department may be considered as representative of wells in the Springfield Plateau which do not intersect solution channels, faults, fracture zones, or linears.

Figure 16 is a drawdown versus time graph for a well penetrating the Gasconade Formation at Valley Springs, Boone County, Arkansas (well #252, Appendix A). The well coincides with a large northeast trending linear which is inferred to be a reverse fault (Plate 2). The graph indicates an increase in drawdown for the first 1,080 minutes at a constant pumping rate of 200 gpm. This represents water drawn from storage. After 1,080 minutes of pumping a source of recharge is encountered and no further drawdown occurs, indicating that a condition of equilibrium has been reached. Another indication of

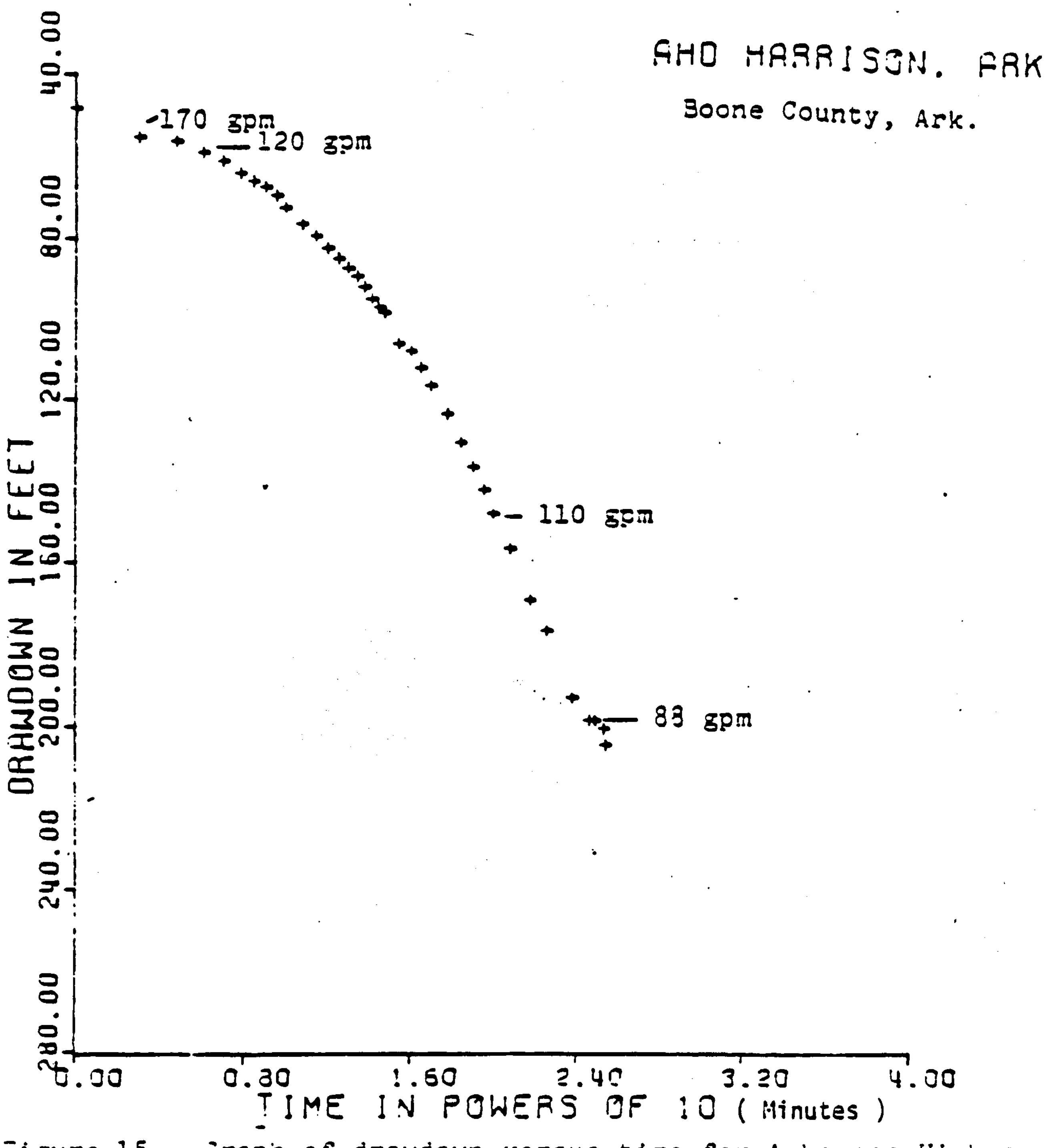


Figure 15. Graph of drawdown versus time for Arkansas Highway Department well at Harrison, Arkansas.

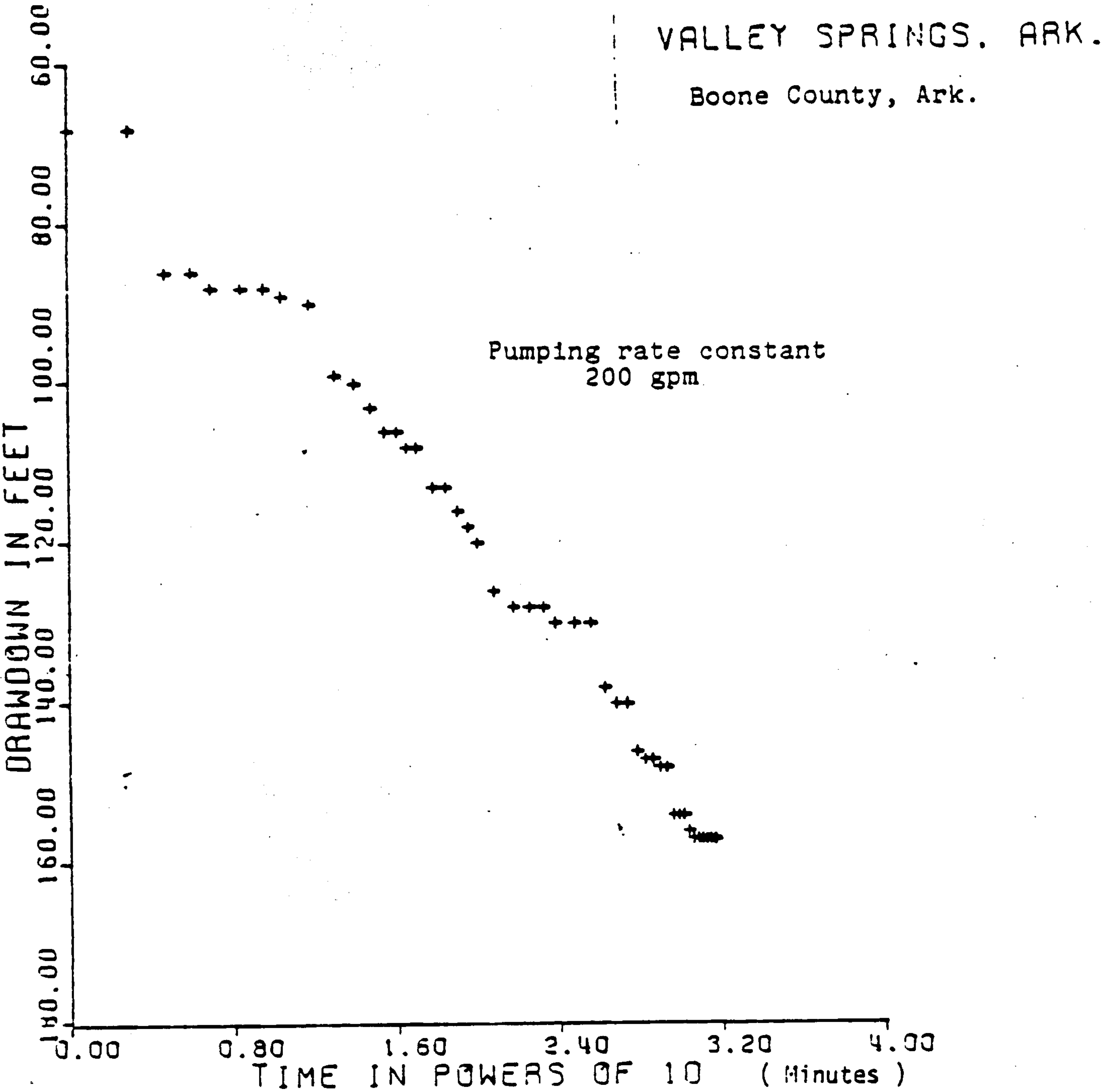


Figure 16. Graph of drawdown versus time for well at Valley Springs, Arkansas.

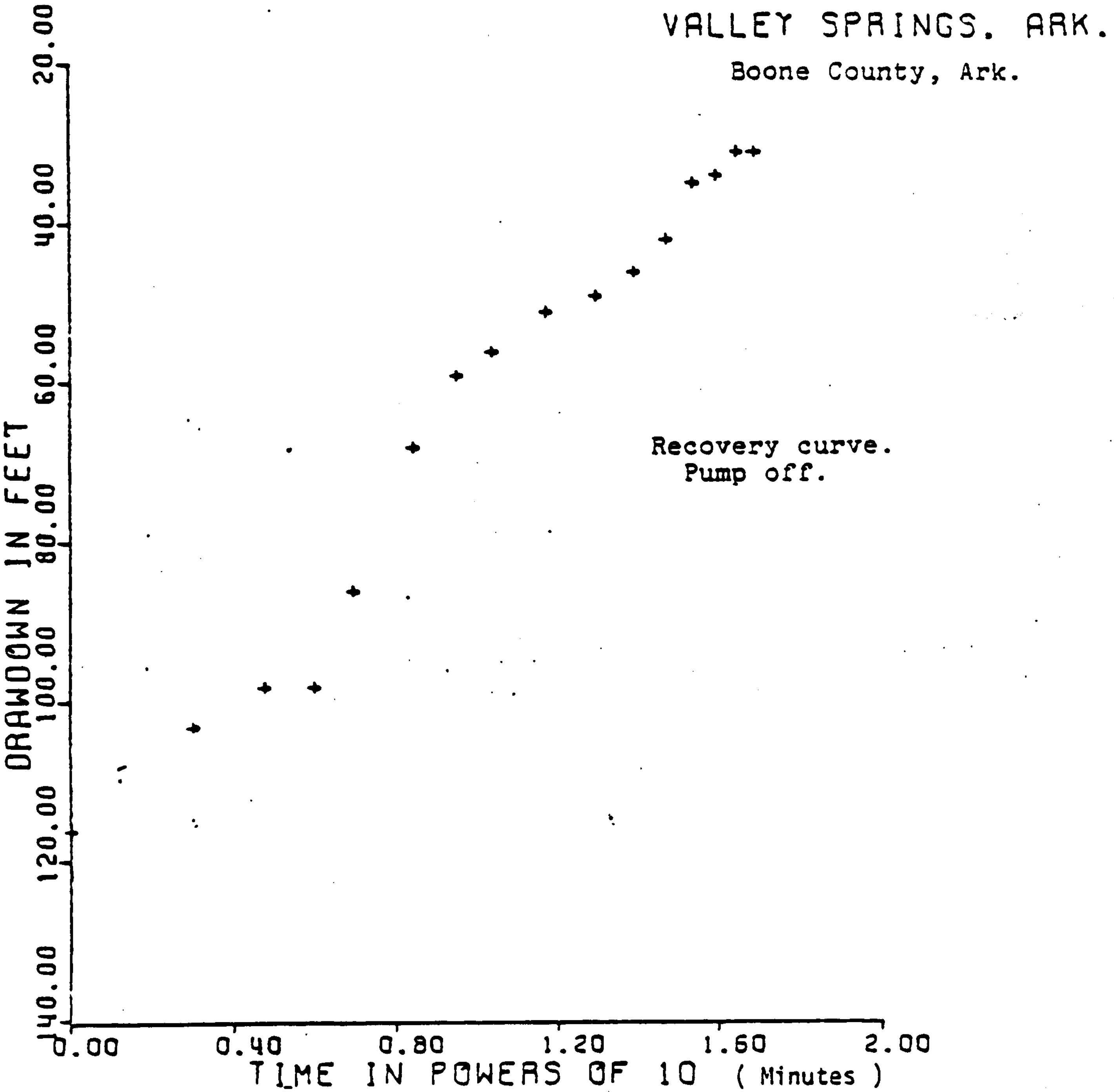


Figure 17. Recovery curve for well at Valley Springs, Arkansas.

aquifers. This is suggested by the comparison of the water levels of wells penetrating only the Roubidoux Formation with those of wells penetrating both the Roubidoux and Gasconade Formations (Appendix A). The lack of substantial differences in water levels between wells for any given locality suggests that movement of groundwater between aquifers due to hydrostatic head differences in the units, occurs in areas where sufficient permeability exists between units. Plate 9 may therefore be considered largely representative of the combined groundwater movement associated with the Roubidoux and Gasconade Formations.

The general direction of groundwater flow is down gradient and at right angles to contours on the potentiometric surface. Water enters the aquifers where the potentiometric surface is high while being discharged where it is low. The principal area of high potentiometric levels in the study area describe a groundwater ridge which extends from Texas County, Missouri, southwest to McDonald and Barry Counties, Missouri and then southward to Washington and Madison Counties, Arkansas. Throughout this ridge water levels average greater than 1,000 feet above sea level, and the ridge is generally reflective of the surface topography. Subsequent regional groundwater movement is primarily north and south of this ridge toward groundwater troughs which are coincident with deeply incised drainage basins.

Departures from the regional trend of groundwater movement may occur in local areas where faulting and fracturing of the carbonate rocks is extensive. Numerous tracer studies using rhodamine dye have shown that water may flow in surface streams in the outcrop area of the aquifers until it reaches cavernous zones. The water then sinks underground and follows the zone of solution for many miles before issuing from springs, sometimes in a different drainage basin (Vineyard and Feder, 1974).

Discharge

Natural discharge of groundwater from the Roubidoux and Gasconade Formations may occur from springs, as effluent seepage along a stream channel, as evapotransportation, and as movement from one aquifer to another. Artificial discharge is mostly from domestic or industrial wells penetrating the aquifers throughout the Salem and Springfield Plateaus. The nature of discharge from the aquifers is a function of geologic and physiographic controls and may be examined in terms of discharge within the Salem and Springfield Plateaus divisions of the Ozark Province. Over long periods of time discharge appears to be balanced by recharge and water levels are not drastically affected.

The most extensive natural discharge from the Roubidoux and Gasconade Formations occurs within the Salem Plateau where the formations are exposed over large areas (Plate 1). The soluble nature of the aquifers coupled with wide areal exposure has produced a topography characterized by deep, narrow valleys and sharp ridges. The uplands are covered for the most part by dolomite of the Jefferson City and Roubidoux Formations; valleys are floored chiefly by the Gasconade Formation (Vineyard and Feder, 1974). The development of extensive caverns and solution channels related to the solubility of the rock and fracture zones within these formations afford conduits for groundwater movement and storage. Some concept of the groundwater storage capacity of the Roubidoux and Gasconade Formations and other aquifers of the Salem Plateau can be gained by considering the number of caves in the region. Of a total of 3,000 known caves in Missouri, over 2,500 are in the Ozarks (Vineyard and Feders, 1974). Many of these caves sustain large springs which represent one of the principal forms of discharge from the aquifers. Most of the springs in the Salem Plateau are located at many points along deeply incised valleys, and offer outlets for subterranean waters flowing down the hydrodynamic gradient. Figure 18 shows that the majority of large springs of Missouri are associated with the topographic development related to the geology within the Salem Plateau. Many of these springs represent discharge points for waters from the Roubidoux and Gasconade Formations (Plate 1). Some appreciation for the amount of discharge from springs issuing from the Roubidoux or Gasconade Formation in the Salem Plateau may be gained from the examination of data presented in Table 2.

Discharge of water from the Roubidoux and Gasconade Formations in the Salem Plateau also takes the form of

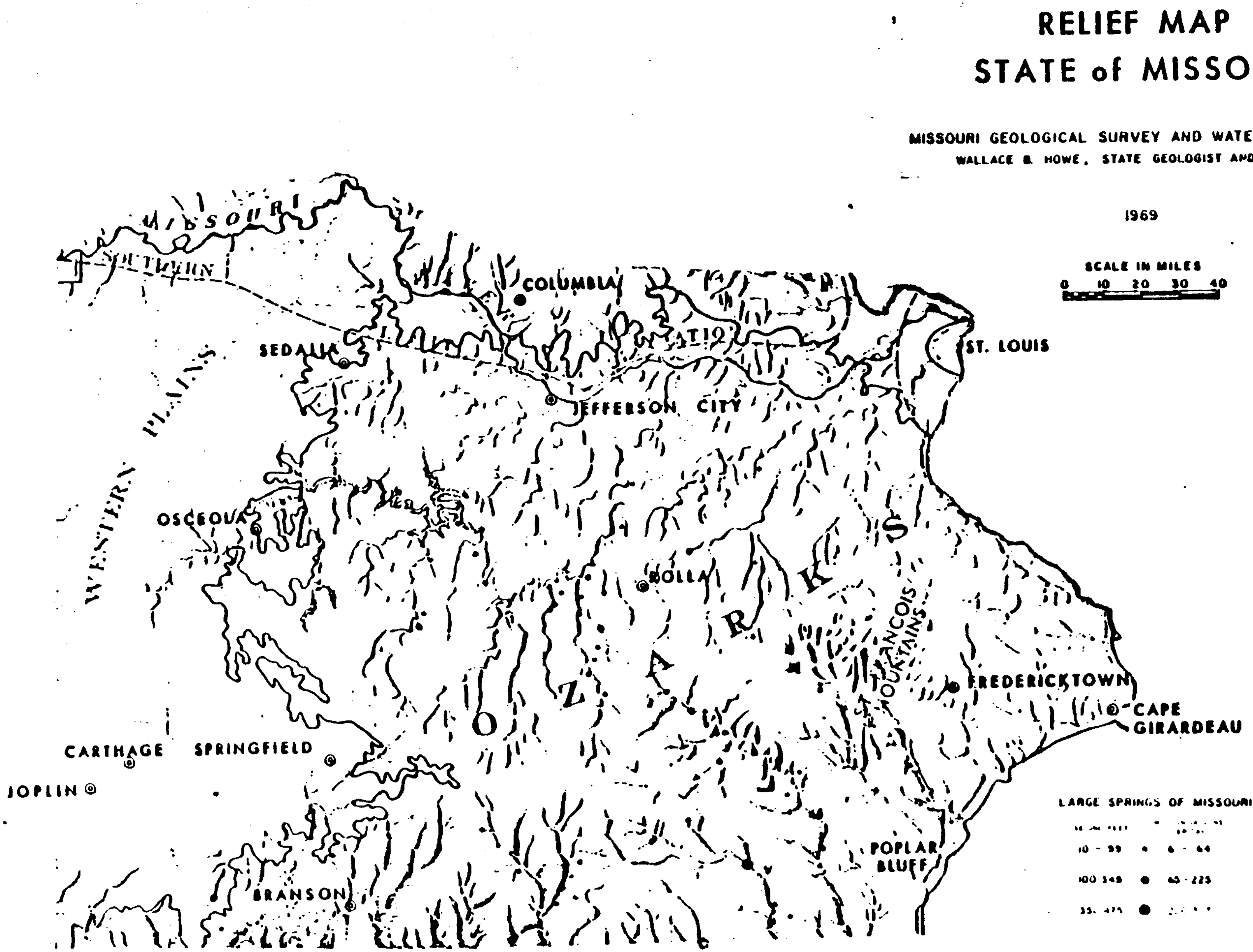

RELIEF MAP
STATE of MISSOURI
MISSOURI GEOLOGICAL SURVEY AND WATER RESOURCES
WALLACE B. HOWE, STATE GEOLOGIST AND DIRECTOR
1969
SCALE IN MILES
0 10 20 30 40
COLUMBIA
ST. LOUIS
SEDALIA
JEFFERSON CITY
OSCEOLA
WESTERN PLAINS
ROLLA
O Z A R K S
FREDERICKTOWN
CAPE GIRARDEAU
CARTHAGE
SPRINGFIELD
JOPLIN
LARGE SPRINGS OF MISSOURI
POPLAR BLUFF
BRANSON

Figure 18.

Table 2

Discharges of Selected Springs Emanating from the Roubidoux or Gasconade Formation

(After Vineyard and Feder, 1974)

Name of Spring	Aquifer	Location	Rate of flow in gallons per day
McDade	Roubidoux	T39N R5W Sec 16	517,000
Boiling	Gasconade	T37N R10W Sec 33	42,000,000
Maramec	Gasconade	T37N R6W Sec 1	93,024,000
Sweet Blue	Gasconade	T36N R17W Sec 30	8,010,000
Bartlett Mill	Gasconade	T36N R12W Sec 16	10,100,000
Bennett	Gasconade	T34N R18W Sec 1	100,000,000
Blue	Gasconade	T28N R6W Sec 31	69,100,000
Crystal	Roubidoux	T26N R15W Sec 22	7,490,000
Keener	Roubidoux	T26N R5E Sec 4	14,200,000
Big	Roubidoux	T25N R11W Sec 26	8,530,000
Greer	Gasconade	T25N R4W Sec 36	187,000,000
Hodgson Mill	Roubidoux	T24N R12W Sec 34	23,500,000
Double	Gasconade	T24N R11W Sec 32	100,000,000
Zanoni	Roubidoux	T23N R12W Sec 7	497,000

effluent seepage to streams. Low-flow frequency analysis of streams can be used as an index of the amount of water contributed by groundwater runoff (Lamonds, 1972). Low-flow or base flow is defined as the discharge entering stream channels from groundwater or other delayed sources (AGI Glossary, 1957). Data on the low-flow characteristics of streams in Arkansas and Missouri have been published by Hines (1965) and Skelton (1966). These data indicate that streams of the Salem Plateau generally have high, well sustained low-flows. Skelton (1966) attributes this to the ability of the Roubidoux and Gasconade Formations to transmit and store large quantities of water. Examples of low-flow discharges of streams in the Salem Plateau are given in Table 3.

Natural discharge of the Roubidoux and Gasconade Formations within the Springfield Plateau appears to take a somewhat different form than that of the Salem Plateau, because the physiography of this area has a more gently rolling landscape, and stream valleys that are not as deeply incised. Surface rocks of the area are primarily Mississippian and Pennsylvanian limestone with some sandstone and shale (Plate 1). The Roubidoux and Gasconade Formations dip gently beneath this cover, and are confined to the subsurface throughout the area. The altitude of the potentiometric surface of the artesian aquifers is generally less than the altitude of spring outlets and stream beds. Discharge from the deep aquifers therefore does not normally

Table 3

Summary of Low-Flow Characteristics of Selected Streams in the Salem and Springfield Plateaus

*Data after Skelton, 1966 **Data after Hines, 1965

Station Number	Name	Drainage Area in Square Miles	Annual low-flow in cubic feet per second for indicated period of consecutive days and indicated recurrence interval, in years — 7-Day 2-year	7-Day 10-year
Salem Plateau				
6-9277.0*	Gasconade River near Nebo	-	31	14
6-9285.0*	Gasconade River near Waynesville	1,680	130	60
6-9284.5*	Roubidoux Creek at Waynesville	-	10	2.0
6-9289.0*	Big Piney River near Houston	-	24	16
6-9278.0*	Osage Fork at Drynob	404	27	14
6-9301.0*	Spring Creek at Spring Creek	-	25	18
7-0574.0*	North Fork River at Twin Bridges	-	38	26
7-0575.0*	North Fork River near Tecumseh	561	270	200
7-0580.0*	Bryant Creek near Tecumseh	570	140	110
7-0715.0*	Eleven Point River near Bardley	793	270	180
Springfield Plateau				
7-1858.5*	North Fork Spring River at Lamar	-	0.1	0
7-1861.0*	Center Creek near Sarcoxie	-	16	6.8
7-1862.0*	Center Creek near Fidelity	-	24	8
7-1868.9*	Shoal Creek near Neosho	-	60	23
6-9184.2*	Sac River near Ash Grove	-	15	1-3
7-480**	West Fork White River near Greenland	83	0.3	-
7-495**	White River near Rogers	1,020	42	7.9
7-490**	War Eagle Creek near Hindsville	262	5.6	1.5
7-1950**	Osage Creek near Elm Springs	129	22	11
7-560**	Buffalo River near St. Joe	825	36	14

take the form of flow to springs or effluent seepage to streams. Springs and stream valleys of the Springfield Plateau are small by comparison to those of the Salem Plateau (Table 4), and typically drain karst topography developed in the limestone bedrock (Harvey and Vineyard, 1967). Patterns of sedimentation associated with the development of the bedrock in the Springfield Plateau produced thin rock units of varying rock type which have prevented the development of large integrated solution channels characteristic of the Salem Plateau (Harvey and Vineyard, 1967). This has generally resulted in the development of shallow aquifers which do not have the yield capabilities of the Roubidoux and Gasconade Formations. Spring discharge and stream low-flow measurements within the Springfield Plateau (Table 3) are lower than those of the Salem Plateau, and may be interpreted as indicative of the lack of available discharge from the deep aquifers.

The principal discharge of the Roubidoux and Gasconade Formations within the Springfield Plateau takes the form of recharge to the shallow aquifers, underflow to adjacent areas, and artificial discharge by deep wells. While the potentiometric surface of these artesian aquifers is generally lower than spring outlets and stream beds, water does often rise within a few hundred feet of the surface (Plate 8), and in many places is within Mississippian limestone strata. These shallower limestone formations therefore receive an undetermined amount of recharge from the

Table 4

Discharges of Selected Springs
of the Springfield Plateau

(After Vineyard and Feder, 1974 and Lamonds, 1972)

Name of Spring	Aquifer	Location	Rate of flow in gallons per day
Scotland	Mississippian L.S.	T27N R32W Sec 1	1,990,000
Bay Scout	Mississippian L.S.	T26N R32W Sec 9	1,040,000
Spring River	Mississippian L.S.	T26N R26W Sec 28	3,290,000
Cave	Mississippian L.S.	T25N R29W Sec 12	2,200,000
Ford Spring	Boone Formation	T20N R30W Sec 7	6,314,351
Big Spring	Boone Formation	T18N R32W Sec 5	3,225,037
Keith Lake	Boone Formation	T18N R31W Sec 1	2,649,830
Johnson	Boone Formation	T17N R30W Sec 15	1,008,222

deeper aquifers. Some indication of this recharge was revealed by a study of the groundwater resources of St. Louis by Miller and others (1974). Working in the Valley Park area, they found that mineralized water from deep aquifers had moved up into shallower horizons in wells that were improperly cased or where casings deteriorated.

Some discharge from deep aquifers takes the form of "underflow" beneath shallow aquifers to areas adjacent to the Springfield Plateau. Evaluation of the water resources of the Joplin area of Missouri by Feder and others (1969) indicates that the potentiometric levels in wells penetrating the Roubidoux and Gasconade Formations are below the water levels of the shallow aquifers. The water from the deep aquifers is therefore confined and does not discharge into the overlying formations. Maps of the potentiometric surface indicate that groundwater movement in the deep aquifers is from east to west, and discharge is west of the state line. Examination of Plate 9 of this report suggests that underflow may also take place to the south and west of the Springfield Plateau in Arkansas.

An undetermined amount of discharge takes place through deep wells penetrating the aquifers within the Springfield Plateau. Detailed studies of the amount and rate of this discharge are generally not available. Although measurements of water levels in deep wells have been made by the United States Geologic Survey in the Arkansas part of the Springfield Plateau, the frequency is not sufficient to determine if pumping has resulted in reduction of water availability (A summary of existing data is included in Table 5). A cursory examination of wells monitored by the Missouri Geologic Survey suggests that water levels in the Missouri portion of the plateau have not been substantially effected by pumping (Dale Fuller, Personal Communication, 1974). However, studies in at least two areas outside the region of this report suggest that substantial discharge has resulted from pumping of the aquifers. For example, Stramel (1957) in a study of the aquifers at Pittsburg, Kansas showed that pumpings of the aquifers for the period 1880 through 1954 resulted in a fairly steady rate of decline of water levels over that period. Reed, Schoff, and Branson (1955) showed that in Ottawa County, Oklahoma the water levels of the deep aquifers were at least 30 feet above the land surface in the early 1920's, but the increase of mining and milling operations since then has resulted in increased water use which lowered the water levels to well below the land surface.

Table 5

Water Level Measurements in Deep Wells of Northern Arkansas

(Data provided by U.S.G.S., Little Rock, Ark.)

Location	County	Depth	LSD	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	Aquifer
19N13W16bab1	Baxter	1540	775	9-22 173.60	11-1 192.49	3-14 175.50	-	11-4 199.03	10-13 205.49	11-9 174.07	10-17 164.77	11-28 135.03	11-21 134.0	G
19N14W28dba	Baxter	1503	690	-	-	2-14 216.10	-	-	-	-	-	-	-	G
9N14W29dbc1	Baxter	1625	720	-	-	-	-	-	-	-	10-18 180.25	11-28 323.0	11-21 319.0	G
0N14W30bbd	Baxter	830	855	-	-	-	-	-	10-13 194.02	11-9 211.40	-	11-28 208.01	11-20 210.33	R
8N33W1ddc	Benton	1150	1210	-	-	-	-	-	-	11-11 197.08	10-20 201.19	11-29 200.21	11-27 201.97	R
9N29W7dab	Benton	1659	1220	-	5-11 139.26	6-9 279.68	5-23 131.77	11-5 120.55	10-14 119.05	11-11 116.35	10-19 117.83	11-29 113.38	11-26 111.17	G
9N29W18bbb	Benton	1144	1345	-	-	-	-	-	12-17 212.56	11-11 181.29	10-19 185.49	11-29 187.15	11-26 184.42	R
9N33W11dad	Benton	1700	1200	-	-	6-8 259.33	-	11-6 250.29	10-14 413.57	-	-	-	-	G
0N28W24bda1	Benton	1150	1380	-	-	-	-	-	-	9-24 352.75	10-19 347.52	11-29 340.13	11-26 340.47	R
0N33W14dbc1	Benton	1614	1230	-	11-3 230.89	6-8 269.29	-	11-6 253.27	11-14 384.55	11-11 300.20	10-20 331.69	11-29 335.90	11-27 328.02	G
1N29W35ddb1	Benton	1760	1406	10-12 294.0	2-9 295.97	2-15 308.02	5-23 308.02	11-5 303.85	10-14 304.29	11-11 300.88	10-19 301.11	11-29 298.22	11-26 296.21	G
8N19W19bcd1	Boone	1648	1150	-	-	6-6 139.82	5-21 140.52	11-4 149.42	10-13 152.31	11-9 175.21	10-18 178.63	12-5 175.87	11-25 182.16	G
1N18W20caa	Boone	604	830	-	-	6-7 157.05	5-21 158.0	11-4 155.48	10-13 160.73	11-9 168.69	10-18 170.43	11-28 166.6	11-25 169.56	R
9N23W4bad1	Carroll	1581	1350	-	8-25 185.87	2-15 196.92	5-22 178.9	11-5 272.89	-	11-10 246.98	10-18 248.35	11-28 235.15	11-25 239.61	R

Table 5 Continued

Location	County	Depth	LSD	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	Aquifer
19N23W8daa1	Carroll	2300	1325	-	-	2-15 275.74	5-22 278.5	-	-	11-10 267.58	10-18 270.71	11-28 221.88	11-25 225.26	G
20N26W10dcd1	Carroll	1332	1250	-	11-2 197.80	2-15 200.77	-	-	-	11-10 473	10-14 418	11-29 394	11-26 450	G
21N26W15baa2	Carroll	1122	1102	-	-	-	-	-	11-19 136.44	11-10 128.50	10-19 139.2	11-29 133.17	11-26 137.29	G
21N26W17bcc1	Carroll	1060	1010	-	-	-	-	-	11-19 86.40	11-10 110.77	10-19 117.19	11-29 121.19	11-26 88.29	R
19N6W23ada1	Fulton	1630	682	-	-	-	-	-	-	-	10-17 232.24	11-27 242.06	11-21 211.82	G
20N8W27ab-1	Fulton	1282	660	10-15 29	2-8 32.59	6-5 18.08	5-21 20.58	11-3 35.08	10-12 42.57	11-8 46.23	10-17 47.49	11-27 48.98	11-21 50.73	G
20N9W18cad	Fulton	1250	880	-	-	6-6 124.38	3-21 137.5	11-3 131.18	10-13 136.9	11-9 135.31	10-17 134.54	11-28 133.76	11-21 131.59	R
19N15W20dbb	Marion	900	680	-	8-24 85.62	2-14 102.38	5-21 97.2	11-4 90.35	11-13 93.80	11-9 107.3	10-18 104.60	11-28 107.25	11-20 107.97	R
19N16W33ccb	Marion	753	750	-	8-24 325.40	2-14 321.22	5-21 275.95	11-4 348.54	10-13 356.10	11-9 362.04	-	11-28 351.15	11-20 353.21	R
19N16W32aaa	Marion	1524	950	-	-	-	-	-	6-21 389.68	11-9 423.56	10-18 479.05	11-28 472.30	11-20 478.37	G
17N20W21bca1	Newton	2576	1344	-	-	-	-	-	-	-	8-11 353.7	12-6 451.5	11-25 472.5	G
18N6W10dcc	Sharp	1525	555	-	5-10 125	-	-	11-3 122.02	10-12 129.63	11-8 132.09	10-16 134.01	11-27 138.44	11-21 129.51	G
19N4W15baa	Sharp	611	590	-	-	-	5-20 16.50	11-3 28.83	10-12 34.37	11-8 36.02	10-16 21.76	-	11-21 29.32	R
15N31W17bbc	Washington	2097	1140	-	-	6-9 126.60	-	11-6 81.65	10-15 92.29	11-12 100.21	10-20 104.66	11-30 148.49	11-27 153.44	G
15N31W30cab1	Washington	2485	1175	-	8-26 25.13	-	-	-	-	11-12 25.83	10-20 26.71	11-30 24.56	-	G
16N32W9abd	Washington	1815	1135	-	-	-	3-24 99.0	-	-	11-11 100.49	10-20 101.14	11-30 101.53	11-27 102.81	G

Water Quality

Quality of water determination for individual deep aquifers in the Ozarks is not available for most areas. The general practice when drilling deep wells in the area is to case off the shallow formations and to leave the remainder of the well uncased. This allows mixing of water from all formations penetrated below the casing. Unless testing of specific horizons is conducted at the time the well is drilled, it is not possible to sample water from an individual aquifer after well completion to determine its representative water quality characteristics. The water quality analyses for wells presented in this report therefore represent mixtures of water rather than sampling of the individual aquifer and are discussed as such.

Water quality analyses for wells penetrating the Roubidoux or Gasconade Formations in the Ozarks area are available from the Missouri Division of Natural Resources, and the Arkansas State Health Department. Tables 6 and 7 represent data for selected wells located in southern Missouri and northern Arkansas. A regional plot of the location of these wells is included as Plate 9.

Water from wells penetrating either of the two aquifers is quite similar as shown by the analysis in Tables 6 and 7. The water is of the calcium-magnesium bicarbonate type, reflecting the predominantly dolomitic character of the rocks. Thus, calcium, magnesium, and bicarbonate are the

Table 6

Chemical Analyses (ppm) from wells penetrating the Roubidoux Formation, Arkansas and Missouri
Missouri analyses supplied by the Missouri Department of Natural Resources
Arkansas analyses supplied by the Arkansas State Health Department

Map No.	Location	County	City	Date Collected	Depth	Csg	Ph	Methal Orange Alk.	Total Solids
3	24N29W27	Barry	Wheaton	12-27-71	1010	408	7.7	200	273
4	24N28W2	Barry	Purdy	11-25-69	931	392	8.0	174	257
7	24N23W36	Stone	Reeds Spring	12-3-70	1100	-	7.8	191	249
10	24N12W34	Ozark	Hodgsen Spring	4-30-71	Spring	-	7.8	192.5	202
11	24N11W28	Ozark	Double Spring	4-30-71	Spring	-	7.8	203.5	222
12	24N10W6	Howell	Siloam Springs	9-25-52	Spring	-	7.4	316	403
13	23N32W8	McDonald	Goodman	8-26-68	1290	430	7.5	113	144
14	23N28W34	Barry	Exeter	4-1-71	990	334	8.0	186	234
17	23N23W33	Stone	Stone Co., N.W.	11-18-69	1325	-	7.9	250	422
18	23N21W29	Taney	Branson North	2-17-71	580	-	7.5	347	433
21	22N32W34	McDonald	Pineville #1	9-10-71	955	-	7.8	124.0	212
23	22N25W14	Barry	Knob Hill Acres	4-15-71	770	-	7.7	266	316
24	22N25W26	Barry	Holiday Acres	3-9-61	400	-	7.4	260.4	296

Table 6 Continued

Map No.	Location	County	City	Date Collected	Depth	Csg	Ph	Methal Orange Alk.	Total Solids
25	22N25W35	Barry	Green Shores	5-6-71	525	-	7.7	246	309
27	22N11W12	Ozark	Alice Mine	2-24-46	755	-	-	483	515
28	21N34W33	McDonald	Southwest #2	3-30-66	989	269	7.3	174.0	306
30	21N29W31	Benton	Pea Ridge	5-7-65	1274	410	7.7	176	226
31	21N26W15	Carroll	Holiday Island #2	1-28-72	1128	500	7.7	230.5	253
32	21N26W17	Carroll	Holiday Island #1	1-28-72	1063	-	7.7	265	277
34	21N21W27	Boone	Omaha	10-7-69	1315	-	7.8	157	262
35	21N18W20	Boone	Diamond City	9-29-72	602	-	7.3	222	370
36	21N18W29	Boone	Lead Hill	9-29-72	703	-	7.3	245	333
37	21N18W32	Boone	Lead Hill	1-23-70	604	-	7.8	244	270
38	21N5W7	Fulton	Mammoth Springs	4-6-70	350	-	7.9	334	332
39	20N33W11	Benton	Gravette	7-29-71	1414	-	7.8	111	140
43	20N28W5	Benton	Garfield	4-7-70	1200	-	7.5	207	237
44	20N14W30	Baxter	Edgewood Bay	5-2-68	830	-	7.1	301	306
45	20N9W18	Fulton	Viola	5-26-70	1250	900	7.8	232	238

Table 6 Continued

Map No.	Location	County	City	Date Collected	Depth	Csg	Ph	Methal Orange Alk.	Total Solids
48	19N33W13	Benton	Decatur	10-6-72	1500	-	7.5	108	87
50	19N23W4	Carroll	Green Forest	2-?-65	2100	-	8.0	228	301
53	19N15W17	Marion	Flippin	2-6-74	800	-	7.7	282	330
54	19N15W20	Marion	Flippin	2-?-70	900	-	7.6	277	293
59	19N4W23	Sharp	Ozark Acres	3-24-69	611	-	7.5	322	326
60	18N19W19	Boone	Bellefonte	6-1-67	1649	-	7.4	175	219
62	18N7W31	Izard	Franklin ?	9-4-70	1100	-	7.9	278	314
64	17N32W11	Benton	Robinson	6-27-69	1505	-	8.2	-	257
65	17N31W1	Washington	Tontitown	5-24-68	1416	350	7.7	-	336
66	17N26W29	Madison	--	6-21-68	1525	-	8.0	-	300
69	16N31W7	Washington	Wedington Woods	3-26-73	1500	-	7.6	251	535
70	16N13W30	Baxter	Big Flat	8-22-72	2603	208	7.7	270	180

Table 6 Continued

Map No.	Hardness as $CaCO_3$ Ca,Mg	Non Carbonate	Chlorine	NaCl	Sulphate	Ca	Mg	Fe	Mn	F	Cr	Cu	Al	Pb	Na	K	NO_3	NO_2
3	200	14	3.2	-	19.8	53.6	19.4	0.06	0	0.10	-	-	0.1	-	1.8	0.9	0.4	-
4	174	20	4.1	-	11.9	41.6	21.9	0.05	0	0.1	-	-	0.2	-	2.2	1.7	0	-
7	191	9.0	1.9	-	13.6	45.2	21.1	0.03	0	0.1	-	-	0.1	-	0.2	1.4	1.1	-
10	192.5	1.8	5.2	-	2.4	44.0	20.5	0.15	0.005	0	0.01	0.02	-	0.001	1.3	1.1	4.2	-
11	200.4	0	4.7	-	3.6	46.8	20.3	0.33	0.005	0	0.01	0.02	-	0.001	1.2	1.0	3.5	-
12	316	48	13.25	-	4.4	73.9	43.7	0.07	0	0.2	-	-	-	-	13.8	-	33.6	-
13	113	0	4.5	-	13.0	25.2	12.2	0.2	0	0.5	-	-	0.1	-	8.3	0.3	0.2	-
14	186	2	3.2	-	11.7	42.8	19.7	0.07	0	0.1	-	-	0.1	-	2.0	0.7	0	-
17	250	10	2.4	-	13.4	52.8	0	0.02	0	0.1	-	-	0.1	-	1.8	2.5	0	-
18	345	0	3.2	-	12.3	69.6	41.6	0.08	0	0.1	-	-	0.1	-	2.0	1.2	0.7	-
21	120	0	15.7	-	14.2	28.0	12.2	0.06	0	0.52	-	-	0.1	-	17.2	2.2	0	-
23	263	0	2.6	-	13.9	53.0	28.7	0.04	0	0.15	-	-	0.1	-	2.0	0.5	0	-
24	260	12	4.1	-	13.2	57.6	31.1	0.5	-	0.1	-	-	0.1	-	0.7	-	-	-
25	246	22	2.6	-	25.9	57.6	30.1	0.03	0	0.1	-	-	0.1	-	1.2	1.2	0	-
27	408.6	0	62.0	-	38.3	30.3	79.5	0	-	-	-	-	-	-	62	-	-	-

Table 6 Continued

Map No.	Hardness as $CaCO_3$ Ca,Mg	Non Carbonate	Chloride	NaCl	Sulphate	Ca	Mg	Fe	Mn	F	Cr	Cu	Al	Pb	Na	K	NO_3	NO_2
28	172	0	28.4	-	32.5	45.6	14.1	0.14	-	0.4	-	-	0.1	-	33.5	2.4	0	-
30	176	2.0	22.0	36.3	16.5	42.0	17.7	0.10	0	0.25	-	-	0	-	12.5	3.0	0.25	T
31	230.5	13.5	1.5	2.5	22	50.4	28.7	0.05	0.002	0.04	0.003	0.05	-	0.01	1.8	-	0.02	0.01
32	265	29	1.5	2.5	22	58.1	36.2	0.05	.01	0.05	0.003	0.05	-	0.01	1.4	0	0.02	0.01
34	157	81	2.0	3.3	62	49.2	27.95	T	0	0	0	-	-	0	1.8	-	0.25	0.01
35	222	22	2.50	4.13	22.2	49.2	29.4	0.21	0.05	0.22	0.003	0.01	0.2	0.01	4.5	-	0.02	0.021
36	245	15	0.1	0.0	11.3	50.4	32.56	0.43	0.05	0.2	0.003	0.01	0.2	0.01	1.5	-	0.02	0.012
37	244	36	0.5	0.8	14	58.0	32.8	T	0	0	0	-	-	0	1.3	-	1.15	T
38	334	36	2.0	3.3	0	72.4	45.9	T	0	0.3	0	-	-	0	-	-	2.30	0
39	102	0	16.5	27.2	54	24	10.2	0.05	0.02	0.91	0.003	0.05	-	0.01	30	-	.03	0.01
43	207	1.0	2.5	4.1	18.7	44.0	23.8	-	0	0.3	0	-	-	0	-	-	0	0
44	296	0	2.5	4.0	0	60.0	35.5	0.2	0	0	0	-	-	0	2.0	0.5	0.92	0
45	232	14	2.0	3.3	0	47.6	30.9	0.1	0	0	0	-	-	0	-	-	0.1	-
48	108	10	3.0	4.95	4.0	40.0	7.29	0.05	0.05	0.02	0.003	0.1	0.2	0.01	4.0	-	1.75	0.01
50	228	12	10.5	17.35	31.5	53.6	25.75	0.15	0	0.25	-	-	0	-	6.5	3.2	0	0.023

Table 6 Continued

Map No.	Hardness as $CaCO_3$ Ca,Mg	Non Carbonate	Chloride	NaCl	Sulphate	Ca	Mg	Fe	Mn	F	Cr	Cu	Al	Pb	Na	K	NO_3	NO_2
53	282	124	4.0	6.6	20.0	55.6	40.58	0.05	0.01	0.2	0.01	0.05	0.2	0.01	0.1	1.1	0.44	0.01
54	277	51	3.0	4.95	18.0	63.2	41.3	0.001	0	0	0	-	-	0	1.5	-	0.40	0
59	320	0	0.5	0.8	6.0	71.6	34.5	0	0	0.10	0	T	0	0	1.0	-	0.10	T
60	164	0	2.5	4.1	14	33.2	19.5	0.15	0	0.50	0	-	-	0	-	-	0.10	0.026
62	278	44	5.5	9.1	11.2	61.2	41.1	-	0	0.1	0	-	-	0	-	-	0.1	0
64	108	0	49	-	11	25	11	-	-	1.2	-	-	-	-	55	2.8	0.2	-
65	84	0	-	-	6.0	17.0	10.0	-	-	-	-	-	-	-	82	3.2	-	-
66	150	0	6.2	-	10	40	12	-	-	1.3	-	-	-	-	68	2.9	0.0	-
69	72	0	119.5	197.2	17.0	14.8	8.5	0.35	0.005	2.3	0.003	0.05	0.20	0.01	37	-	0.48	0.010
70	180	0	4.5	7.43	52	40.0	19.44	0.05	0.005	1.20	0.003	0.1	0.2	0.01	38.0	-	0.20	0.02

Table 7

Chemical Analyses (ppm) from wells penetrating the Gasconade Formation, Arkansas and Missouri
Missouri analyses supplied by the Missouri Department of Natural Resources
Arkansas analyses supplied by the Arkansas State Health Department

Map No.	Location	County	City	Date Collected	Depth	Csg	Ph	Methal Orange Alk.	Total Solids
1	26N28W36	Barry	Monett	2-19-66	1550	-	7.3	134	212
2	25N24W4	Stone	Crane #2	3-25-70	1120	-	7.9	127	226
5	24N28W36	Barry	Butterfield	2-18-70	1350	-	8.1	166	229
6	24N24W12	Stone	Galena #2	5-12-69	1300	-	7.6	148	186
8	24N20W34	Taney	Forsyth	4-12-71	970	-	8.2	222	305
9	24N19W27	Taney	-	4-12-71	1000	-	7.8	307	373
15	23N27W28	Barry	Cassville	2-26-70	1370	-	7.9	112	202
16	23N27W29	Barry	Cassville	5-10-71	1195	300	8.0	181	258
19	23N21W32	Taney	Branson #3	3-4-64	1085	460	7.2	300	310
20	22N33W25	McDonald	Lanagen	8-13-70	1340	-	7.8	125	201
22	22N28W28	Barry	Washburn	12-28-70	1675	-	7.7	91	116
26	22N21W9	Taney	Hollister #4	6-17-70	990	285	7.8	250	318
29	21N33W15	McDonald	Noel	7-22-71	1300	-	8.1	142	308
33	21N26W27	Carroll	Holiday Isl. #4	2-8-73	1880	531	7.4	199	200

Table 7 Continued

Map No.	Location	County	City	Date Collected	Depth	Csg	Ph	Methal Orange Alk.	Total Solids
40	20N33W11	Benton	Gravette #2	?	1600	400	7.4	125	173
41	20N33W14	Benton	Gravette #3	?	1614	-	7.6	134	137
42	20N29W13	Benton	Avoca	8-?-74	2076	-	8.5	-	254.0
46	19N33W11	Benton	Decatur	?	1760	-	7.9	146	175
47	19N33W11	Benton	Decatur	?	1710	600	7.4	124	140
49	19N32W11	Benton	Peterson Indust.	12-6-71	1723	435	8.0	114	161
51	19N19W8	Boone	Bergman	9-17-71	1725	215	7.7	159	129
52	19N16W32	Marion	Summit	9-12-72	1520	-	7.8	250	261
55	19N14W28	Baxter	Cassville	2-20-70	1400	-	7.5	290	323
56	19N14W29	Baxter	Cotter	2-2-73	1625	-	7.5	253	260
57	19N13W9	Baxter	Mt. Home #2	4-15-65	1505	-	7.4	296	371
58	19N13W16	Baxter	Mt. Home #3	4-15-65	1540	550	7.3	270	333
61	18N19W19	Boone	Hiway Department	8-1-69	2000	972	7.6	225	246
63	18N6W10	Sharp	Ash Flat	9-17-64	1600	-	7.4	279	300
67	17N20W21	Newton	Marble Falls	10-3-74	2573	503	7.45	168	239
68	16N32W9	Washington	Lake Wedington	4-19-68	1815	253	7.6	168	381

Table 7 Continued

Map No.	Hardness as $CaCO_3$ Ca,Mg	Hardness as $CaCO_3$ Non Carbonate	Chloride	NaCl	Sulphate	Ca	Mg	Fe	Mn	F	Cr	Cu	Al	Pb	Na	K	NO_3	NO_2
1	134	22	8.2	-	11.9	47.2	9.2	4.0	-	0.2	-	-	0.1	-	5.2	1.4	1.9	-
2	127	15	3.7	-	15.4	31.2	15.6	0.1	0	0.1	-	-	0.1	-	2.0	1.0	0	-
5	166	12	2.9	-	15.4	40.8	18.5	0.04	0	0.1	-	-	0.1	-	2.9	1.0	0	-
6	148	8.0	3.6	-	8.2	32.6	18.5	0.04	0	0.1	-	-	0.1	-	2.2	0.2	0.2	-
8	222	6.0	4.2	-	14.0	42.4	29.6	0.16	0	0.16	-	-	0.1	-	1.7	0.4	0.6	-
9	307	3.0	2.6	-	5.1	63.2	36.9	0.02	0	0.1	-	-	0.1	-	1.2	1.4	0.2	-
15	112	12	2.4	-	13.4	28.0	13.1	0.03	0	0.10	-	-	0.1	-	0.9	0.9	0	-
16	181	15	2.6	-	14.8	45.6	19.9	0.1	0	0.1	-	-	0.1	-	1.6	1.2	0.6	-
19	308	8.0	5.4	-	11.7	63.2	36.4	0.08	-	0.1	-	-	0.1	-	1.9	1.0	0.13	-
20	114	0	28.2	-	13.6	24.8	12.6	0.07	0	0.54	-	-	0.1	-	32.5	1.4	0	-
22	91	4.0	2.2	-	9.1	21.2	10.2	0.04	0	0.26	-	-	0.1	-	1.5	1.0	0	-
26	250	14	2.0	-	12.6	51.2	17.0	0.01	0	0.1	-	-	0.1	-	3.0	1.7	0	-
29	104	0	74.9	-	12.8	23.2	11.2	0.12	0	0.9	-	-	0.1	-	64.5	1.9	0	-
33	199	15	1.5	2.5	8.0	38.4	28.7	0.32	0.013	0.2	0.003	0.05	0.20	0.01	2.0	-	0.02	0.011
40	108	0	12.5	20.6	14.0	24.8	11.15	-	0	0.95	0	-	-	0	28	-	0.60	0

Table 7 Continued

Map No.	Hardness as $CaCO_3$ Ca,Mg	Non Carbonate	Chloride	NaCl	Sulphate	Ca	Mg	Fe	Mn	F	Cr	Cu	Al	Pb	Na	K	NO_3	NO_2
41	100	0	11.0	18.15	10.5	22.4	10.7	-	0	1.15	0	0	0	0	29	2.5	0.30	0.002
42	84	0	42.0	-	17.0	20.4	8.0	0.05	0.005	1.55	-	-	-	-	24.0	4.2	-	-
46	146	10	2.0	3.3	6.0	37.2	15.3	0	0	0	-	-	0	0	2.0	1.1	0	0
47	124	2.0	2.0	3.5	9.0	29.5	12.5	0.10	0	0.1	-	-	0	0	3.6	-	0.005	0
49	114	28.8	8.0	13.2	53	26.8	18.4	0.08	0.02	0.03	0.012	-	-	0.01	2.7	-	0.15	0.01
51	159	0	2.0	4.1	12.5	40	2.0	.08	0.05	0	-	-	-	-	-	-	1.5	0
52	250	20	2.5	4.13	4.3	57.2	30.86	0.05	0.05	0.06	0.003	0.1	-	0.008	1.5	-	0.10	0.01
55	290	46	1.0	1.65	9.75	63.2	43.25	0.05	0	0	0	-	-	0	0.18	-	0	0
56	253	7.0	2.8	4.5	14.0	50.4	32.6	0.36	0.003	0.20	0.003	0.05	0.2	0.01	1.0	-	0.02	0.01
57	296	6.0	4.0	6.6	24	64.0	34.5	0.20	0	0	0	0	0	0	2.0	1.9	0.66	0
58	270	32	6.0	9.9	11	56.8	32.10	0.15	0	0	0	-	0	0	3.0	1.6	4.25	0
61	225	31	2.5	4.1	10.0	54.8	29.0	0.15	0	0	0	-	-	0	2.0	-	0.05	0
63	279	25	3.0	4.95	16	59.2	37.9	0.2	0	0	-	-	0	0	3.5	1.8	3.6	T
67	168	2.8	2.9	4.8	16	40.6	17.3	0.06	0.01	0.23	0.01	0.05	0.2	0.01	-	-	0.01	0.01
68	118	0	114	188	7.0	32.8	8.5	0.2	0	0.85	0	-	-	0	93.0	3.5	0.8	T

dominant constituents dissolved in the water. Other dissolved mineral constituents are present in small amounts. The source and significance of dissolved mineral constituents and properties of water are summarized in Table 8.

Although water from the aquifers is moderately hard to very hard, it is of good chemical quality and is suitable for most uses. Dissolved solids range from 87 to 535 parts per million. The calcium content ranges from 14.8 to 73.9 parts per million and magnesium has a range of 0 to 79.5 parts per million. Iron is present in varying quantities, but is generally below the 0.3 mg/l maximum as prescribed by the United States Public Health Service (1962) drinking-water standards. Sulfates average slightly greater than 16 parts per million and range from 0 to 64 parts per million. Chloride concentrations are quite variable ranging from 0 to 119.5 parts per million. Nitrate concentrations range from 0 to 33.6 parts per million.

The distribution of dissolved minerals in groundwater corresponds in a general way to the overall direction of movement of water. A comparison of the location of selected chemical constituents shown in Plate 10 with the elevation of the potentiometric surface (Plate 9) indicates the following:

1. Total dissolved solid concentrations are low along groundwater ridges and increase as water moves down the hydrodynamic gradient toward groundwater troughs. This increase is caused by additional material being dissolved.

Table 8

Source and significance of dissolved mineral constituents and properties of water

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

(After Feder and others, 1969)

Source and significance of dissolved mineral constituents and properties of water—Continued

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

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

2. The ratio of calcium to magnesium is high along groundwater ridges and decreases in the direction of movement toward groundwater troughs. This distribution is most evident in the areas surrounding the White River drainage basin. In this region, recharge to the aquifers is accomplished, in part, by vertical infiltration of water through Mississippian limestone strata of the Springfield Plateau. This provides a source for increased concentration of calcium, and as a result, calcium-magnesium ratios are high in these areas. Subsequent movement of the water down the hydrodynamic gradient is confined to Ordovician dolomite. This results in the decline of calcium/magnesium ratios toward the discharge zones.

Evaluation of the distribution of chloride concentrations in the deep aquifer waters suggests that chlorides increase with the regional gradient from the southwestern portion of the study area toward the Arkoma Basin. Chloride concentrations average 17 parts per million for wells located in Benton County, Arkansas. To the south in Washington County, the concentration of chloride increases to an average of 94 parts per million. Southeast of this area deep water wells are not generally drilled because of the extreme depth of the aquifers and high drilling costs. Two gas exploration wells have been drilled in northern Johnson County by Arkansas Western Gas Company, The AWG Gregory #1, located in Sec. 8, T. 12 N., R. 25 W., and AWG Federal ES 084 #1, located in Sec. 8, T. 12 N., R. 24 W., penetrate the Roubidoux-Gunter Member to a depth of approximately 4,000 feet. Calculations using formation density and induction-electric logs indicate that the formation waters have a salinity concentration ranging from 2,000 to 3,000 parts per million.

The increase in chloride and total dissolved solid concentrations of formation waters with distance from the outcrop area is characteristic of many artesian systems associated with isolated geologic basins (Bredehoeft and others, 1963). Isocon maps for the Ordovician mid-continent area illustrate this condition (Dott and Ginter, 1930).

Formation Hydraulics

The specific capacity is an indirect measure of that transmissibility and storage capacity combination for the formation the well is taking water from. One of the difficulties of calculating either parameter separately in these wells is that the water is coming from several strata. Water supply wells are normally cased to a depth of 500 feet below the surface. Water from any strata below the casing may enter the well and contribute to the yield. Another difficulty in calculating either transmissibility or storage coefficient is that the wells are artesian. The static water level is above the formation producing the main portion of the yield. The drawdown in all of these wells does not reach the top of the acquifer.

The apparent transmissibility of the wells that pump test data could be obtained for are given in the following table. These transmissibilities are apparent rather than true because the water is rising above the top of the primary water producing formation and is not a true measure of the transmissibility of the acquifer.

TABLE 9

Well Location	Apparent Transmissibility gpd/ft	Specific Capacity gal/ft
Decatur	1318	3.52
Summit	218	0.3
Ark. Hwy. Dept.	419	0.75
Eureka Springs	680	0.69
Lost Bridge Village	2534	2.1
Valley Springs	1553	1.27
Bergman	unknown	10.7
Big Flat	116	0.23
Cotter #2	3683	3.0
Holiday Island #1	5866	8.8
Holiday Island #4	10602	5.9

All of the above wells are producing water from the Gasconade formation except Big Flat. The Bergman well transmissibility is unknown because the well is apparently drawing water from a fault and at a pumping rate of 149 gallons per minute the drawdown was stable at 14 feet for 10 hours. The well must be pumped at a much higher rate to determine apparent transmissibility.

The total area between the Arkansas-Missouri state line and the location of the contour marking sea level of the top of the Roubidoux formation is 3405 square miles. The average thickness of the formation over this area is 208 feet. The coefficient of storage is believed to be approximately 3 x 10^{-4}. The water stored in this section would be approximately 136,000 acre-feet.

The surface area between the Arkansas-Missouri state line and the countour marking 800 feet below sea level of the top of the Gunter sandstone is 4380 square miles. The water stored in this section is 4,709,000 acre-feet. This is based upon an average thickness of 40 feet and a coefficient of storage of .042.

LITHOFACIES ANALYSIS

PROCEDURE

Samples from 21 wells in northern Arkansas were chosen from the Arkansas Geological Commission well-sample library on the basis of the well's location, its depth, and the availability of mechanical well logs. Each well was given a reference number that either coincides with or continues the series of numbers used in the Arkansas Water Resources Management Information System Report (closed file, 1974). Wells used in the lithofacies investigation are listed and numbered in Table 10. Well numbers and names are used to identify the wells in the text and numbers alone are used to locate wells on the lithofacies maps (Plates 11, 12, 13, 14) and cross-sections (Plates 15, 16, 17). The number of wells available for investigation was limited due to a paucity of wells in northern Arkansas that are sufficiently deep to penetrate the Roubidoux and Gasconade Formations, and also to the fact that samples from several wells that penetrate these formations are not on file in the Arkansas Geological Commission library. Figure 19 shows the locations of the wells analyzed in this investigation.

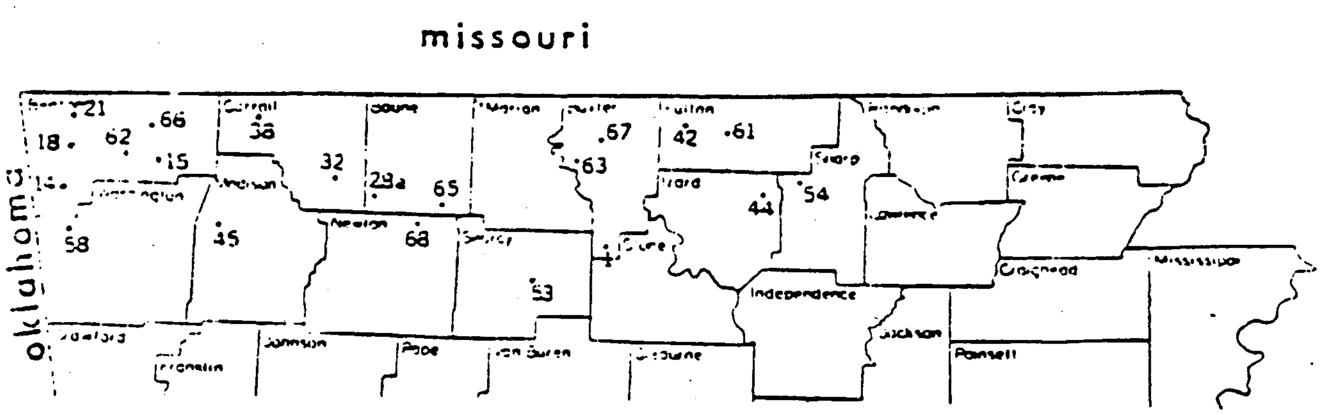


Figure 19: Index map showing well locations and reference numbers.

The disaggregated samples from both cable tool and rotary drilled wells were analyzed using a binocular microscope, and the lithic compositions of the samples were recorded. The rock types recorded included dolomite, sandy dolomite, cream colored chert, gray chert, blue chert, oolitic chert, sandstone, silicified sandstone, shale and limestone. The percent of each constituent was estimated and logged by using a column constructed on engineering graph paper. A color code was established so that each constituent could be recorded without confusion. The crystal size of the dolomite and sandy dolomite was also noted along with the average grain size of all quartz sand particles. Figure 20 depicts the column and color code used to record the samples. The logs were rechecked and the tops of the Roubidoux and Gasconade Formations and the Gunter Member were selected.

Roubidoux Formation: Upper Boundary

The Roubidoux Formation is generally differentiated from the overlying Jefferson City Dolomite on the basis of a definite increase in the sand and/or chert fraction within the section. Often this boundary is represented by the first appearance of continuous sand occurrences in the samples, indicating the presence of interbedded sandstone units. The Jefferson City Dolomite is essentially free of quartz sand and definable sandstone units.

Occasionally sandstone is not abundant near the top of the Roubidoux (Well numbers 1, 21, 32, 42, 66). In these situations the top of the Roubidoux was picked on the occurrence of in-

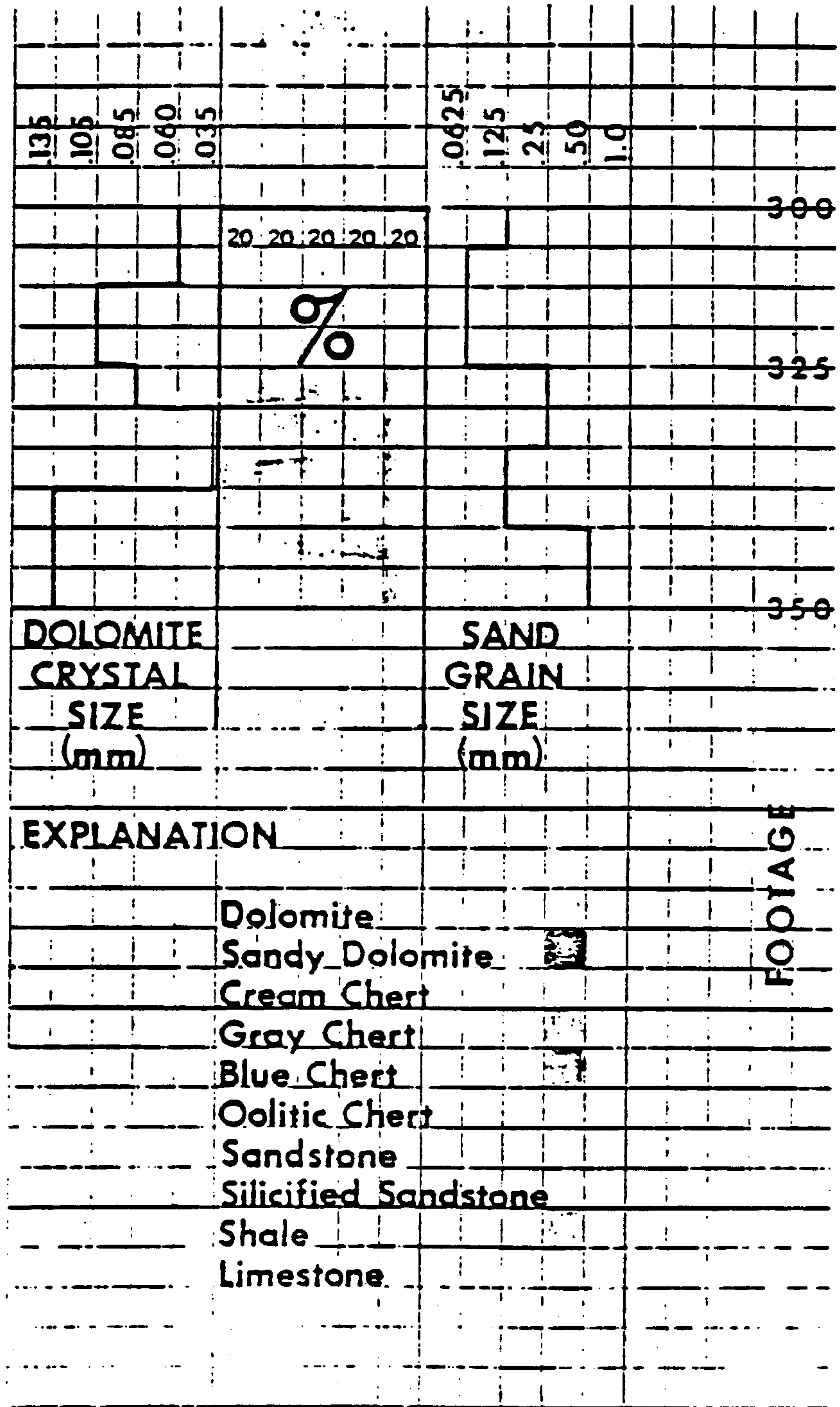


Figure 20: Well log format used to record lithic data from well samples

creasing percentages of chert. This selection is satisfactory in that the overlying Jefferson City is entirely dolomite in most of the wells and chert occurrences are almost nonexistent.

Analysis of the dolomite crystal size and quartz sand grain size reveals no characteristic repetative from well to well that would have enhanced the choice of the tops of Roubidoux Formation in the wells analyzed. However, comparison of the constructed lithologic logs with picks from the Missouri Geological Survey (insoluble residue logs), the Arkansas Water Resources Management Information System report (electric and insoluble residue logs), and the United States Geological Survey (electric logs) were useful in setting limits within the section where this boundary occurs.

Analysis of electric logs in the selection of formation tops within the section did not prove useful. No single characteristic could be found in the electric logs that consistantly indicates the top of the Roubidoux Formation. This was probably due to the amount of carbonate rock in the section, along with a deficiency of other rock types.

Gasconade Formation: Upper Boundary

The top of the Gasconade Formation was selected at a horizon marked by the total to near total absence of sand and chert from the section. In the few wells where sand and chert persist (Well numbers 1, 44, 45, 61, 66) the top of the Gasconade was chosen as the horizon where these fractions exhibited a very marked decrease in abundance with respect to the overlying Roubidoux Formation percentages.

Crystal size and quartz sand grain size analysis did not prove to be of aid in delineating the top of Gasconade Formation. As with the Roubidoux, picks by other workers from various log types aided in setting boundaries for the Gasconade.

Gunter Sandstone Member: Boundaries

The Gunter Member of the Gasconade Formation was delineated by a distinct and significant quartz sand per cent increase near the base of the Gasconade. This increase is usually greater than 10 percent of the sample and the sand is quite continuous down section. In many wells the appearance of quartz sand at the top of the Gunter is the first sand encountered within the Gasconade Formation.

The base of the Gunter Member (and Gasconade Formation) was selected at a horizon where quartz sand was absent or did not represent at least 10 per cent of the sample. In wells where samples were not available in a part of the section where a formation boundary occurred, the most logical of the other available boundary selections was utilized.

Chert Types: Gasconade and Roubidoux Formations

Numerous distinctive types of chert were encountered in the Roubidoux and Gasconade Formations. The chert was analyzed to determine if either formation was characterized by a particular type. Much of the literature about this particular sequence of strata suggests that chert types characteristic of specific formation boundaries occur in insoluble residues (Groskopf and McCraken, 1949; Searight, 1955; McCraken, 1964). However, the analysis of the bulk samples from the interval did not reveal any particular color or type of chert as entirely representative. It seems that residue characteristics are rather difficult to use in the analysis of the Roubidoux and Gasconade Formations.

Facies Analysis

The total percentages of sand, chert, and dolomite in the Roubidoux and Gasconade Formations were calculated for each well. This was done by utilizing the number of units on the log that define a particular interval (such as the Roubidoux Formation). This number was multiplied by 100 and considered to be the maximum per cent a specific rock type could achieve within the section. The number of units that were actually occupied by the specific rock types were then tabulated and also multiplied by 100. A ratio was erected between these two numbers and this ratio was set equal to the actual percent of the specific rock type (the unknown value) and divided by 100 percent. The equation was then solved for the unknown and the actual percent of each specific rock type was tabulated.

After completion of these calculations the rock type distributions of the Roubidoux and Gasconade Formations were examined to see if the sand and chert fractions of the section showed any evident trends throughout the area.

The culmination of the thickness determinations and the lithic percentage evaluations was the construction of isopach and lithofacies maps of the Roubidoux and Gasconade Formations

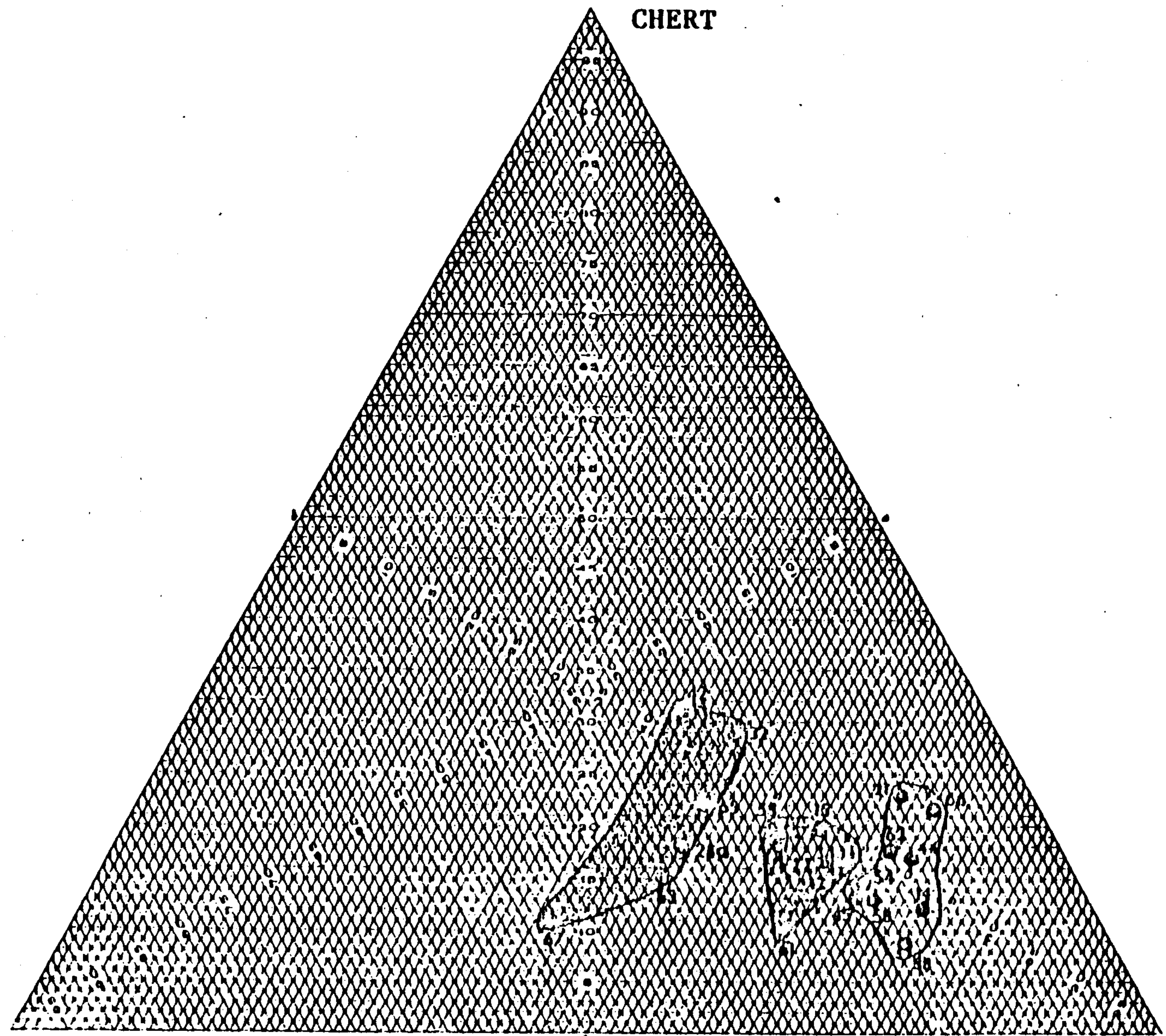


Figure 21: Compositional triangle showing lithofacies groupings for the Roubidoux Formation. Numbers refer to specific wells examined.

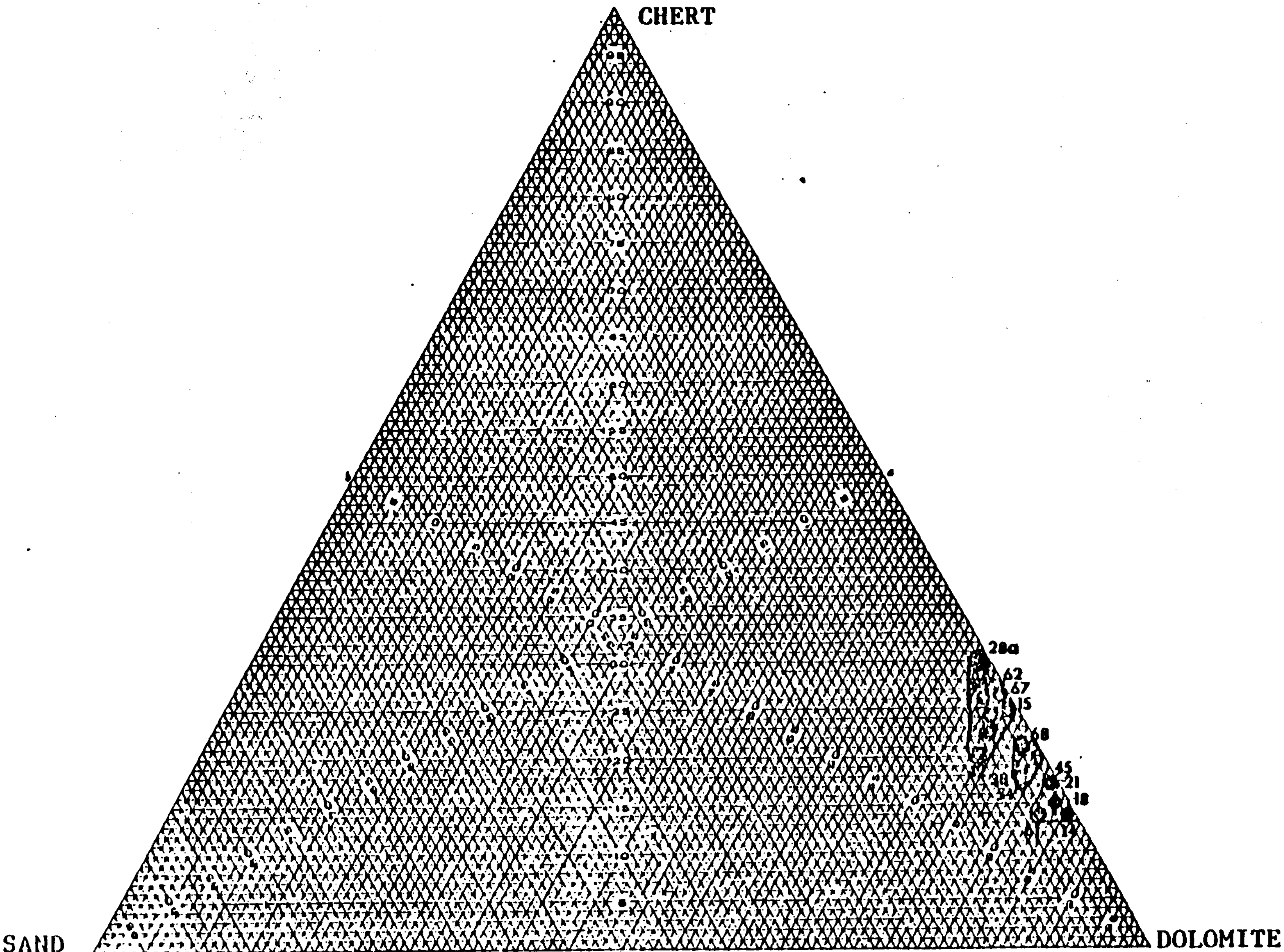


Figure 22: Compositional triangle showing lithofacies groupings for the Gasconade Formation. Numbers refer to specific wells examined.

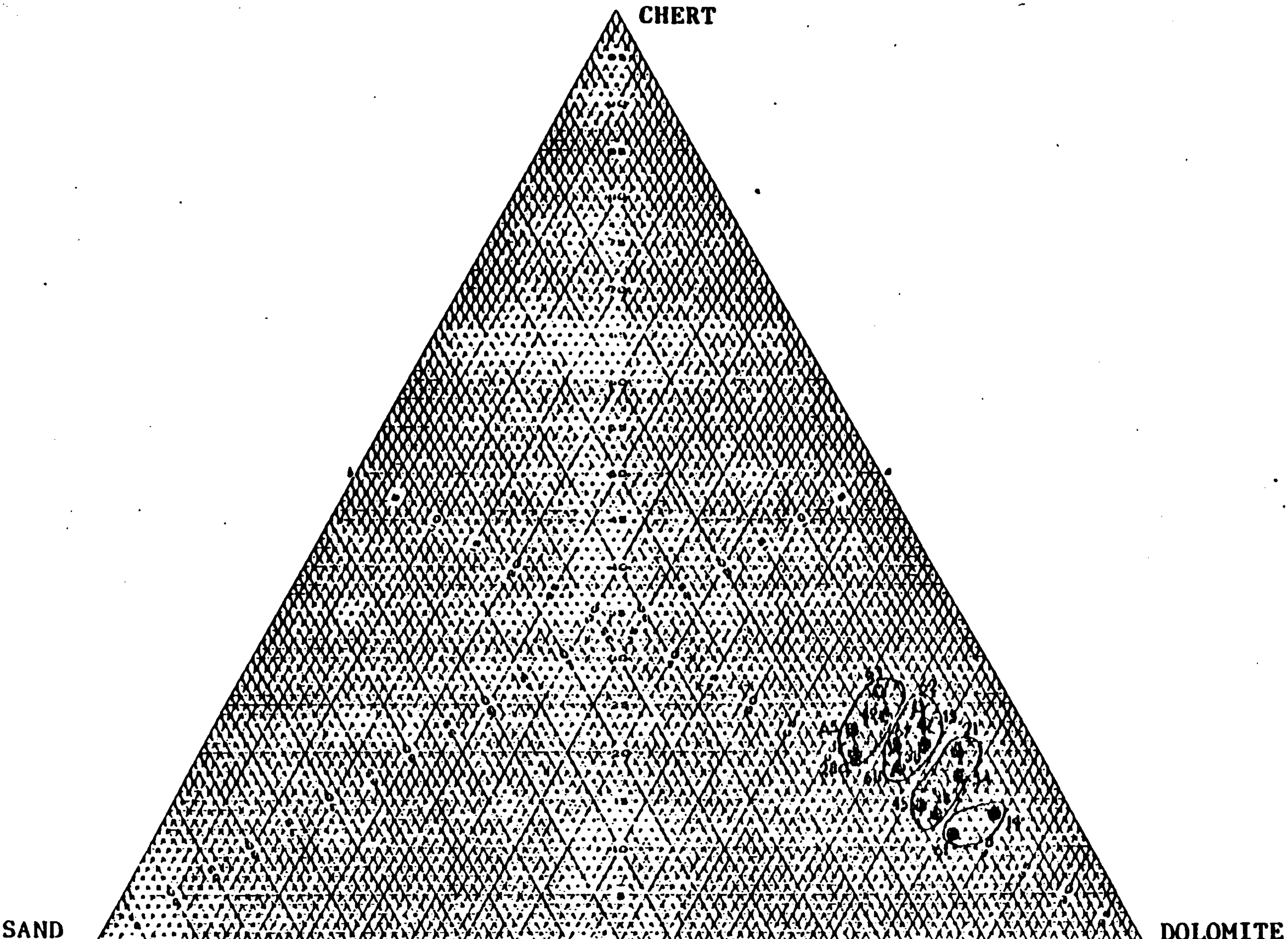


Figure 23: Compositional triangle showing lithofacies groupings for the Roubidoux and Gasconade Formations. Numbers refer to specific wells examined.

and of the Gunter Sandstone Member for northern Arkansas.

The maps were constructed on a base map having a scale of 1:500,000 and reduced. An isopach map was prepared and the regional lithofacies was superimposed over the isopach contours. The lithofacies distribution for each formation was determined by plotting the percentages of dolomite, sand and chert for each well on a compositional triangle, and grouping the results into similar percentage-based lithofacies. Figures 21 and 22 show the groupings as they were recorded for the Roubidoux and Gasconade Formations. The same procedure was followed for a lithofacies plot of the entire section - the Roubidoux and Gasconade Formations. This was done so that the overall lithic character of the sequence could be analyzed with respect to ground water occurrence in the area. Figure 23 shows the compositional triangle plot for the entire section. Plates 11, 12 and 13 in the back of this report are the isopach and lithofacies maps of the Gunter Member, Gasconade Formation and Roubidoux Formation spectively. It should be noted that the lithofacies map of the Gunter Sandstone Member is a sand percentage map. This was dictated by a paucity of other rock types in the interval.

Three structural cross-sections were prepared for the entire sequence; two depicting the north to south trends of the section and one depicting the east to west trends. Plates 15, 16 and 17 show these trends and also the location of the cross-sections with respect to northern Arkansas.

REGIONAL ANALYSIS

Gunter Sandstone Member

The Gunter Member was penetrated in 15 of the 21 wells that were analyzed in this report. In these wells the Gunter consists of sandstone, dolomite and chert. The sandstone is composed of white to clear, fine to medium, rounded to sub-rounded quartz grains, that usually exhibit a frosted surface. Caplan (1960) reported that the sand grains are coarser in size near the Eminence contact in several localities. This coarsening was not noted in the examination of the Gunter in any of these wells. The sandstone content of the Gunter ranges in amount from a low of around 16 per cent in the Viola water-well (42) in Fulton County to a high of approximately 97 percent in the Arkansas Western Gas Number One Bryan Well in Boone County (28A).

The sandstone of the Gunter Member in northern Arkansas are of two types: 1) dolomitic quartz sandstone and 2) silicious quartz sandstone. The difference in these two types is the cement present. The kind of cement was determined by appearance of the sand under a binocular microscope and by testing the sample with dilute hydrochloric acid. Of these two types, dolomitic quartz sandstone is by far the most abundant rock type in the Gunter Member. Only minor amounts of silicious quartz sandstone are present in northern Arkansas. However, both of these types of sandstone occur with dolomite and chert, which suggests that extensive interbedding of sandstone, dolomite, and chert is a characteristic of the Gunter in the subsurface.

Cementation of the sandstone of the Gunter ranges from very weak to very strong. Most of the calcareous cemented (dolomitic) sandstone is quite friable and breaks down easily to individual quartz grains. The siliciously cemented sand grains are well bonded and not easily separated.

The quartz sand grains that comprise these sandstones show remarkable consistency across the study area. The size range of these grains is from .125 mm to .25 mm in every well analyzed in northern Arkansas. This excellent sorting is suggestive of repeated reworking of the sand grains, possibly in an advancing strandline during deposition of the Gunter Member.

The surface features of the quartz sand grains are of some use in delineating the Gunter Member in the section. The grains are almost always clear to very white, and have a frosted surface. This characteristic is useful because the sand that occurs in the section above the Gunter Member is usually a shade of gray or off-white.

The frosting on the surface of the quartz grains in the Gunter is probably due to processes similar to those described for the Everton Formation (Middle Ordovician) by Suhm (1970). He concluded that eolian processes were not important and that chemical solution processes were responsible for the frosted surfaces on most quartz sand grains.

Dolomite is the second major constituent of the Gunter in the wells of northern Arkansas. This also includes rock logged as sandy dolomite. The dolomite is light to medium-gray, fine to medium crystalline and only locally contains quartz sand grains. Sandy dolomite in the Gunter Member observed in this investigation does not constitute a major fraction of the unit in any of the wells. The dolomite of the Gunter Member is virtually indistinguishable from the dolomite of the remainder of the Gasconade Formation. The color ranges from medium to light-gray and crystal sizes range from .060 mm to .105 mm. The dolomite crystal size of the Gunter Member is more uniform than the crystal size of the dolomite in the rest of the Gasconade. However, this slight increase in uniformity is not sufficiently pronounced to be of assistance in selecting the boundaries of the Gunter Member.

The Gunter Member of northern Arkansas also contains minor amounts of chert. The chert is commonly cream or gray and quite dense in appearance. Some ooliths occur within the chert in a few wells. The grain size of the ooliths is comparable to the quartz sand grain sizes encountered. Overall, there are no distinguishing characteristics of the chert within the Gunter that would enable their segregation from chert of the overlying Gasconade Formation.

The Gunter Sandstone Member of the subsurface of northern Arkansas ranges in thickness from 25 feet to 120 feet. However, this latter figure is not typical as extreme thicknesses (over 100 feet) only occur in one area of northern Arkansas. The excessive thicknesses (more than 100 feet) encountered in a few of the wells were grouped closely around the Carrollton Dome in Carroll, Boone, and Newton Counties. These anamolous thicknesses may well represent part of a channel fill as described by Caplan (1960). Further evidence for this assumption can be obtained by comparing Knight's (1954) lithofacies map and cross section of the Gunter, Figure 2, with the isopach and lithofacies map of the Gunter in the back of this report (Plate 11). Both maps show a localized thickening and an increase in sand percentage along a belt trending northward from the area of anamolous thicknesses in northern Arkansas. This could suggest that a well developed channel did in fact exist during the time of deposition of the Gunter, supplying significant quartz sand to the areas adjacent to and within the channel.

The Gunter thickens regionally in a southeastwardly direction across the state.

Sand percentages for the Gunter Member also exhibit an increase toward the southeast suggesting a source in that direction. Also of interest are three anamolous areas of higher sand percentages -- one in the eastern edge of the state in Sharp County; one around the Carrollton Dome; and the other in the northern edge of Benton County. Chenoweth (1968) has suggested that during the time of deposition of the Lower Ordovician, an archipelago existed in eastern Oklahoma due to highs in the Precambrian basement rocks of the area. It is possible that the areas of thickened strata in northern Arkansas are associated with such an archipelago. Anamolous amounts of sand derived from the surrounding highs could have been deposited in adjacent areas.

These areas are not believed to have been part of the islands themselves, because in the wells analyzed a normal succession of rock units exists and no overstepping of units as described by Chenoweth in Oklahoma seems to occur.

Parts of Benton, Carroll, and Washington Counties formed an embayment in the western part of the area. This part of the state may have been low and more sand derived from the surrounding terrain accumulated.

Gasconade Formation

The Gasconade Formation, excluding the Gunter Member, is composed almost completely of dolomite. Small quantities of sandstone and chert occur, but only locally do these constituents form a significant part of the unit.

The dolomite of the Gasconade Formation in northern Arkansas is light to medium-gray and ranges in crystal size from .035 mm to .135 mm. Complete dolomite rhombs are common, but the overall appearance of the dissaggregated samples suggests that most of the dolomite has a xenotopic fabric. Dolomite with a hypidiotopic fabric is also present but much less common.

The various types of dolomite that occur (based on color and fabric) do not have specific positions stratigraphically within the Gasconade. Distributions of various colors and textures are random throughout the section. A particular type of dolomite may occur continuously for 50 to 100 feet. The zone of uniform occurrence is succeeded by zones that display a wide range of crystal sizes, colors and sand content within 25 feet.

It is difficult to predict that a particular type of dolomite will occur at a given position within the section in northern Arkansas. The origin of the dolomite is believed to be through the replacement of calcite or aragonite.

The chert fraction of the Gasconade Formation in northern Arkansas forms approximately 25 per cent of the unit with some variance noted. The colors recorded for the chert of the Gasconade are cream, blue, and gray. All have a dense appearance and only occasionally is oolitic chert encountered. Overall, the chert of the Gasconade is like that of the Gunter Member. The chert increases in content from the top of the Gasconade Formation toward the top of the Gunter Member, and decreases within the Gunter. This trend was observed in virtually every well logged in this study.

Quartz sand is a minor constituent of the Gasconade Formation. The sand is usually light to medium-gray, and amounts encountered range from 0 to about 5 per cent. The grain size measurements made reveal that the sand present is quite variable, ranging from .0625 mm to .25 mm across the state. No particular grain size is present consistently in any part of the section analyzed, and the use of the quartz sand grain sizes as stratigraphic guides is not viable in the Gasconade of northern Arkansas. Frosted grains are also quite abundant among the sands of the Gasconade and are probably the result of the processes described for the Gunter sands. The sand content increases eastward across the state, and a well developed sand unit is present near the middle of the formation in eastern Arkansas. The unit is rather constant in thickness (around 15 to 20 feet), but associated sand stringers in the City of Viola water well (42) produce a total thickness of 50 feet. Correlation of this unit is difficult in the three wells in which it has been logged. Future drilling in the area may show that the unit can be correlated, and that it may be of some importance as an aquifer within the Gasconade Formation.

Limestone is the only other rock type encountered in the Gasconade of northern Arkansas. The limestone is light brown and is extremely crumbly. The appearance is very granular and the crystal size of the calcite was not determinable.

The Gasconade Formation, excluding the Gunter Member, thickens across northern Arkansas in a southeasterly direction from about 300 feet in Benton and Washington Counties to approximately 570 feet in Stone, Izard, Fulton, and Sharp Counties (Plate 2). An area of thinner strata occurs around the Carrollton Dome. This, along with the relatively sharp boundary between the Gunter Member and the rest of the Gasconade; and the lithofacies pattern of the Gasconade that indicates an area of terrigenous sediment deposition in the northern portion of the state prior to carbonate deposition suggest that the unit was deposited in possibly two phases.

After deposition of the Gunter Member in a sea transgressive from the south, a minor regression occurred. This regression allowed the deposition of sediments derived from the exposed northern areas in Missouri in the extreme northern parts of Arkansas. As this regression waned and another transgressive phase began, the area was inundated by deeper waters and carbonate deposition proceeded. However, because of the sediments derived from the north, the northern part of Arkansas was left with a somewhat higher sand content than the areas to the south that had not received any of the terrigenous sediments.

The upper portions of the Gasconade of northern Arkansas are relatively consistent, especially in composition. Thickness variations are more pronounced across the state than in the Gunter Member.

Roubidoux Formation

The Roubidoux Formation of northern Arkansas consists of dolomite, sand and chert. This unit is more sandy than the Gasconade (excluding the Gunter Member) and is a more important aquifer. Unlike the Gasconade, the Roubidoux displays certain stratigraphic characteristics that enable subdivision of the unit based on variations in lithic constituents -- basically sand and chert. These units will be discussed as separate entities in the text.

Roubidoux Formation - Unit A

The lowermost subdivision of the Roubidoux Formation of northern Arkansas is composed dominantly of dolomite, with sand and chert content ranging upward to approximately 25 per cent of the total unit. This unit rests unconformably on the underlying Gasconade Formation, and is not widespread throughout northern Arkansas. It is restricted to the northwestern and north-central parts of the state. To the south and east, this unit disappears completely. The distribution of the Unit A may be seen by examining the structural cross-sections included with this report (Plates 15, 16, and 17).

Dolomite is the dominant constituent of Unit A. The dolomite has a crystal size ranging from .035 mm to .135 mm, is light to medium-gray and has a fabric that ranges from hypidiotopic to xenotopic. Some occasional sand grains occur in the dolomite of Unit A, but sandy dolomite is not volumetrically important.

Quartz sand is the next most commonly occurring constituent of Unit A in the Roubidoux. The sand content may range up to about 25 per cent of the unit, but more commonly forms between 10 and 20 per cent. The sizes of the quartz grains range widely from .0625 mm to .25 mm, and show no predictable patterns within the subdivision. The color of the sand is not widely variable, usually being light gray or occasionally white. The grains are rounded to subrounded (dominant) and are loosely cemented with calcareous and silicious cements. On the whole, the sandstone of Unit A does not appear to occur as thick continuous beds, but as thin interbedded layers with dolomite and chert.

The chert in this subdivision is much like the chert of the Gasconade and the remainder of the Roubidoux. Colors recorded for the chert in this unit are cream, gray, and blue. Some oolitic chert is present in minor amounts. However, in the lower unit the amounts of oolitic chert are insignificant, especially as composed to local occurrences in the upper sections of the

Roubidoux Formation. All of the chert types have a dense appearance and occur in less significant quantities than sand. Thicknesses of this unit range from 60 to 125 feet, with maximum thicknesses in the northern part of the state.

Roubidoux Formation - Unit B

The middle subdivision of the Roubidoux Formation in northern Arkansas is the most important of the units for two reasons: 1) it is the most widespread of the three units and occurs in every well, and 2) it consists of significantly more sand and chert than the other two subdivisions. This characteristic may prove useful to the water resource occurrence in the state, if the porosity and permeability of the unit are greatly enhanced by increased amounts of these constituents.

Overall, the lithic constituents of Unit B do not differ to any great extent from those of Unit A. Dolomite, sandstone, and chert are the major rock types, but the quantity of each does create a substantial difference.

Dolomite is a major constituent of Unit B and occurs throughout the unit in varying amounts. It is light to medium-gray, with crystal sizes ranging from .035 mm to .135 mm. The somewhat granular appearance again suggests hypidiotopic to xenotopic fabric, and although complete dolomite rhombs are common, none of the samples examined appeared to have an idiotopic texture. Occasional sand and chert fragments are also present in the dolomite of Unit B, but occurrences are not significant and have no stratigraphic meaning.

The quartz sands of Unit B are commonly light gray and range in grain size from .0625 mm to .25 mm. The distribution of the sizes is random and unimportant in a stratigraphic sense. Subrounded grains are most common, but rounded grains also frequently occur. The cements are both calcareous and siliceous, but cementation is poor and the sandstone is quite friable. In contrast with the units above and below, the sand of Unit B appears to occur in somewhat thicker intervals and also appears to be more continuous laterally across the state.

Unit B is also characterized by significant amounts of chert, constituting slightly less of the section than the associated sand. Blue, gray, and cream chert is common, with minor amounts of oolitic chert occurring locally near the top of the unit. The chert has the dense appearance ascribed to the cherts of the Roubidoux and also seems to form thicker, more continuous intervals within the unit as compared to the other two units.

Thicknesses of Unit B range from 40 to 260 feet, and the unit is the only one of the three divisions present to the south and east across the state (Plates 15, 16, and 17).

Roubidoux Formation - Unit C

The third subdivision of the Roubidoux Formation in northern Arkansas, Unit C, contains the least amounts of sand and chert of the three units, and is at the top of the Roubidoux with its upper boundary overlain by the Jefferson City Dolomite.

Dolomite is by far the dominant rock type of Unit C, and its appearance is similar to the underlying dolomite of the other two units. Crystal sizes range from .035 mm to .135 mm, the color is light to medium-gray, and the overall fabric is hypidiotopic. Sand and chert fragments are present in minor amounts.

The sand content of Unit C is low with amounts never exceeding 20 per cent of the section and generally being much lower. The grains are light gray, subrounded quartz and have a size range of .0625 mm to .25 mm. The sands of Unit C appear to occur in thin beds interbedded with the thicker beds of dolomite and chert.

The chert content is as low or lower than the sand content of Unit C, and its overall character is similar to chert described earlier. Colors are blue, cream, and gray. The oolitic chert described in the other divisions occurs in slightly increased amounts in Unit C. This is probably the local zone of brown quartzose oolitic chert described by Grohskoph and McCraken (1949). Thicknesses of Unit C range from 20 to 120 feet, and the unit is restricted to the northwest portion of the area.

The Roubidoux Formation of northern Arkansas appears to have a somewhat similar depositional record to that of the Gasconade Formation. The unit thickens in an overall southeasterly direction from about 180 feet in the north to over 260 feet (except for the Carrollton Dome region) in the southerly portions of the study area. Anamolous areas of thickened Roubidoux exist in several parts of northern Arkansas as seen on the Isopachous and

Lithofacies map with this report (Plate 13). These areas are probably due to one of two things. Either the underlying Gasconade Formation is thinner in these areas, thereby leaving them slightly lower than the surrounding and enabling thicker Roubidoux accumulation, or these areas underwent differential compaction to a somewhat greater degree than their surroundings, allowing more Roubidoux sediment to accumulate in the overly compacted areas. There does appear to be a correlation between the somewhat thinner areas of the Gasconade Formation and the thicker deposits of the Roubidoux. An example of this is the Carrollton Dome region, where the Roubidoux attains a thickness of approximately 280 feet. This same area is covered by an anamolously thin section of Gasconade. Other areas that exhibit this trend are in central Washington and Madison Counties and in northern Fulton County. Both of these areas have thick Roubidoux sections and thin Gasconade sections (Plates 12 and 13).

The Roubidoux Formation also displays a central zone of higher sand and chert in northern Arkansas, with a zone to the south of increased dolomite content (Plate 13). This again suggests that terrigenous sediments were supplied to some extent from the north, and were emplaced in the central embayment. However, most of the deposition of the Roubidoux took place during a transgression of deeper waters from the south, much like the Gasconade Formation.

Also of interest is the high dolomite content of the western

Table 10

Well Reference Number	Location Twp	Rge	Sec	County	Owner or Driller	Year Completed	Total Depth below Land Surface	Formation above MSL	Formation at Total Depth	Formation available from W.S.
1	16N	13W	30	Baxter	Town of Big Flat	1972	2603'	1305'	Gasconade	Gasconade
63	19N	14W	28	Baxter	Gassville #1 w.w.	--	1503'	670'	Gunter	Gunter
67	20N	13W	33	Baxter	Baxter Lab #1 w.w.	--	1865'	780'	Eminence	Eminence
14	18N	33W	34	Benton	Ozark Products Co. #1	--	2227'	1190'	Eminence	Eminence
15	19N	29W	18	Benton	City of Rogers	1954	1660'	1375'	Gunter	Gasconade
18	19N	33W	13	Benton	City of Decatur	--	1430'	1250'	Eminence	Eminence

Well Reference Number	Type of Well Log Available	Source of Well Log	Roubidoux Formation Top	Roubidoux Formation Thickness Overall	Thickness ZoneC	Thickness ZoneB	Thickness ZoneA	Gasconade Fm. Top	Gasconade Fm. Thickness	Gunter Mbr. Top	Gunter Mbr. Thickness	Remarks
1	Insol Res. Electric-Gamma	Mo. Survey U.S.G.S.	-1055 2360	230	-	230	-	-1285 2590	--	--	--	Previously called Gunter Well
63	--	--	-55 (725)	230	-	230	-	-285 (955)	495'	-780 (1450)	50+	T.D. in Gunter
67	--	--	--	--	-	--	-	-295 (1075)	490'	-785 (1565)	55	Samples Begin in Roubidoux
14	Insol Residue	Mo. Survey	-5 (1195)	205	75	40	90	-210 (1400)	340'	-550 (1740)	40	-
15	Insol Residue	Mo. Survey	315 (1060)	210	40	150	20	105 (1270)	--	--	--	Roubidoux Top pick from Mis- No Samples
18	Insol Residue	Mo. Survey	--	--	-	--	-	170 (1080)	310	-140 (1390)	30	No Samples For Roubidoux

Well Reference Number	Location Twp	Rge	Sec	County	Owner or Driller	Year Completed	Total Depth below Land Surface	Formation above MSL	Formation at Total Depth	Formation Available from W.S.
21	20N	33W	11	Benton	City of Gravette #2	1954	1603'	1199'	Eminence	Eminence
62	19N	31W	12	Benton	Millsap-Grady Jones #1	--	2338	1273	Pre-Cambrian	Pre-Cambrian
66	20N	30W	?	Benton	City of Pea Ridge	--	1255	?	Roubidoux	Roubidoux
28A	18N	22W	24	Boone	AWG RHEA Bryan #1	--	2343	1894	Eminence	Eminence
65	18N	19W	33	Boone	Valley Springs water well	--	2050	1375	Gunter (Base)	Gunter (Base)
32	19N	23W	4	Carroll	City of Green Forest	1963	1587	1349	Gasconade	Gasconade

Well Reference Number	Type of Well Log Available	Source of Well Log	Roubidoux Formation Top	Roubidoux Formation Thickness Overall	ZoneC	ZoneB	ZoneA	Gasconade Fm. Top	Gasconade Fm. Thickness	Gunter Mbr. Top	Gunter Mbr. Thickness	Remarks
21	Insol. Residue	Mo. Survey	139 (1060)	190	55	135	--	-51 (1250)	310	-361 (1560)	25	--
62	--	--	143 (1130)	210	20	100	90	-67 (1340)	305	-372 (1645)	40	Incomplete Roubidoux Samples
66	--	--	? (1130)	---	70	---	--	--	---	---	--	--
28A	Insol. Res. and Electric	Mo. Survey and A.W.G.	274 (1620)	265	--	---	--	9 (1885)	335	-326 (2220)	110	Incomplete Samples
65	Electric	U.S.G.S.	85 (1290)	230	--	230	--	-145 (1520)	410	-555 (1930)	120	Section Appears Repeated
32	Insol. Residue	Mo. Surve-	-16 (1365)	215	35	105	25	-231 (1580)	---	---	---	--

Well Reference Number	Location Twp	Rge	Sec	County	Owner or Driller	Year Completed	Total Depth below Land Surface	Formation above MSL	Formation at Total Depth	Formation Available from W.S.
38	21N	26W	27	Carroll	Holiday Island #4	1972	1880	1520	Eminence	Eminence
61	20N	8W	27	Fulton	Salem W.W. #1	1956	1282'	660'	Gunter	Gunter
42	20N	9W	18	Fulton	Viola W.W. #1	1964	1600	800'	Eminence	Eminence
44	18N	7W	31	Izard	Franklin #2 Adcock Drillers	1970	1300	670'	Gasconade	Gasconade
45	16N	27W	6	Madison	Independent Oil and Gas #1 Banks	--	2515	1545	Eminence	Eminence
68	17N	20W	20	Newton	Marble Falls W.W.	--	2503	1544	Gunter (Base)	Gunter (Base)

Well Reference Number	Type of Well Log Available	Source of Well Log	Roubidoux Formation Top	Roubidoux Formation Thickness Overall	Thickness Zone C	Thickness Zone B	Thickness Zone A	Gasconade Fm. Top	Gasconade Fm. Thickness	Gunter Mbr. Top	Gunter Mbr. Thickness	Remarks
38	Insol. Residue and Electric	Mo. Survey U.S.G.S.	560 (960)	185	120	65	--	375 (1145)	335	40 (1480)	70	Incomplete Roubidoux Samples
61	--	--	255 (415)	265	---	265	--	-10 (670)	535	-545 (1205)	60+	---
42	Insol. Residue	Mo. Survey	-80 (880)	210	---	210	--	-290 (1090)	490	-730 (1580)	40	Poorly Developed Gunter Section
44	Insol. Residue	Mo. Survey	-360 (1030)	250	---	250	--	-610 (1280)	---	---	--	---
45	Insol. Residue	Mo. Survey	59 (1486)	250	---	125	125	-190 (1735)	305	-495 (2040)	60	---
68	Electric	U.S.G.S.	-176 (1720)	180	---	120	60	-356 (1900)	440	-796 (2340)	120	---

Well Reference Number	Location Twp	Rge	Sec	County	Owner or Driller	Year Completed	Total Depth below Land Surface	Formation above MSL	Formation at Total Depth	Formation Available from W.S.
53	15N	16W	25	Searcy	Marshall #3	---	2415	1100	Gasconade	Gasconade
54	18N	6W	10	Sharp	Ash Flat #1	---	1545	555	Gunter	Gunter
58	16N	32W	9	Washington	Lake Wedington Park Forest Service	1973	1815	1135	Eminence	Eminence

Well Reference Number	Type of Well Log Available	Source of Well Log	Roubidoux Formation Top	Roubidoux Formation Thickness Overall	ZoneC	ZoneB	ZoneA	Gasconade Fm. Top	Gasconade Fm. Thickness	Gunter Mbr. Top	Gunter Mbr. Thickness	Remarks
53	Insol. Residue	Mo. Survey	-1030	235	---	235	--	-1265 (2365)	---	---	---	---
54	Insol. Residue	Mo. Survey	-200 (755)	220	---	220	--	-420 (975)	545	-965 (1520)	25+	---
58	Electric	U.S.G.S.	-70 (1205)	210	---	210	--	-280 (1415)	315	-595 (1730)	40	---

edge of northern Arkansas. This is in contrast to the pattern exhibited by the Gasconade Formation. It is possible that this portion of the state became isolated from the bulk of the supply of terrigenous sediments. Then as inundation of the area occurred, extensive carbonate deposition took place and carbonates occur as the dominant sedimentary facies of the region.

SUMMARY AND CONCLUSIONS

The development of groundwater resources of the Ozark Plateaus region is essential to future economic growth in northern Arkansas and Missouri. Yields from shallow aquifer wells are generally inadequate to supply the needs of industry and municipalities. Adequate supplies must therefore be developed from deeper aquifer units. The Roubidoux and Gasconade Formations are the most accessible and reliable deep aquifers in the area. The future development and proper utilization of these aquifers depends on understanding the regional hydrogeologic characteristics of the Roubidoux and Gasconade Formations in the recharge and discharge areas.

of the Roubidoux and Gasconade Formations in Missouri and Arkansas. The specific objectives were accomplished in the following manner.

1) The description of the lithologic character of the aquifers and their areal distribution has been provided by synthesizing pertinent information sources.

   The Roubidoux and Gasconade Formations, and the Gunter Sandstone Member of the Gasconade Formation, are the most reliable and accessible sources of water supplies for industrial and municipal development in the Ozark Plateaus region. The area of outcrop of the formations is confined to the Salem Plateau region of south central Missouri where the units are exposed in belts peripheral to the Ozark dome. Regionally the strata dip beneath successively younger units from the uplift toward surrounding basins.

   Throughout most of the area the upper part of the Gasconade Formation consists of fine to coarsely-crystalline dolomite. The basal Gunter Member is composed of sandstone in south central Missouri and north central Arkansas and increases in dolomite content east and west of this area.

   The lithology of the Roubidoux Formation is primarily cherty to sandy, finely-crystalline, light-gray to brown dolomite. Well developed sandstone bodies are present in portions of Missouri, but have not been observed in Arkansas.

2) Isopachous maps for the aquifers along with a structure map contoured on the base of the Roubidoux Formation were prepared. The maps consist of data published by McCracken (1965) for the Missouri portion of the study area, and data derived from the analysis of available well logs and samples for the Arkansas Ordovician sequence.

Regional thickness trends within the aquifers follow the pattern of increasing in thickness from northwest to southeast. The Gasconade Formation, including the Gunter Member, has a range of thickness from 160 to 660 feet. The Gunter Sandstone Member averages 30 feet thick over much of the area, and ranges from 0 to 120 feet thick. The thickness of the Roubidoux Formation ranges from 100 to 280 feet.

3) The distribution of yields and specific capacities for wells penetrating the Roubidoux and Gasconade Formations have been evaluated. Yield and specific capacities maps were constructed from data obtained from various State, engineering, and Federal agencies in Missouri and Arkansas. These maps offer some estimate of the availability of water from the aquifers.

Reported yields from wells penetrating the Roubidoux or Gasconade Formations represent the contribution from all aquifers open below the casing rather than the water available from individual aquifers. Yields from wells penetrating the Roubidoux Formation range from 4 gpm to 600 gpm and average 50-60 gpm. Specific capacities of these wells are generally less than 1 gpm/ft. Wells penetrating the Gasconade Formation have yields ranging from 4 gpm to 732 gpm, with an average of 170 gpm. Specific capacities average less than 2 gpm/ft.

4) To determine the relationship of recharge, groundwater movement, and discharge associated with the aquifers, a map of the potentiometric surface was constructed from reported water level measurements in wells penetrating the deep aquifers. Records from continuous recording devices were then evaluated to determine the influence of precipitation on water levels. Graphs of drawdown versus time were derived from available pump tests to determine the effects of local recharge and discharge. Spring discharge and stream low-flow data were examined as indicators of the character of recharge and discharge from the aquifers.

Groundwater recharge, which is derived from precipitation, takes place over virtually the entire area underlain by carbonate rocks, but is greatest within the Salem Plateau region where the aquifers crop out. The different responses of wells to individual rainfalls show that recharge is more frequent and rapid in this area than in the Springfield Plateau where the aquifers are confined to the subsurface.

The configuration of the potentiometric surface reflects the artesian conditions present within the aquifers and generally corresponds to major features of the land surface. Groundwater ridges underlie major stream channels. Water moves down the hydrodynamic gradient from groundwater ridges to groundwater troughs.

Discharge of groundwater takes the form of effluent seepage along stream channels, flowing springs, movement from one aquifer to another, and artificial discharge from wells. Discharge within the Salem Plateau is more extensive than that of the Springfield Plateau.

5) Selected water quality data were evaluated to determine the regional quality of waters associated with the aquifers.

Groundwater from wells penetrating the Roubidoux and Gasconade Formations is the calcium-magnesium, bicarbonate type. Although the water is hard to very hard, it is of good chemical quality and suitable for most uses. The distribution of dissolved minerals in the groundwater corresponds in a general way to the overall direction of movement of water. Total dissolved solids are low along groundwater ridges and high in groundwater troughs. Calcium/magnesium ratios are high along groundwater ridges and decrease toward groundwater troughs. Chloride concentrations increase with the regional gradient from the southwest portion of the study area toward the Arkoma Basin.

RECOMMENDATIONS

Knowledge of the extent and capabilities of water resources from the Roubidoux and Gasconade Formations is necessary in order to utilize them properly. This study has described the regional geologic and hydrologic character of the aquifers and offers some reasonable estimate of water availability and the factors influencing groundwater occurrence. The study utilized existing subsurface and hydrologic data which offer knowledge that may be sufficient for the present level of groundwater development of the area. The present data, however, may prove insufficient in many respects as the utilization of groundwater resources increases.

The following recommendations for further studies should be considered as increased utilization of groundwater from the Roubidoux and Gasconade Formations occurs.

1) Data are needed to outline more accurately the depths, thicknesses, facies changes, and continuity of the aquifers. As new wells are drilled they should be evaluated and the new data incorporated to increase the accuracy of existing maps.

2) Detailed evaluation of existing geophysical well logs was beyond the scope of this study. Analysis of these data may offer valuable information on porosity, permeability, safe yield, occurrence of of subsurface movement of water within the aquifer units.

3) The present study suggests that water yields are significantly higher along linear traces and fault zones. A more comprehensive study is necessary to establish the magnitude of influence that linear and fracture systems exert on water availability from the aquifers.

4) The existing water level monitoring program in northern Arkansas should be expanded to include several well sites equipped with continuous monitoring devices. This would provide more accurate information on discharge, recharge and water declines.

5) A program of co-operation between drillers, engineering companies, and state and federal agencies should be initiated in Arkansas to insure the optimum development and utilization of data from newly drilled wells.

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Appendix A

Well Data for Water Well Yield and Specific Capacity Maps

ABBREVIATIONS

<u>Box Headings</u>

ft. - feet
g.p.m. - gallons per minute
fm - formation
T.-N. - Township-North
R.-W, E. - Range-West, East

<u>Stratigraphic Units</u>

	Cambrian System
Ce	Eminence Formation
M	Mississippian System
Mbn	Boone Formation
Mbk	Burlington-Keokuk Formation
Mch	Chouteau Group
Mfg	Fern Glen Formation
Mg	Grand Falls Formation
Mn	Northview Formation
Mpb	Pitkin-Fayetteville Formation
Mr	Reeds Spring Formation
Msl	St. Louis Formation
Mw	Warsaw Formation
O	Ordovician System
Oc	Cotter Formation
Og	Gasconade Formation
Ojc	Jefferson City Formation
Or	Roubidoux Formation
P	Pennsylvanian System
Pcc	Cherokee Group
Qal	Alluvium

Parentheses () indicate production after treatment

Missouri Data after Robertson, 1963

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
1	Maries	T. 41 N. R. 9 W. 9	Ojc	600	Ce	15	220	15	40	0.4	320	
2	Miller	T. 40 N. R. 15 W. 32	Or	405	Ce	45	180	20			27	750
3	Lowry City 1 St. Clair	T. 39 N. R. 26 W. 13	P		Og	42	625	157	90	1.7	250	871
4	St. Clair	T. 39 N. R. 24 W. 33	Mbk	650	Og	160	150	91	114	0.8	250	890

Well #	Namé County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
5	St. Clair	T. 39 N. R. 24 W. 34	Mbk	650	Og	160	148	124	15	8.0	337	933
6	Cuba #1 Crawford	T. 39 N. R. 4 W. 31	P	602	Ce	55	225	135	19	7.1	190	1,038
7	Schell City 1 Vernon	T. 38 N. R. 29 W. 33	Pcc	714	Og	125	35	250	5	50.0	317	744
8	St. Clair	T. 38 N. R. 25 W. 17	Mch	550	Og	160	10	125	6	20.9	138	725
9	St. Clair	T. 35 N R. 25 W. 31		500	Og	30	105	40	95	0.4	60	809
10	Pulaski	T. 35 N R. 11 W. 26	Ojc	600	Ce	10	285	75	5	25.0	46	1,162
11	Phelps	T. 38 N. R. 9 W. 2	Or	395	Og	205	255	40	105	0.4	17	914
12	Vernon	T. 37 N R. 31 W. 17	Pcc	852	Or	165	26	160	130	1.2	101	757
13	St. Clair	T. 37 N R. 27 W. 21	P	415	Or	105	80	40	120	0.3	99	806

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
14	St. Clair	T. 37 N. R. 25 W. 1		440	Or	73	125	30				
15	Hickory	T. 37 N. R. 22 W. 19	Mbk	416	Or	55	185	15	15	1.0	24	1,038
16	Hickory	T. 37 N R. 21 W. 36	Oc	450	Og	45	85	35	22	1.6	110	1,068
17	Phelps	T. 37 N R. 8 W. 2	Ojc	600	Og	245	292	80	58	1.6	100	1,143
18	Phelps	T. 37 N. R. 7 W. 4	Ojc	530	Ce	10	155	100			234	1,098
19	Phelps	T. 37 N R. 6 W. 4	Or	310	Og	160	245	10			84	1,048
20	Nevada 1 Vernon	T. 36 N R. 31 W. 5	P	1,001	Og	147	78	275				
21	Eldorado Springs 2 Cedar	T. 36 N. R. 28 W. 21		1,046	Og	220	70	175				842
22	Cedar	T. 36 N. R. 28 W. 28	P	946	Og	125	166	315	5	63.0	550	916

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
23	Hickory	T. 36 N. R. 24 W 11	Mbk	430	Or	45	125	15	20	0.7	165	1,002
24	Hickory	T. 36 N. R. 22 W. 2	Oc	700	Og	340	110	41	85	0.5	212	918
25	Pulaski	T. 36 N. R. 11 W. 17	Or	450	Ce	15	223	20	30	0.6	330	1,056
26	Phelps	T. 36 N. R. 7 W. 18		432	Og	22	270	10				1,230
27	Nevada Vernon	T. 35 N. R. 31 W. 5	Pcc	1,100	Ce	25	127	732	31	23.6	275	864
28	Vernon	T. 35 N. R. 31 W. 12	Pcc	1,050	Og	150	140	350	8	43.8	250	891
29	Laclede	T. 35 N. R. 15 W. 32	Ojc	571	Ce	10	174	10	None	-	253	1,260
30	Pulaski	T. 35 N R. 13 W. 13	Ojc	525	Og	340	370	15			210	1,142
31	Pulaski	T. 35 N. R. 13 W. 17	Ojc	510	Og	325	175	20	None		24	1,072

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
32	Pulaski	T. 35 N. R. 12 W. 3	Ojc	455	Og	215	340	12	None		23	1,082
33	Pulaski	T. 35 N. R. 12 W. 8	Or	505	Og	320	365	20			61	1,113
34	Bronaugh Vernon	T. 34 N. R. 32 W. 20	Pcc	853	Or	78	195	82	15	5.5	280	871
35	Sheldon Vernon	T. 34 N. R. 31 W. 35	P	930	Or	155	185	73	2	36.5	207	932
36	Cedar	T. 34 N R. 26 W. 4	Mbk	456	Or	60	220	20	6	3.3	41	957
37	Cedar	T. 34 N. R. 26 W. 8	Mbk	850	Ce	15	200	105	2	52.0	237	963
38	Buffalo 1 Dallas	T. 34 N. R. 20 W. 28	Ojc	715	Ce	25	181	75			400	1,168
39	Dallas	T. 34 N. R. 18 W. 33	Ojc	323	Og	157	110	25			81	1,178
40	Laclede	T. 34 N. R. 13 W. 20	Ojc	700	Ce	15	272	25			454	1,180

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
41	Phelps	T. 34 N R. 9 W. 18	Or	450	Ce	10	190	40	None		275	1,160
42	Texas	T. 33 N. R. 11 W. 27	Ojc	463	Og	90	378	15			111	1,478
43	Dent	T. 33 N. R. 6 W. 30		405	Og		300	10			307	1,300
44	Bollinger	T. 33 N. R. 10 E. 30	Oc	630	Or	215	35	20			14	673
45	Liberal 1 Barton	T. 32 N. R. 33 W. 2	P	817	Or	87	160	86	3	28.3	295	892
46	Lamar 2 Barton	T. 32 N. R. 30 W. 18	Pcc	981	Og	35	247(238)	30(320)	(57)	(5.6)	575	975
47	Lamar 1 Barton	T. 32 N. R. 30 W. 30		971	Og	35	220	20(255)	(16)	(15.9)	553	957
48	Dade	T. 32 N. R. 25 W. 14	Mfg	445	Or	30	107	20			21	996
49	Polk	T. 32 N. R. 22 W. 35		475	Or	35	170	12	10	1.2	41	1,215

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	Penetration of Basal Fm. (Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
50	Polk	T. 32 N. R. 21 W. 9	Oc	294	Or	44	141	15	75	0.2	15	1,192
51	Laclede	T. 32 N. R. 12 W. 7	Ojc	722	Og	385	170	37	12	3.0	503	1,342
52	Texas	T. 32 N. R. 12 W. 11	Or	337	Og	182	90	26	62	0.4	205	1,148
53	Dent	T. 32 N. R. 5 W. 7		305	Og		230	4	None		242	1,246
54	Golden City Barton	T. 31 N. R. 29 W. 26	Mw	893	Og	148	155	150	29	5.2	400	1,060
55	Dade	T. 31 N. R. 28 W. 36	Msl	1,202	Ce	10	200	155	120	1.3	350	1,091
56	Dade	T. 31 N. R. 27 W. 5	Mw	670	Or	35	235	35			23	
57	Dade	T. 31 N. R. 26 W. 8	Mbk	455	Or	5	140	20			30	1,000

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
58	Greenfield Dade	T. 31 N. R. 26 W. 19	Mbk	1,006	Og	276	235	293	30	9.8	361	1,075
59	Walnut Grove Green	T. 31 N. R. 24 W. 11	Mw	838	Og	25	215	100	12	8.3	265	1,212
60	Wright	T. 31 N. R. 13 W. 22	Ojc	300	Or	130	102	11			240	1,277
61	Texas	T. 31 N. R. 10 W. 6	Ojc	455	Og	90	315	17	45	0.4	400	1,438
62	Reynolds	T. 31 N. R. 1 W. 8	Or	384	Og		270	35				
63	Bollinger	T. 31 N. R. 9 E. 3	Or	190	Og	65	122	5			135	991
64	Dade	T. 30 N. R. 29 W. 13		660	Or	15	92	20	None			1,119
65	Dade	T. 30 N. R. 28 W. 5	Mw	705	Or	85	112	30			24	1,101
66	Dade	T. 30 N. R. 27 W. 35	Mw	600	Or	35	185	20			36	1,077

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
67	Ash Grove Greene	T. 30 N. R. 24 W. 21	Mbk	725	Og	40	60	115	17	6.8	255	1,070
68	Marshfield 1 Webster	T. 30 N. R. 18 W. 10	Oc	940	Ce	10	200	173	80	2.2	300	1,487
69	Webster	T. 30 N. R. 18 W. 11	Oc	965	Og	405	190	175			80	1,480
70	Wright	T. 30 N. R. 13 W. 12	Ojc	400	Og	60	256	7	36	0.2	40	1,410
71	Texas	T. 30 N. R. 11 W. 17	Oc	481	Og	12	274	10	20	0.5	50	1,462
72	Bollinger	T. 30 N. R. 10 E. 5	Oc	600	Or	160	125	125	60	2.1	38	570
73	Bollinger	T. 30 N. R. 10 E. 6	Oc	635	Og	135		60	77	0.8		
74	Jasper	T. 19 N. R. 33 W. 10	Mw	1,245	Og	345	142	198	30	6.6	410	
75	Jasper	T. 29 N. R. 33 W. 10	Mw	909	Or	105	120	207	150	1.4	400	

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
76	Lawrence	T. 29 N. R. 27 W. 23		1,075	Ce	10	164	80			310	1,301
77	Lawrence	T. 29 N. R. 25 W. 6	P	775	Or	120	13	55	20	2.7	143	1,050
78	Lawrence	T. 29 N. R. 25 W. 14	Mw	764	Or	150	165	36	19	1.9	220	1,222
79	Green	T. 29 N. R. 22 W. 10	Mbk	1,275	Ce	70	345	602	65	9.3	405	1,298
80	Green	T. 29 N. R. 22 W. 29	Mbk	1,216	Ce	12	233	350	17	20.6	389	1,258
81	Green	T. 29 N. R. 21 W. 17	Mbk	1,256	Ce	72	340	430	26	16.5	401	1,333
82	Green	T. 29 N. R. 20 W. 6	Mr	723	Og	85	120	50			115	1,330
83	Hartville Wright	T. 29 N. R. 15 W. 1	Ojc	785	Ce	20	217	99	12	8.2	364	1,402
84	Wright	T. 29 N. R. 14 W. 6	Ojc	300	Og	30	165	10			128	1,416

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
85	Wright	T. 29 N. R. 13 W. 22	Ojc	208	Or	23	160	4			100	
86	Texas	T. 29 N. R. 12 W. 10	Ojc	300	Or	100	34	25	9	2.8	18	1,308
87	Wright	T. 29 N. R. 12 W. 33	Oc	675	Og	135	136	75	94	0.8	82	1,479
88	Jasper	T. 28 N. R. 33 W. 6	Mw	950	Og	5	158	23	17	1.4	425	1,030
89	Jasper	T. 28 N. R. 33 W. 8	P	925	Og	30	44	(330)	297	(1.1)	390	900
90	Webb City Jasper	T. 28 N. R. 32 W. 5		857	Og		100	170	220	0.8	290	
91	Jasper	T. 28 N. R. 32 W. 13	Mw	1,230	Ce	25	55	340	256	1.3	450	995
92	Jasper	T. 28 N. R. 32 W. 34	Mw	945	Og	15	170	100			290	1,042
93	Carthage 1 Jasper	T. 28 N. R. 31 W. 5	Mw	1,250	Ce	25	110	360	290	1.2	430	1,007

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
94	Jasper	T. 28 N. R. 31 W. 33	Mbk	805	Or	150	45	90			330	997
95	Lawrence	T. 28 N. R. 27 W. 28	Mbk	720	Or	95	75	30	None		301	1,205
96	Lawrence	T. 28 N. R. 26 W. 30	Mr	891	Og	210	36	300	63	4.8	247	1,181
97	Mt. Vernon 2 Lawrence	T. 28 N. R. 26 W. 31	Mbk	1,115	Ce	10	129	450	37	12.3	266	1,250
98	Lawrence	T. 28 N. R. 25 W. 17	Mn	610	Og	50	99	32	12	2.7	150	1,280
99	Greene	T. 28 N. R. 24 W. 6	Mw	1,210	Ce	5	(140)	(472)	(52)	(9.0)	181	1,302
100	Republic 2 Greene	T. 28 N. R. 23 W. 20	Mbk	1,189	Ce	20	200	242	5	48.5	350	1,303
101	Greene	T. 28 N. R. 22 W. 7	Mbk	1,080	Og	375	39	252	44	5.8	313	1,140
102	Green	T. 28 N. R. 22 W. 11	Mbk	1,230	Ce	15	170	400			410	1,263

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
103	Greene	T. 28 N. R. 22 W. 13	Mbk	1,235	Ce	20	152	165	3	55.0	325	1,260
104	Rogersville Webster	T. 28 N. R. 19 W. 19	Mbk	1,260	Og	360	245	60	None		175	1,485
105	Webster	T. 28 W. R. 18 W. 2	Mn	750	Og	55	230	70	170	0.4	246	1,667
106	Fordland Webster	T. 28 N. R. 18 W. 6	Mr	700	Og	60	190	95	130	.7	201	1,604
107	Seymour 2 Webster	T. 28 N. R. 17 W. 2		1,225	Ce	85	296	232	115	2.0	313	1,653
108	Wright	T. 28 N. R. 14 W. 13	Oc	600	Og	105	225	11			280	1,483
109	Wright	T. 28 N. R. 13 W. 10	Ojc	300	Og	67	32	22	40	0.5	42	1,278
110	Mt. Grove 2 Wright	T. 28 N R. 12 W. 9	Oc	1,036	Ce	60	160	206	180	1.1	87	1,457
111	Cabool 3 Texas	T. 28 N R. 11 W. 12	Or	700	Ce	45	114	165	76	2.2	410	1,269

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
112	Newton	T. 27 N. R. 33 W. 34	Mr	710	Or	150	Flowed	175+				915
113	Jasper	T. 27 N. R. 33 W. 3	Mw	1,300	Ce	35	90	150	135	1.1	452	996
114	Duenweg 2 Jasper	T. 27 N. R. 32 W. 10	Mbk	1,228	Og	298	90	100	92	1.1	342	1,067
115	Sarcoxie Jasper	T. 27 N. R. 29 W. 8	Mw	1,258	Ce	20	104	275	35	7.9	446	1,172
116	Sarcoxie Jasper	T. 27 N. R. 29 W. 17	Mw	1,059	Og	20	100	100	34	3.0	102	1,180
117	Christian	T. 27 N. R. 24 W. 10	Mbk	804	Or	155	150	30			303	1,364
118	Christian	T. 27 N. R. 24 W. 23		875	Og	5	150	20+				1,359
119	Christian	T. 27 N. R. 21 W. 21	Mfg	635	Or	125	Flowed	225	Flowed		155	1,110
120	Christian	T. 27 N. R. 20 W. 25	Mr	902	Og	20	190	16	135	0.1		1,398

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
121	Sparta Christian	T. 27 N. R. 20 W. 36	Mbk	1,100	Og	155	269	143(100)	66(40)	2.2(2.5)	279	1,423
122	Douglas	T. 27 N. R. 13 W. 7		425	Or		200	4				1,360
123	Douglas	T. 27 N R. 12 W. 35	Ojc	495	Og	295	357	4			66	1,228
124	Douglas	T. 27 N. R. 11 W. 14	Or	700	Ce	20	165	23	6	3.8	500	1,254
125	Willow Spgs 2 Howell	T. 27 N. R. 9 W. 29		960	Ce	5		90				1,336
126	Shannon	T. 27 N. R. 4 W. 11	Or	675	Og	516	280	30	None		318	1,066
127	Wayne	T. 27 N. R. 7 E. 5	Or	350	Og	165	150	20	150	0.1	180	540
128	Wayne	T. 27 N. R. 7 E. 31	Qal	250	Og		130	15			205	509
129	Newton	T. 26 N. R. 32 W. 6	Mw	905	Or	140	140	66	None			1,033

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
130	Diamond 1 Newton	T. 26 N. R. 31 W. 10	Mbk	1,250	Ce	25	40	30	85	0.3	518	1,180
131	Newton	T. 26 N. R. 31 W. 15	Mw	975	Or	150	130	65	8.5	8.1	468	1,125
132	Newton	T. 26 N. R. 30 W. 5	Mbk	832	Or	90	18	122			266	1,178
133	Pierce City 2 Lawrence	T. 26 N. R. 28 W. 21	Mbk	1,160	Og	215	38	320	69	4.6	409	1,196
134	Pierce City 1 Lawrence	T. 26 N R. 28 W. 21	Mbk	1,000	Og	70	120	233			295	1,290
135	Monett 1 Lawrence	T. 26 N. R. 27 W. 30	Mg	1,200	Ce	25	184	350	163	2.1	415	
136	Lawrence	T. 26 N. R. 26 W. 10		1,196	Ce	20	180	520	73	7.1	421	1,362
137	Aurora 1 Lawrence	T. 26 N. R. 26 W. 12	Mbk	1,240	Ce	5	195	250	167	1.5	327	1,371
138	Stone	T. 20 N. R. 24 W. 33	Mkb	895	Og	45	126	75	159	0.49	316	1,242

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	Penetration of Basal Fm. (Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
139	Ava 3 Douglas	T. 26 N. R. 16 W. 11	Ojc	838	Ce	10	248(238)	100(178)	(17)	(10.5)	140	1,272
140	Ava 1-b Douglas	T. 26 N. R. 16 W. 13	Ojc	903	Ce	25	290	250				1,340
141	USCCC-2 Howell	T. 26 N. R. 10 W. 16	Or	780	Ce	55	240	25	40	0.6	650	
142	Butler	T. 26 N. R. 5 E. 34	Or	630	Og	530	150	20	None			580
143	Butler	T. 26 N. R. 7 E. 17	Og	550	Og		149	25	327	0.1		540
144	Seneca 3 Newton	T. 25 N. R. 34 W. 35		950	Or		20	175	31	5.6		860
145	Seneca 5 Newton	T. 25 N. R. 34 W. 35	Mw	1,435	Ce	60	236	335	66	5.1	410	1,004
146	Newton	T. 25 N R. 32 W. 27	Mw	950	Or	80	200	20	3	6.7	49	1,204
147	Newton	T. 25 N. R. 31 W. 7		800	Or	100	40	150			12	1,046

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
148	Newton	T. 25 N. R. 31 W. 19	Mg	1,210	Ce	40	28	390			386	1,004
149	Neosho 1 Newton	T. 25 N. R. 31 W. 19	Mr	977	Og	270		350			350	1,038
150	Granby 1 Newton	T. 25 N. R. 30 W. 6		968	Or		113	150+			337	1,105
151	Green	T. 25 N. R. 27 W. 19	Mbk	770	Or	45	135	50			32	1,413
152	Stone	T. 25 N. R. 23 W. 18		630	Or	65	28	10			28	1,118
153	Oregon	T. 25 N. R. 3 W. 6	Or	450	Og	160	190	40	14	2.9		963
154	Butler	T. 25 N. R. 6 E. 29	Or	450	Og	310	45	40	25	1.6	150	440
155	Newton	T. 24 N. R. 34 W. 8	Mbk	1,260	Og	310	69	505	112	4.5	300	846
156	Newton	T. 24 N. R. 32 W. 4	Mbk	1,450	Ce	80	45	243			479	1,190

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
157	Newton	T. 24 N. R. 30 W. 32	Mg	910	Or	140		0.3	Flowed		300	1,150
158	Wheaton Barry	T. 24 N. R. 29 W. 27	Mbk	1,008	Og	58	120	50	80	0.6	408	1,387
159	Purdy Barry	T. 24 N. R. 28 W. 2	Mbk	931	Og	22	105	260	75	3.5	392	1,480
160	Stone	T. 24 N. R. 23 W. 26	Mg	1,005	Og	55	322	75	121	0.62	365	1,349
161	Taney	T. 24 N. R. 20 W. 20	Oc	500	Or	160	165	24	None		24	958
162	Taney	T. 24 N. R. 20 W. 32	Oc	1,015	Ce	15	295	152	25	6.1	256	946
163	Taney	T. 24 N. R. 18 W. 13	Oc	598	Og	90	250	40	23	1.7	206	1,088
164	Clark	T. 24 N. R. 11 W. 11	Or	800	Og	495	700	20	None		370	1,058
165	West Plains 3 Howell	T. 24 N. R. 8 W. 21	Ojc	851	Og	475	89	85	None			958

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
166	Alton 1 Oregon	T. 24 N. R. 4 W. 33	Ojc	970	Og	580	75	33	115	0.3	800	890
167	Oregon	T. 24 N. R. 2 W. 15	Ojc	800	Og	500	150	22			330	774
168	Ripley	T. 24 N. R. 1 W. 28	Or	375	Og	155	70	20	170	0.1	202	736
169	Butler	T. 24 N. R. 6 E. 9	Or	200	Or		70	15			80	357
170	Butler	T. 24 N. R. 6 E. 18	Or	400	Og	275	70	60			175	409
171	Goodman 2 McDonald	T. 23 N. R. 32 W. 8	Mbk	1,290	Og	225	296	140	14	10.0	430	1,261
172	Exeter Barry	T. 23 N. R. 28 W. 34	Mg	990	Or	170	81(190)	200	126	1.6	334	1,555
173	Cassville 1 Barry	T. 23 N. R. 27 W. 29	Mbk	1,200	Og	225	144	250	62	4.0	300	1,326
174	Cassville 3 Barry	T. 23 N. R. 27 W. 29	Mg	1,370	Ce	20	170(257)	200(200)	73(63)	2.7(3.2)	348	1,309

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
175	Stone	T. 23 N. R. 23 W. 7	Oc	854	Og	230	79	198	11	18.0	203	
176	Taney	T. 23 N. R. 21 W. 12	Oc	425	Or	150	137	60			120	840
177	Branson 3 Taney	T. 23 N. R. 21 W. 32	Oc	1,085	Ce	10	294	129	180	0.7	460	955
178	Ozark	T. 23 N. R. 16 W. 4	Oc	402	Or	52	220	30	40	0.7	212	1,061
179	Howell	T. 23 N. R. 9 W. 33	Oc	450	Or	80	100	30	80	0.4	200	1,101
180	Thayer 3 Oregon	T. 23 N. R. 5 W. 31	Ojc	535	Og	55	200	240	110	2.2	250	698
181	Ripley	T. 23 N. R. 2 E. 21	Or	275	Og	190	60	20			125	471
182	Ripley	T. 23 N. R. 2 E. 34	Ojc	301	Og	31	46	40	None		150	390
183	Butler	T. 23 N. R. 5 E. 9	Og	290	Og		60	46			160	380

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
184	McDonald	T. 22 N. R. 33 W. 12	Mr	986	Og	125	36	200	Flowed		150	892
185	McDonald	T. 22 N. R. 33 W. 14		1,045	Or	115	245	25	10	2.5	85	1,137
186	McDonald	T. 22 N. R. 33 W. 36	Mr	900	Or	150		120	Flowed			838
187	Pineville-3 McDonald	T. 22 N. R. 32 W. 33	Mbk	1,400	Og	285	135	150	174	0.9	454	1,045
188	Roaring River-3 Barry	T. 22 N. R. 27 W. 35	Oc	847	Og	85	120	62	20	3.1		1,110
189	Barry	T. 22 N. R. 25 W. 13	Oc	717	Og	116	335	12	17	0.7	415	1,165
190	Barry	T. 22 N. R. 25 W. 35	Oc	525	Or	185	160	21	7		263	1,046
191	Stone	T. 22 N. R. 23 W. 23	Oc	700	Or	145	160	28	20	1.4	200	988

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
192	Sch of Ozarks 3 Taney	T. 22 N. R. 21 W. 7	Oc	1,100	Ce	25	218	150	95	1.6	363	927
193	Hollister 4 Taney	T. 22 N. R. 21 W. 9	Oc	990	Ce	10	148	237	30	7.9	285	826
194	Hollister 3 Taney	T. 22 N. R. 21 W. 9	Oc	449	Or	173	42	30			150	740
195	Taney	T. 22 N. R. 17 W. 9	Oc	675	Or	105	340	20	40	0.5	460	1,072
196	Gainsville Ozark	T. 22 N. R. 13 W. 7	Ojc	860	Ce	15	63	115	93	1.2	383	760
197	Oregon	T. 22 N. R. 6 W. 5	Oc	635	Og	125	168	75			352	969
198	Thayer Oregon	T. 22 N. R. 5 W. 30	Ojc	302	Og	30	7	200	90	2.2	100	544
199	Ripley	T. 22 N. R. 1 W. 1	Oc	350	Or	65	42	25			150	627
200	McDonald	T. 21 N. R. 34 W. 27		991	Or	35	100	20	160	0.1		1,020

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
201	S.W. City 1 McDonald	T. 21 N. R. 34 W. 33	Mr	989	Og	40	23	78	38	2.1	269	940
202	Noel 5 McDonald	T. 21 N. R. 33 W. 15		1,100	Ce	45		300	140	2.1	80	832
203	Noel-2 McDonald	T. 21 N. R. 33 W. 22		850	Or	150		56	Flowed		99	836
204	D.W. Sibley Benton	T. 21 N. R. 33 W. 22	Mbn	900	Og	30		30				
205	Pea Ridge Benton	T. 21 N. R. 29W. 31	Mbn	1,769	Og		295.97	185	94.8	1.95	410	1,406
206	Seligman Barry	T. 21 N. R. 28 W. 23	Mbk	1,693	Og	415	570	200	60	3.3	455	1,565
207	Holiday Isl 2 Carroll	T. 21 N. R. 26 W. 15	Oc	1,128	Og	82		500	60	8.33	500	
208	Holiday Isl 1 Carroll	T. 21 N. R. 26 W. 17	Oc	1,063	Og	81	100	600	68	8.82		1,010
209	Barry	T. 21 N. R. 26 W. 21	Oc	653	Og	8	80	22			225	978

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec Capacity	Casing	Elevation
210	Holiday Isl 4 Carroll	T. 21 N. R. 26 W. 27	Oc	1,880	Ce	10	520	502	85	5.9	531	1,520
211	Barry	T. 21 N. R. 25 W. 2	Oc	450	Or	170	80	26.5	45	0.6	252	985
212	Barry	T. 21 N. R. 25 W. 6	Oc	340	Or	45	80	15+			250	937
213	Stone	T. 21 N. R. 22 W. 6	Mr	950	Or	125	468	25	18	1.4	28	1,256
214	Taney	T. 21 N. R. 22 W. 12	Oc	800	Og	40		90	None		42	1,020
215	Omaha Boone	T. 21 N. R. 21 W. 27	Mbn	1,315	Or			52			64	
216	Diamond City Boone	T. 21 N. R. 18 W. 20	Oc	602	Or			60				
217	Diamond City Boone	T. 21 N. R. 18 W. 20	Oc	760	Or			140				
218	Ozark Marion	T. 21 N. R. 16 W. 12	Oc	1,080	Or		130	350				775

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
219	Oakland Rec Area Marion	T. 21 N. R. 15 W. 6	Oc	885	Og	276	129	100	200	0.5	104	771
220	Mammoth Spring Fulton	T. 21 N. R. 5 W. 7	Oc	350	Or	235	70	230	50	4.6		573
221	Gravette 2 Benton	T. 20 N. R. 33 W. 11	Mbn	1,603	Ce	23	170	140			400	1,199
222	Gravette 3 Benton	T. 20 N. R. 33 W. 14	Mbn	1,610	Ce	1		300				
223	East of Avoca Benton	T. 20 N. R. 29 W. 13	Mbn	1,968	Ce		325	230	50	4.6		1,432
22[illegible]	Lost [illegible]ridge Village Benton	T. 20 N. R. 28 W. 13	Oc	1,625	Ce	77	346	240	115	2.08	504	1,034
225	Eureka Spgs Carroll	T. 20 N. R. 26 W. 16	Oc	1,332	Og		178.65	500				1,232
226	Eureka Spgs Carroll	T. 20 N. R. 26 W. 16	Oc	1,418	Ce	55	259	250	358.5	0.69	407	1,250

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
227	Brown Oil Tool Marion	T. 20 N. R. 15 W. 8	Oc	775	Or	132	127.52	100	375	0.26	100	775
228	Viola Fulton	T. 20 N. R. 9 W. 18	Oc	1,250	Or		126	140	40	3.5	900	800
229	Decatur Benton	T. 19 N. R. 33 W. 11	Mpb	1,720	Og		258	350	99.3	3.52	600	1,200
230	Decatur Benton	T. 19 N. R. 33 W. 13	Mpb	1,450	Og	10	136	250	264	0.94		1,250
231	Peterson Industries Benton	T. 19 N. R. 32 W. 11	Mpb	1,723	Ce	88	380	300	125	2.4	435	1,235
232	Rogers Benton	T. 19 N. R. 29 W. 18	Mbn	1,662	Og	355		500	674	0.92		
233	City of Green Forest Carroll	T. 19 N. R. 23 W. 4	Mpb	1,587	Og	7	230	70	583	0.11		1,349
234	City of Green Forest Carroll	T. 19 N. R. 23 W. 8	Mpb	2,300	Ce		277.24	200			110	1,325

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
235	Bergman Boone	T. 19 N. R. 19 W. 8	Mbn	1,725	Og	205	355	150	14	10.7	215	1,285
236	Yellville Marion	T. 19 N. R. 16 W. 33	Oc	753	Or		328.4	60				840
237	Summit Marion	T. 19 N. R. 16 W. 32	Oc	1,520	Ce	82		61	195	0.3		
238	Flippin Marion	T. 19 N. R. 15 W. 20	Oc	900	Or		87.12	80				630
239	Gassville 1 Baxter	T. 19 N. R. 14 W. 28	Oc	1,400	Og	548	122	581	184	3.15		670
240	Cotter 2 Baxter	T. 19 N. R. 14 W. 29	Oc	1,625	Ce	177	284	400	132	3.03		720
241	Mtn Home 2 Baxter	T. 19 N. R. 13 W. 9	Oc	1,505	Og	555	167	185	53	3.49		740
242	Cherokee Village Sharp	T. 19 N. R. 5 W. 21	Oc	1,555	Ce	200	210	280	470	0.59		750
243	Douglas Adcock Benton	T. 18 N. R. 32 W. 12	Mbn	1,320	Or	120		150			1,320	

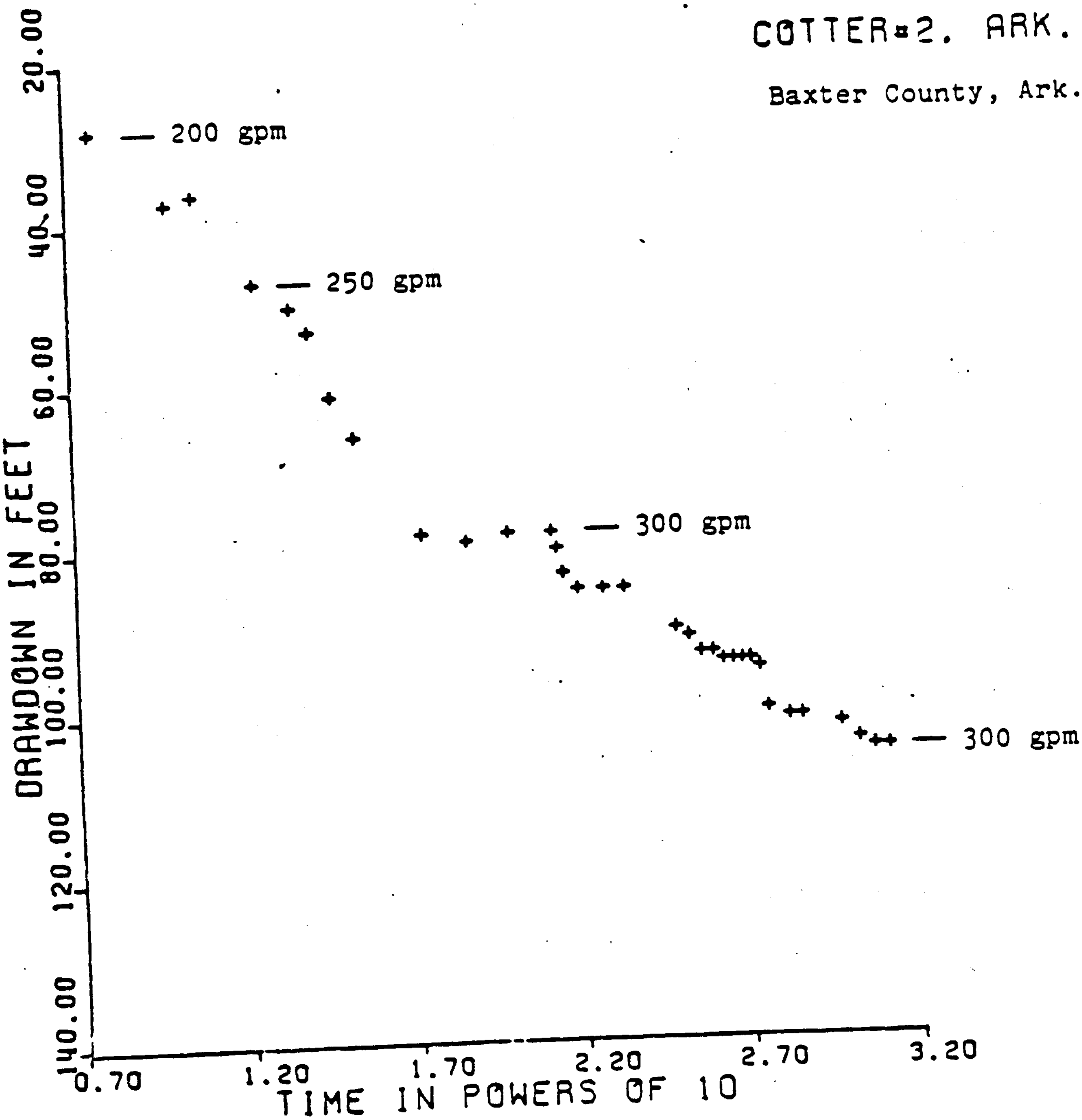
Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
244	Bellefonte Boone	T. 18 N. R. 19 W. 19	Mbn	1,649	Or		141	96	115	.83		1,150
245	Ark Highway Dept Boone	T. 18 N. R. 19 W. 19	Mbn	2,000	Og	415	123.6	88	198	0.75	972	1,050
246	Franklin Izard	T. 18 N. R. 7 W. 31	Oct	1,100	Or			30				
247	Ash Flat Sharp	T. 18 N. R. 6 W. 10	Oct	1,545	Og	615	173	150	28	5.4		555
248	Plus Poultry Benton	T. 17 N. R. 33 W. 6	Mbn	1,515	Og	90	141	396			300	1,009
249	Tontitown Washington	T. 17 N. R. 31 W. 1	Mbn	1,416	Or	166		60			350	
250	East of Springdale Benton	T. 17 N. R. 29 W. 9	Mbn	2,076	Ce	106		250	185	1.35		
251	Marble Falls Newton	T. 17 N. R. 20 W. 21	Mbn	2,573	Ce	43	355	250	140	1.8	503	1,344

Well #	Name County	Location	Surface Formation	Depth	Penetration of Basal Fm. (Fm.)	(Ft.)	Static Water Level	Yield GPM	Draw Down	Spec. Capacity	Casing	Elevation
252	Valley Spgs Boone	T. 17 N. R. 19 W. 3	Mbn	2,050	Og		332	200	157	1.27		1,043
253	Lake Wedington Washington	T. 16 N. R. 32 W. 4	Mbn	1,815	Ce	45	100.6	26			253	1,135
254	Wedington Woods Washington	T. 10 N. R. 31 W. 7	Mbn	1,500	Or			60	140	0.42		
255	Big Flat Baxter	T. 16 N. R. 13 W. 30	Mbn	2,603	Or	243	656	54	237	0.23	208	1,305
256	J.W. Jrissom Washington	T. 15 N. R. 31 W. 17	Mbn	2,097	Ce		150	43	95	0.45	30	1,140
257	Marshall Searcy	T. 15 N. R. 16 W. 25	Mbn	2,415	Og	75	206	55				1,100

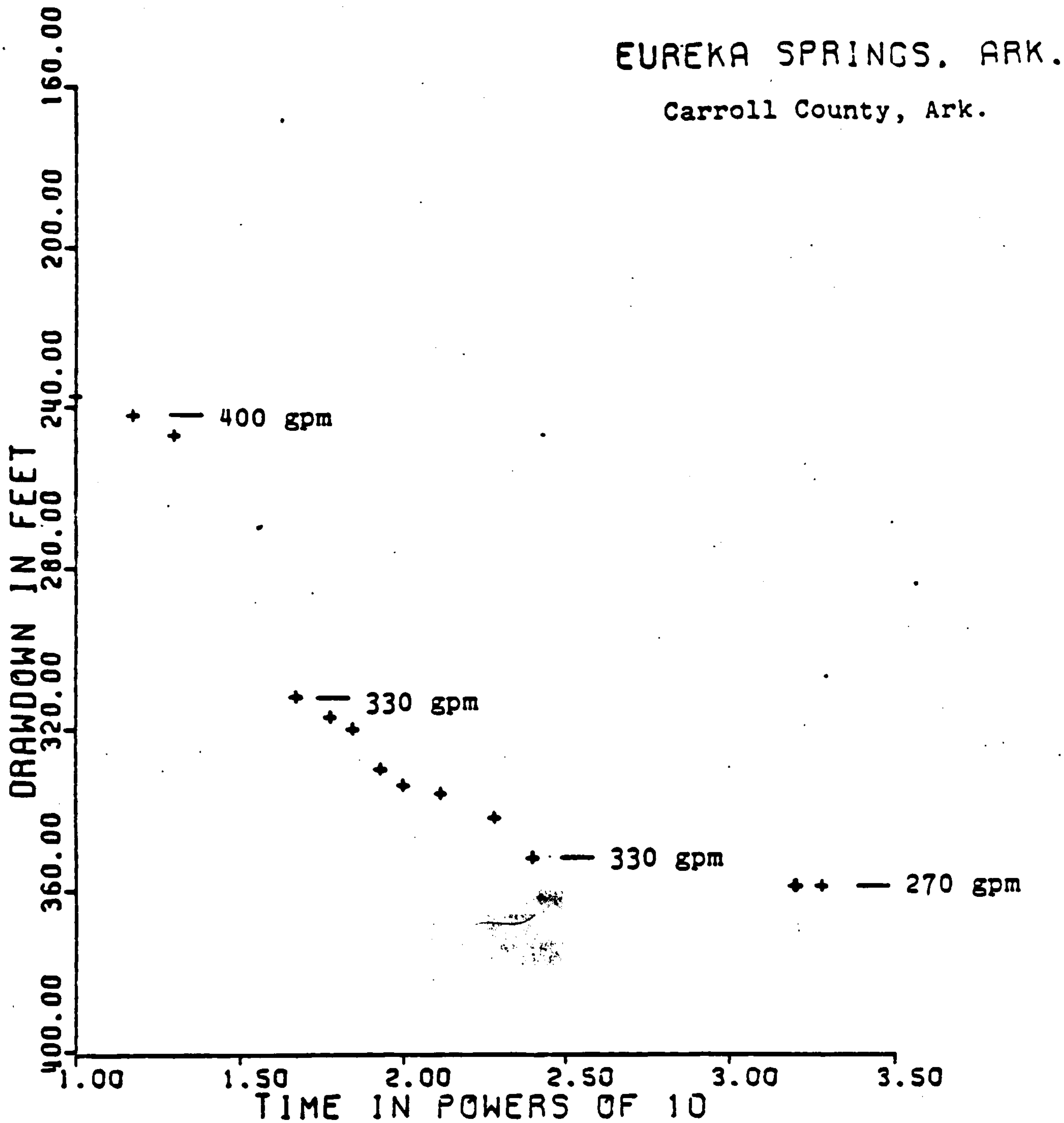
Appendix B

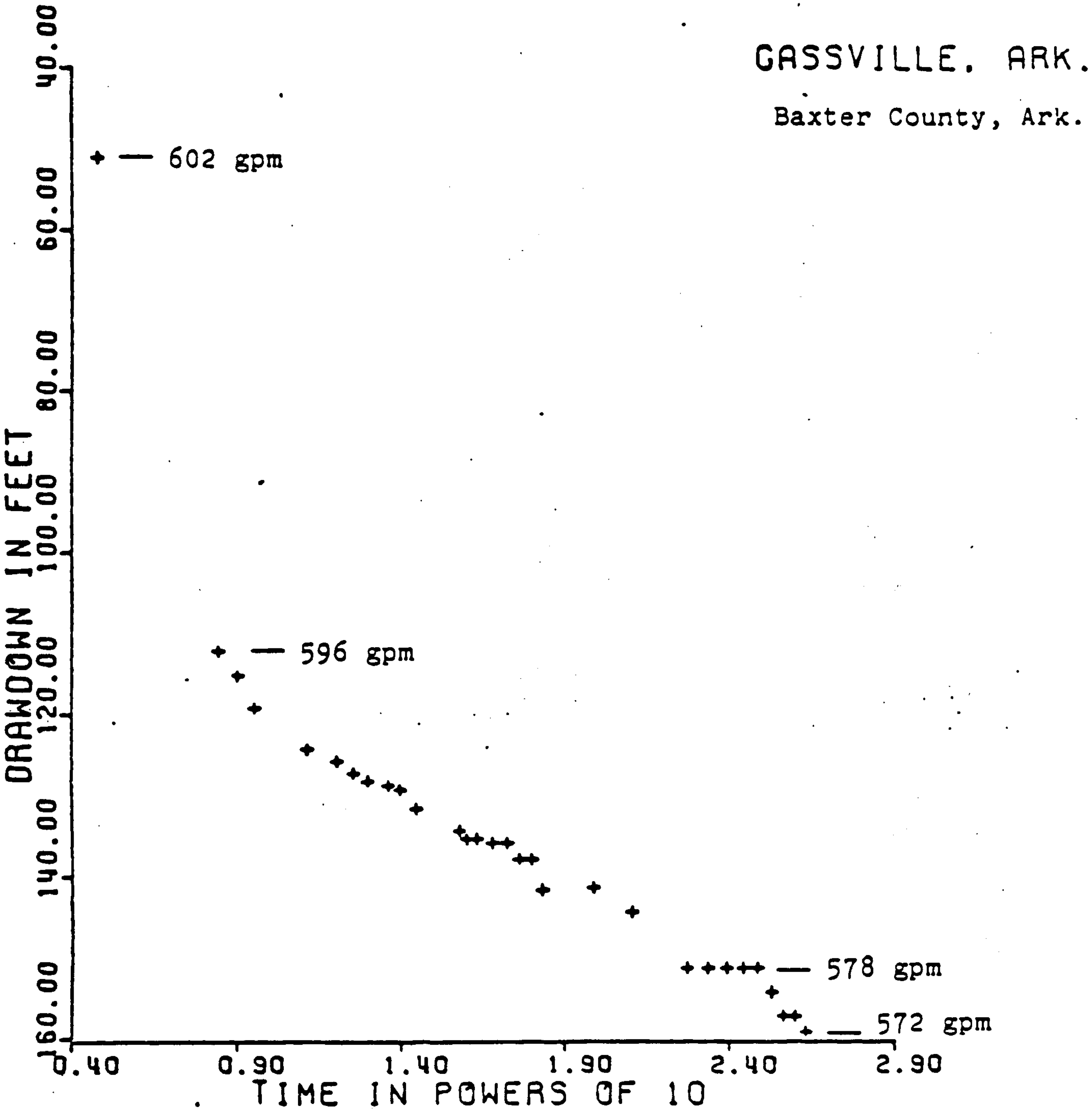
Graphs of drawdown versus time
for selected wells penetrating
the Roubidoux and Gasconade Formations

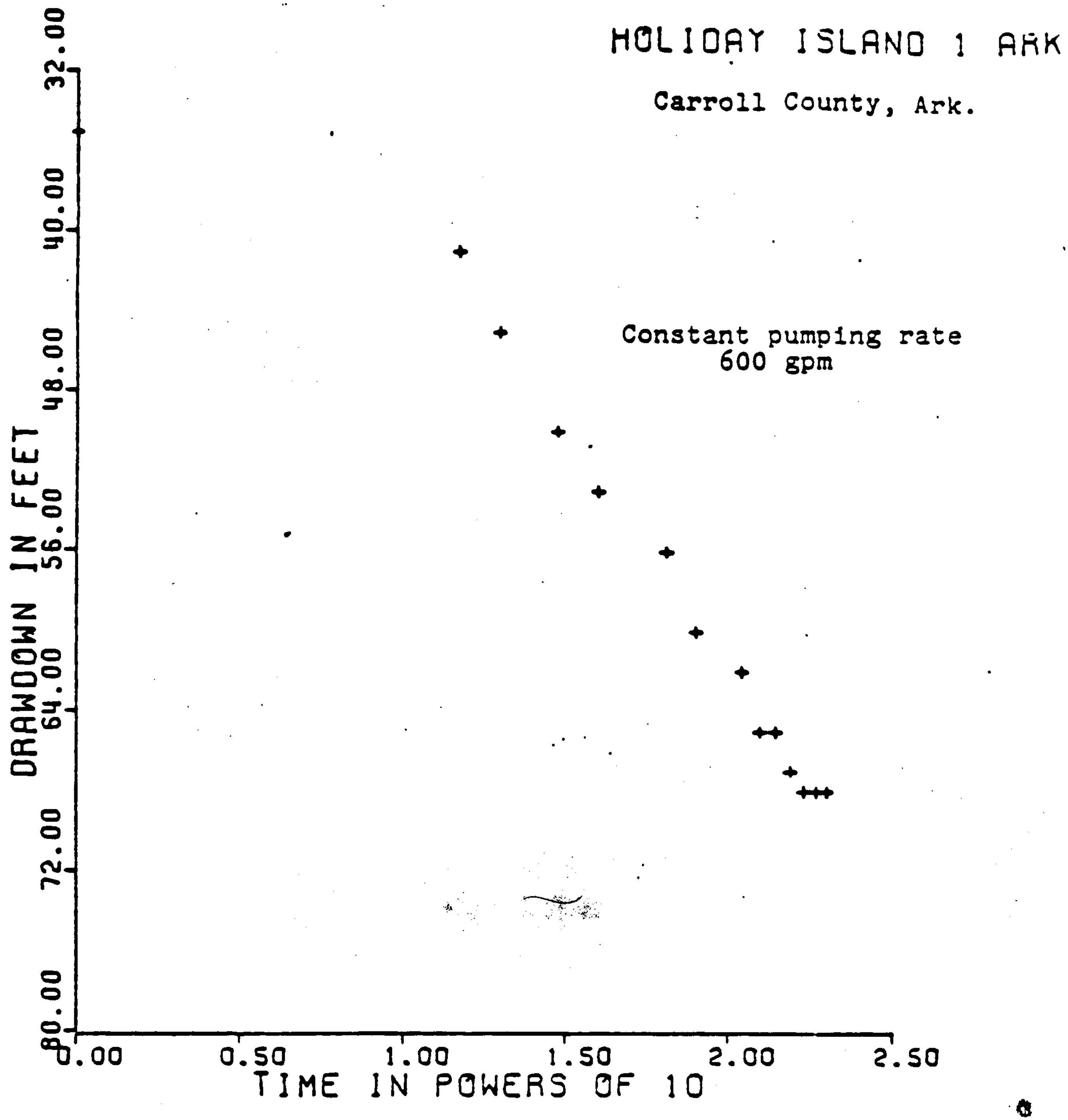
Time (minutes) in powers of ten

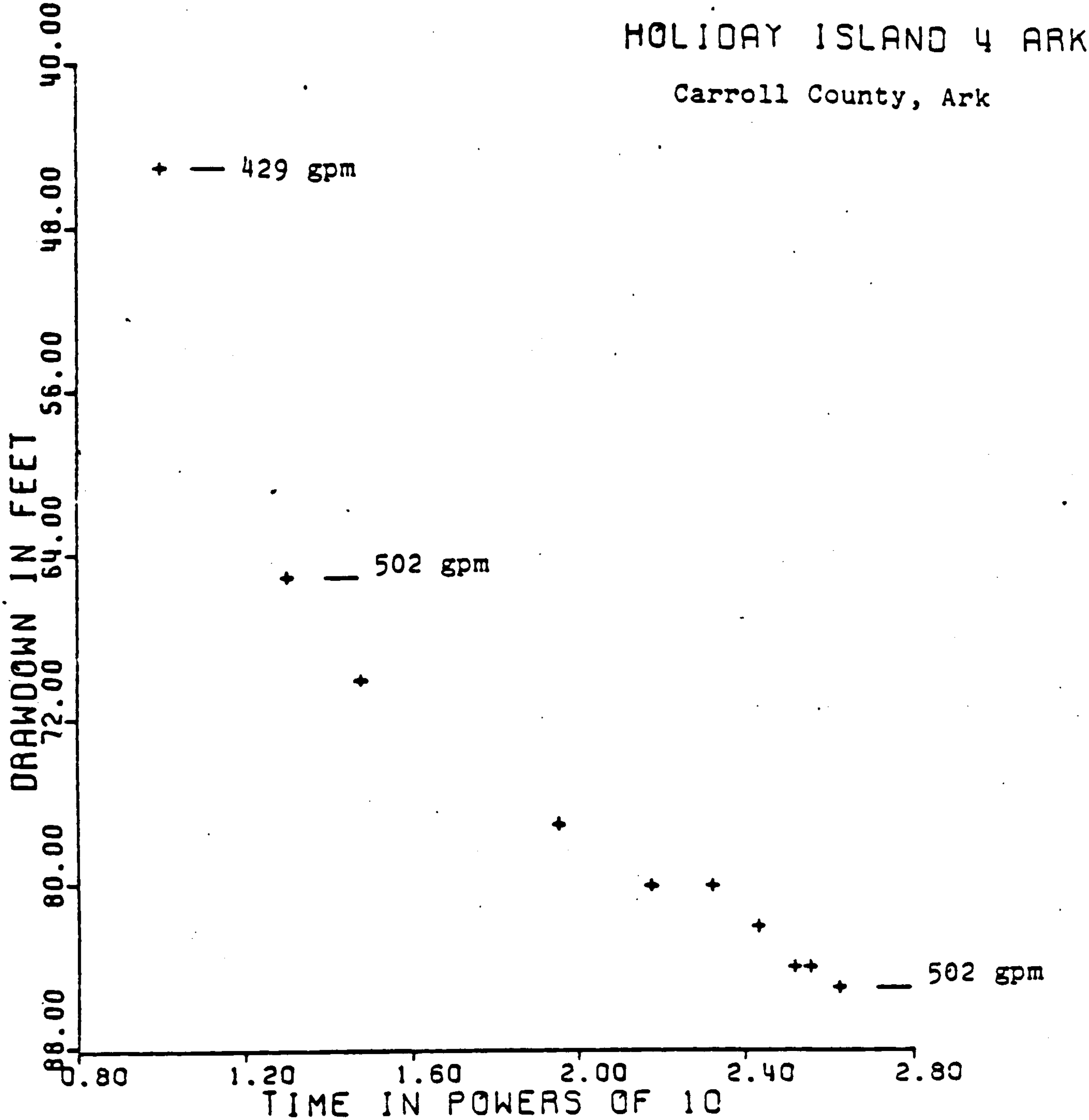


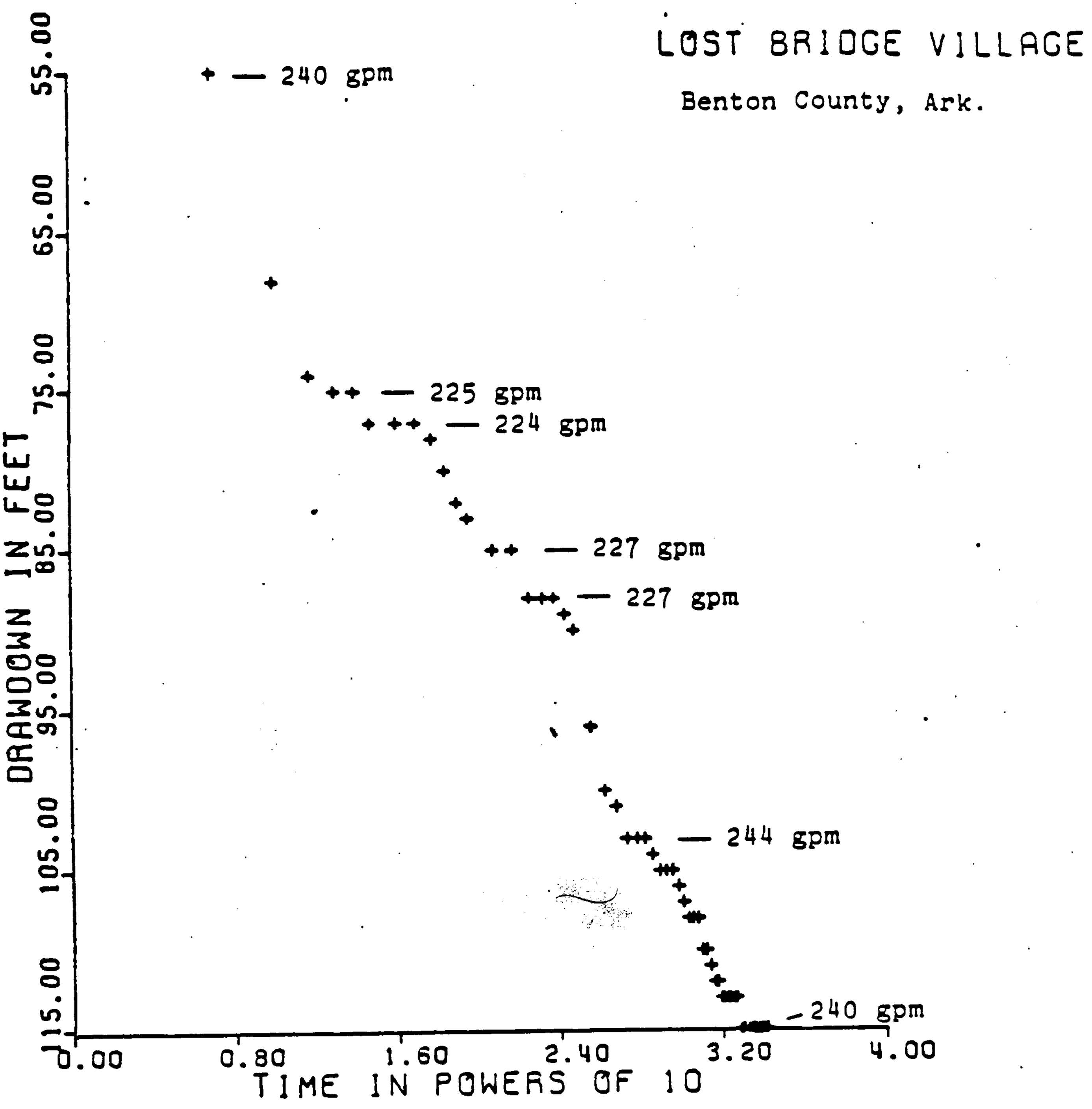
COTTER=2. ARK.
Baxter County, Ark.
200 gpm
250 gpm
300 gpm
300 gpm
DRAWDOWN IN FEET
20.00
40.00
60.00
80.00
100.00
120.00
140.00
0.70
1.20
1.70
2.20
2.70
3.20
TIME IN POWERS OF 10


EUREKA SPRINGS, ARK.
Carroll County, Ark.
DRAWDOWN IN FEET
160.00
200.00
240.00
280.00
320.00
360.00
400.00
400 gpm
330 gpm
330 gpm
270 gpm
1.00
1.50
2.00
2.50
3.00
3.50
TIME IN POWERS OF 10

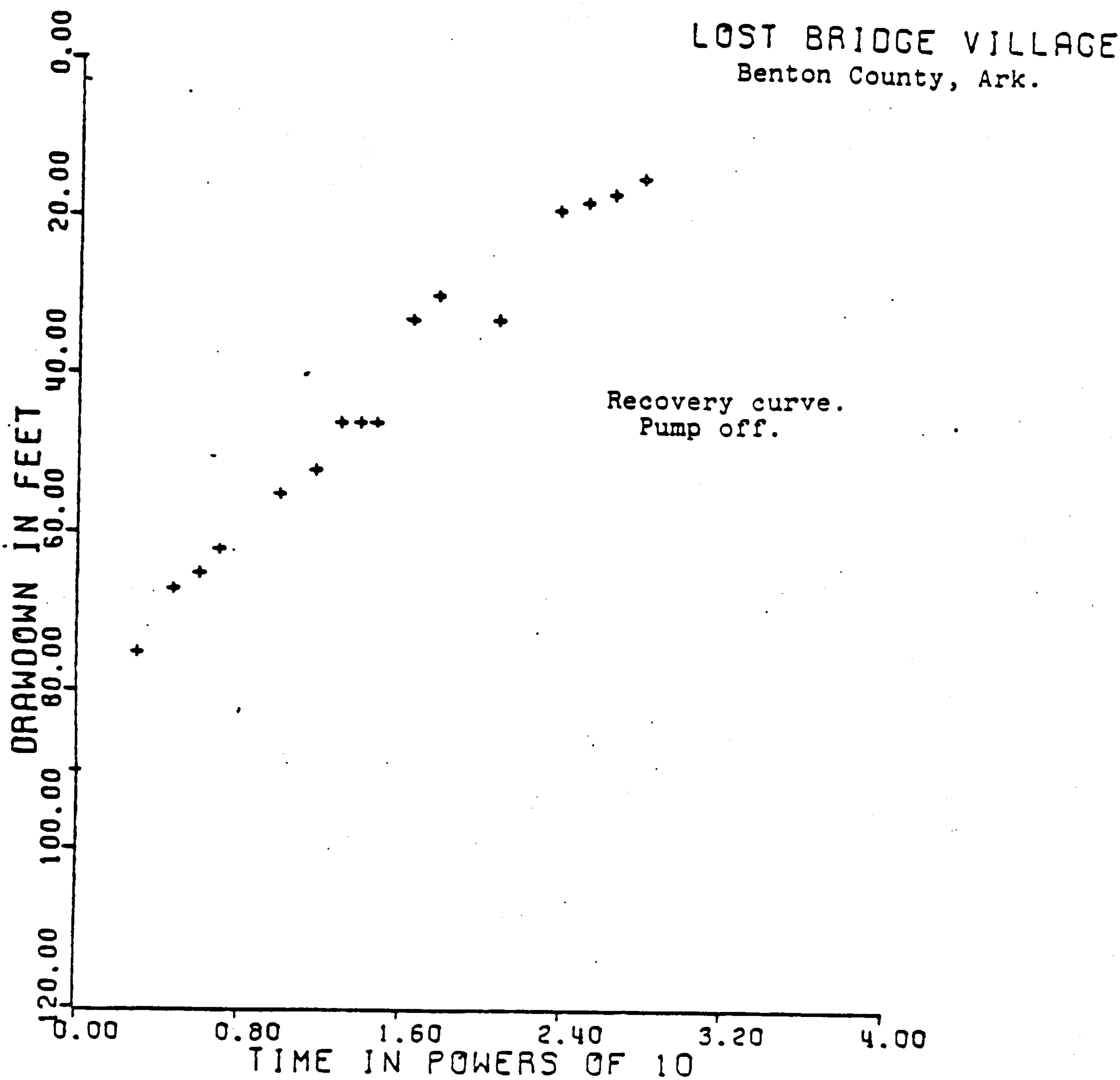

GASSVILLE, ARK.
Baxter County, Ark.
602 gpm
596 gpm
578 gpm
572 gpm
DRAWDOWN IN FEET
40.00
60.00
80.00
100.00
120.00
140.00
160.00
0.40
0.90
1.40
1.90
2.40
2.90
TIME IN POWERS OF 10

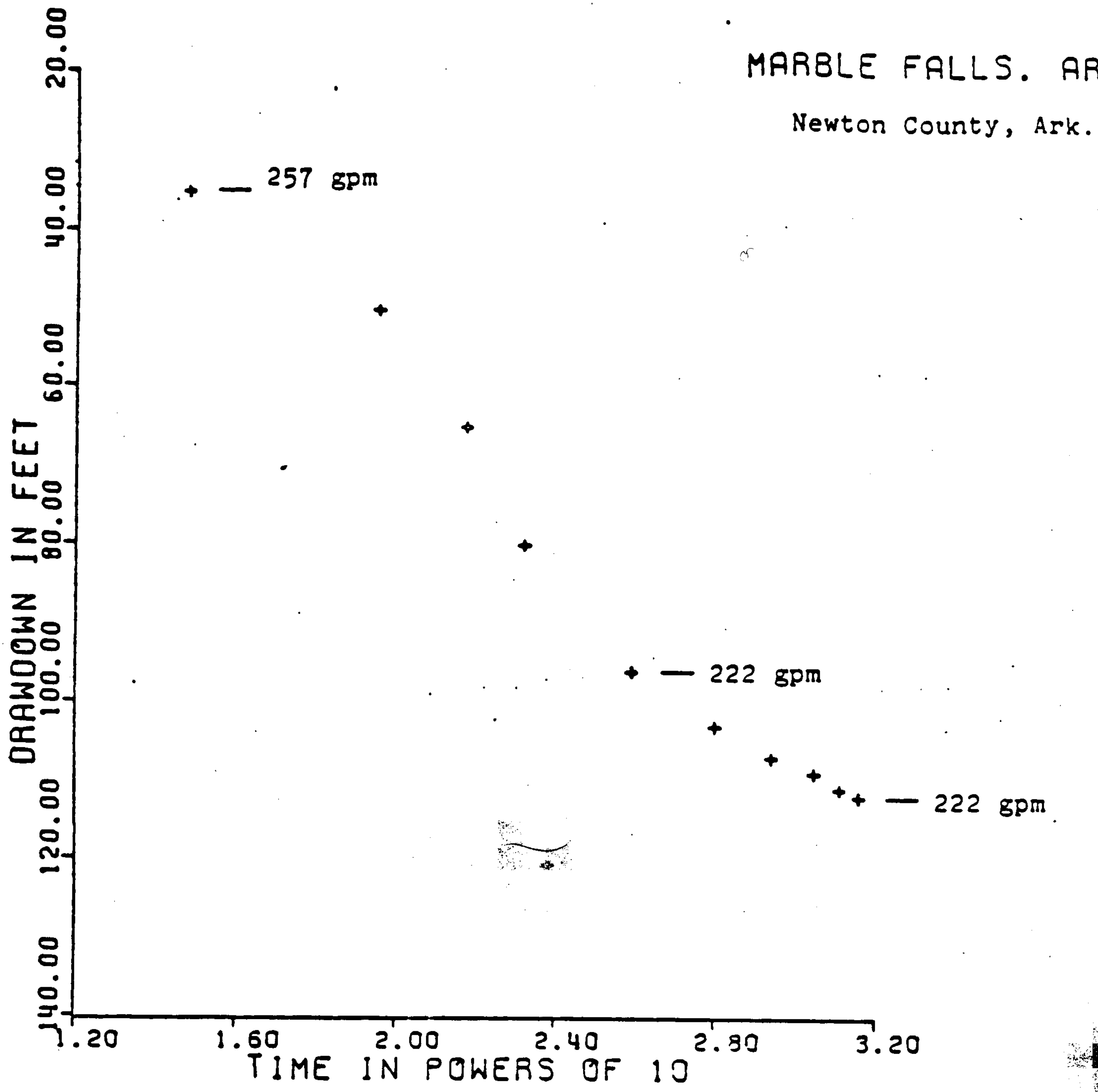

HOLIDAY ISLAND 1 ARK
Carroll County, Ark.
Constant pumping rate
600 gpm
DRAWDOWN IN FEET
32.00
40.00
48.00
56.00
64.00
72.00
80.00
0.00
0.50
1.00
1.50
2.00
2.50
TIME IN POWERS OF 10


HOLIDAY ISLAND 4 ARK
Carroll County, Ark
429 gpm
502 gpm
502 gpm
DRAWDOWN IN FEET
40.00
48.00
56.00
64.00
72.00
80.00
88.00
0.80
1.20
1.60
2.00
2.40
2.80
TIME IN POWERS OF 10

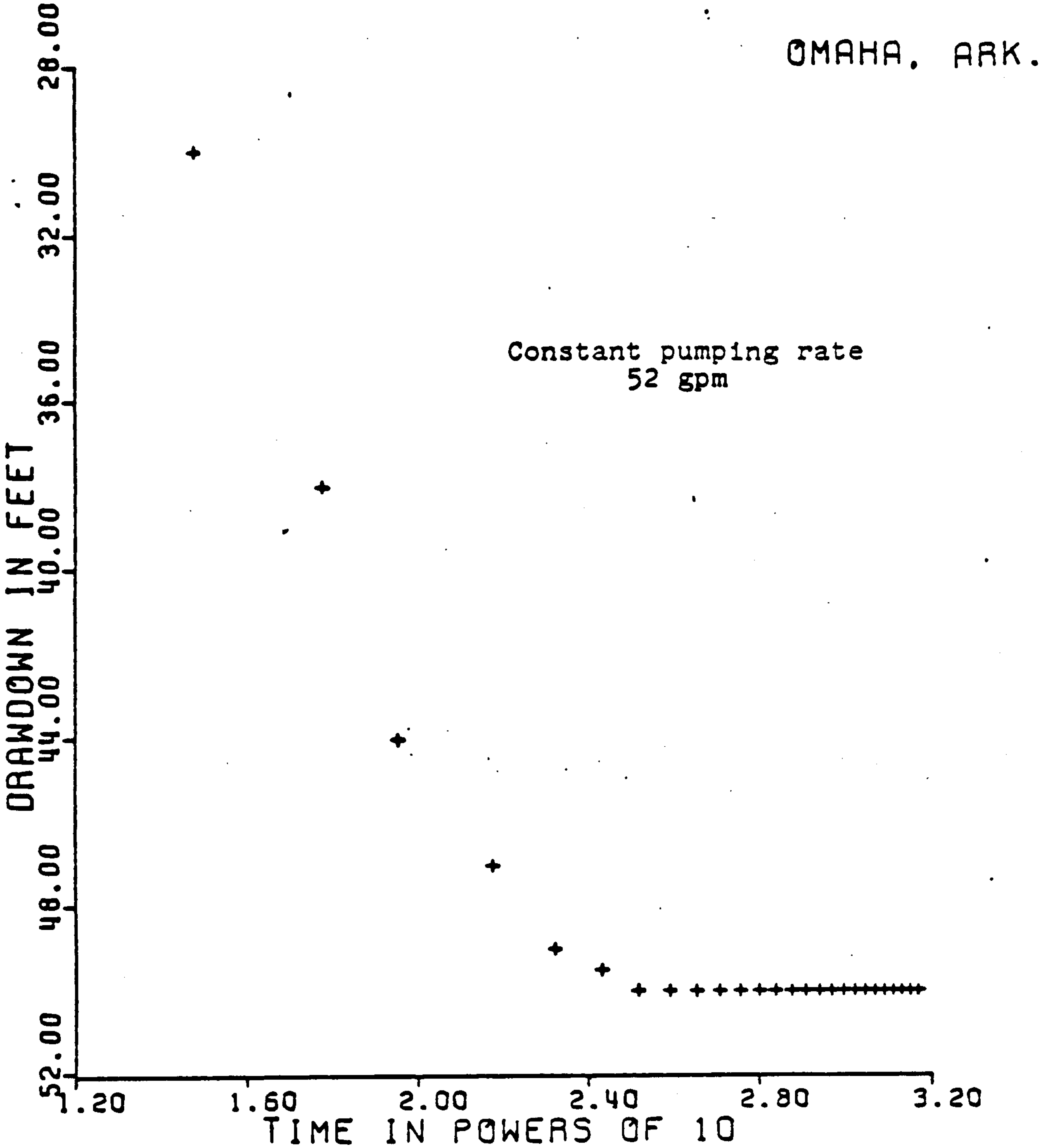


LOST BRIDGE VILLAGE
Benton County, Ark.
240 gpm
225 gpm
224 gpm
227 gpm
227 gpm
244 gpm
240 gpm
DRAWDOWN IN FEET
55.00
65.00
75.00
85.00
95.00
105.00
115.00
0.00
0.80
1.60
2.40
3.20
4.00
TIME IN POWERS OF 10

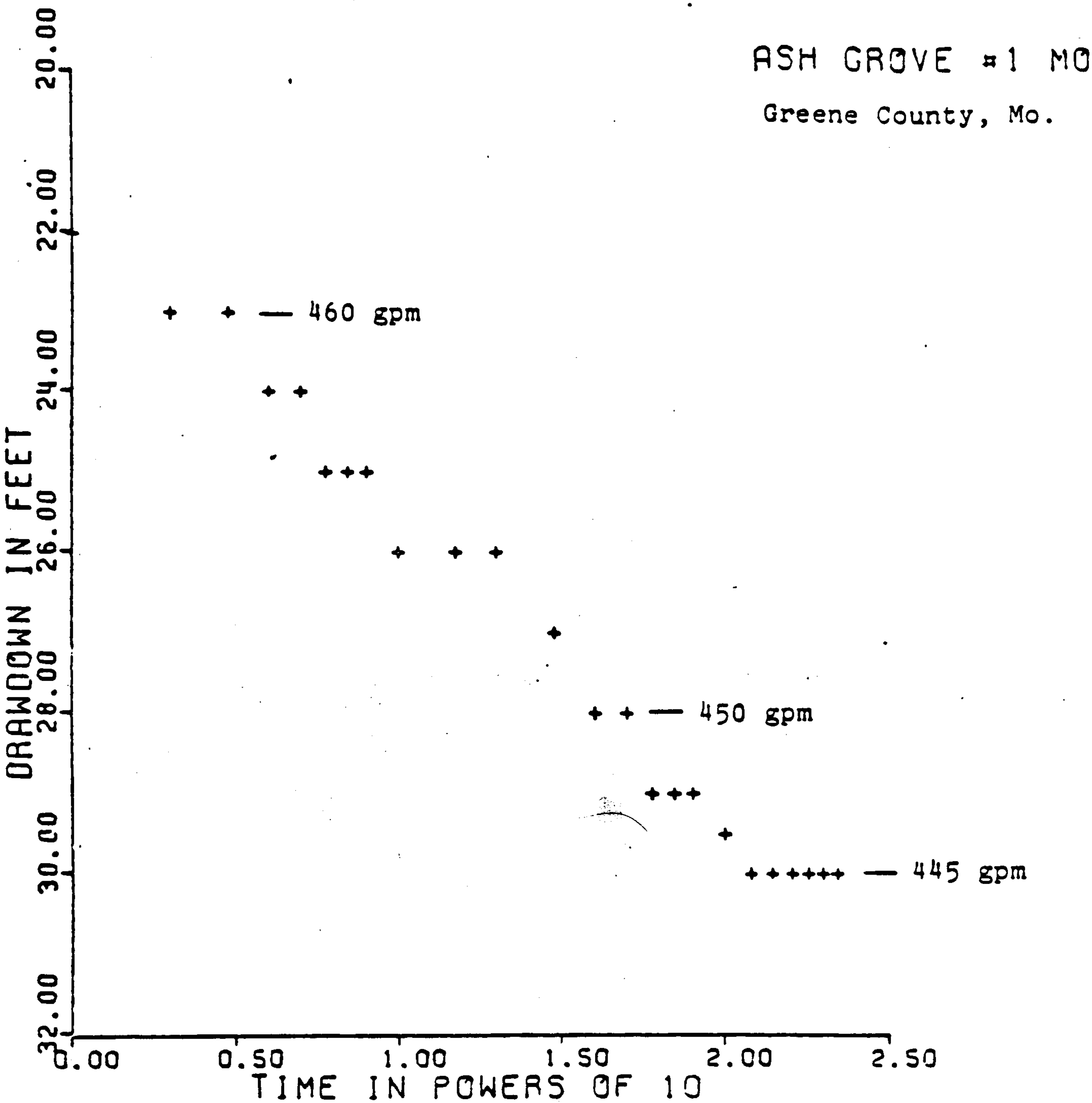

LOST BRIDGE VILLAGE
Benton County, Ark.
Recovery curve.
Pump off.
DRAWDOWN IN FEET
0.00
20.00
40.00
60.00
80.00
100.00
120.00
0.00
0.80
1.60
2.40
3.20
4.00
TIME IN POWERS OF 10

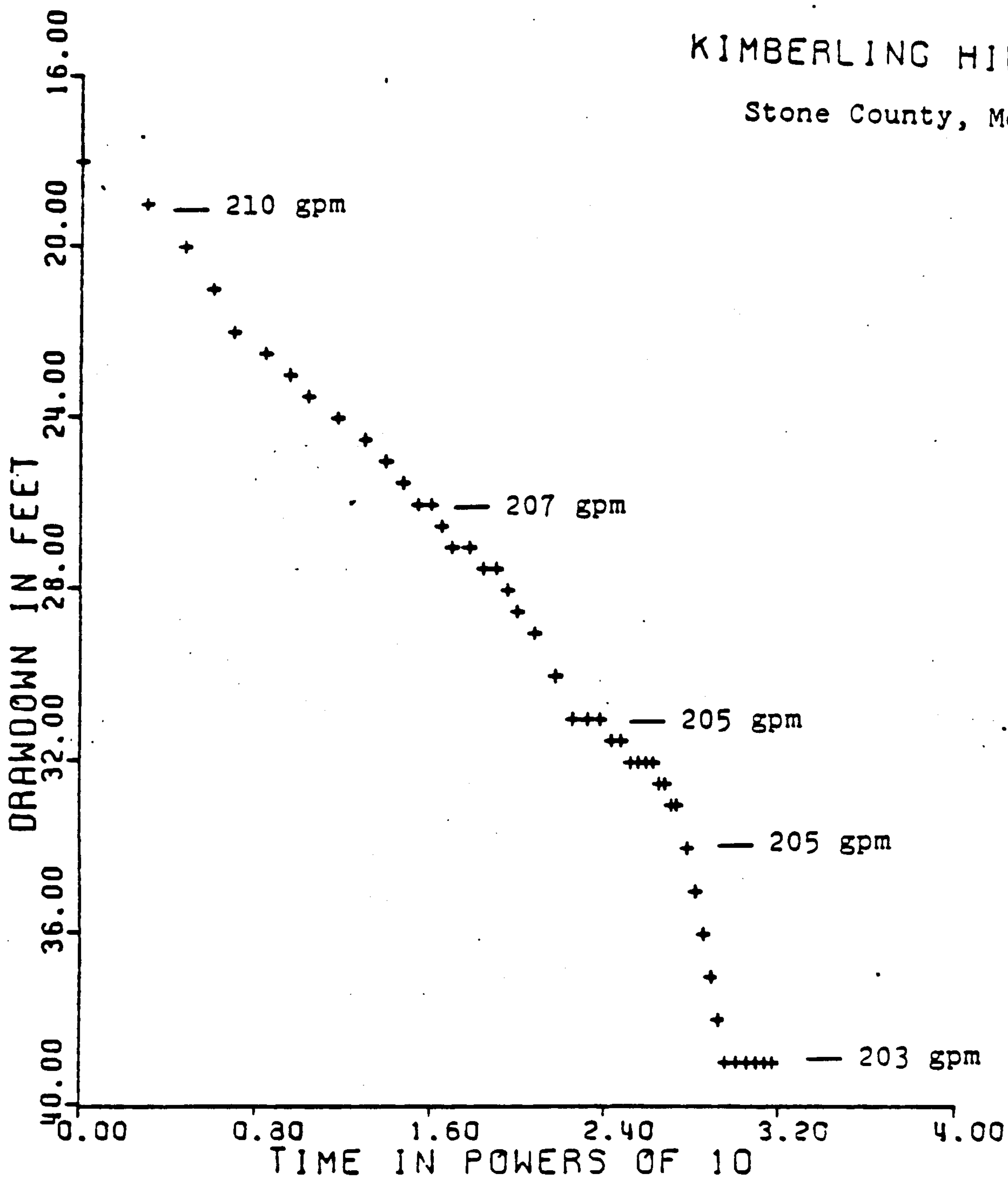


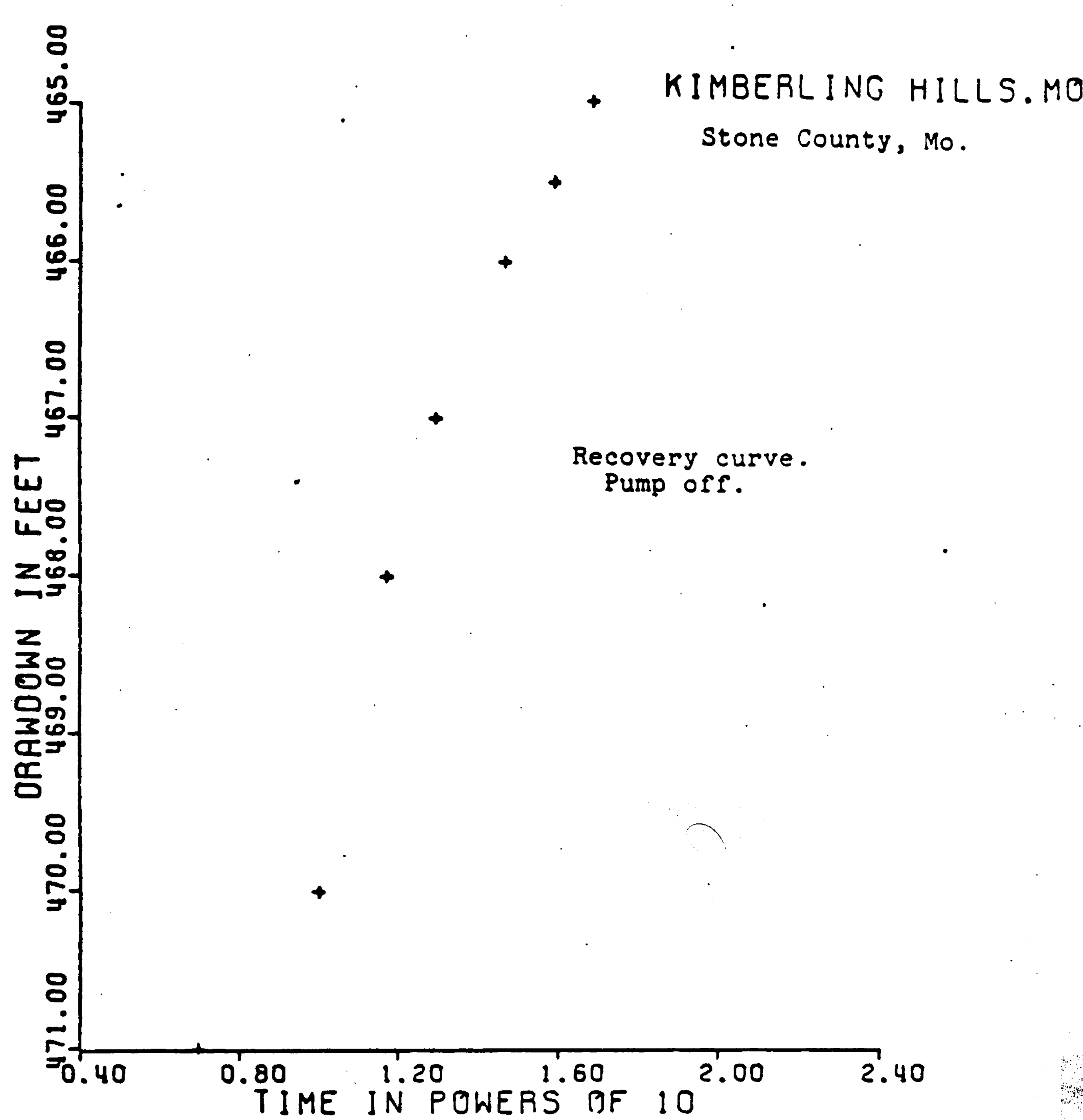
MARBLE FALLS. AR
Newton County, Ark.
257 gpm
222 gpm
222 gpm
DRAWDOWN IN FEET
20.00
40.00
60.00
80.00
100.00
120.00
140.00
1.20
1.60
2.00
2.40
2.80
3.20
TIME IN POWERS OF 10



OMAHA, ARK.
Constant pumping rate
52 gpm
DRAWDOWN IN FEET
28.00
32.00
36.00
40.00
44.00
48.00
52.00
1.20
1.60
2.00
2.40
2.80
3.20
TIME IN POWERS OF 10

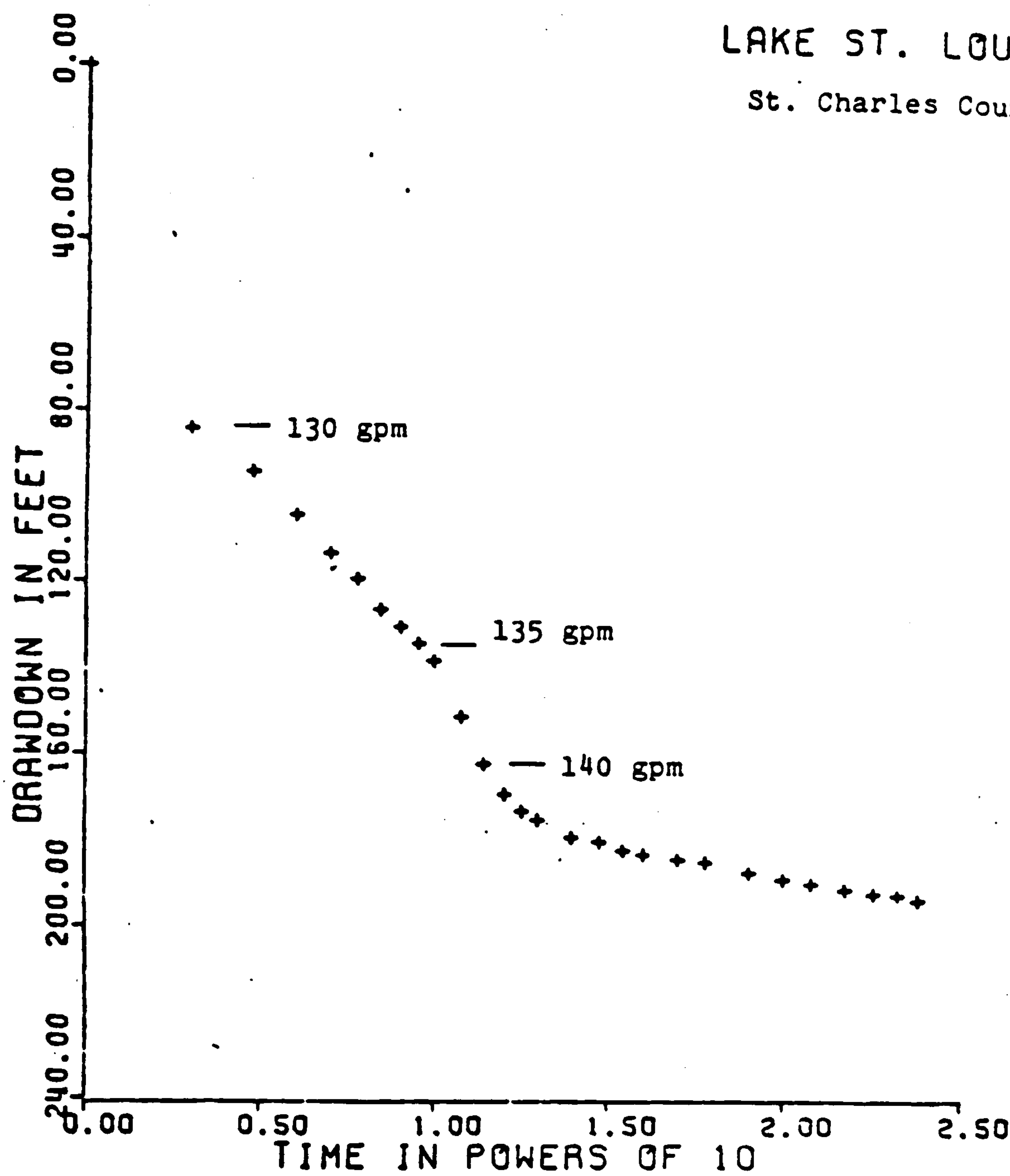

ASH GROVE #1 MO
Greene County, Mo.
460 gpm
450 gpm
445 gpm
DRAWDOWN IN FEET
20.00
22.00
24.00
26.00
28.00
30.00
32.00
0.00
0.50
1.00
1.50
2.00
2.50
TIME IN POWERS OF 10

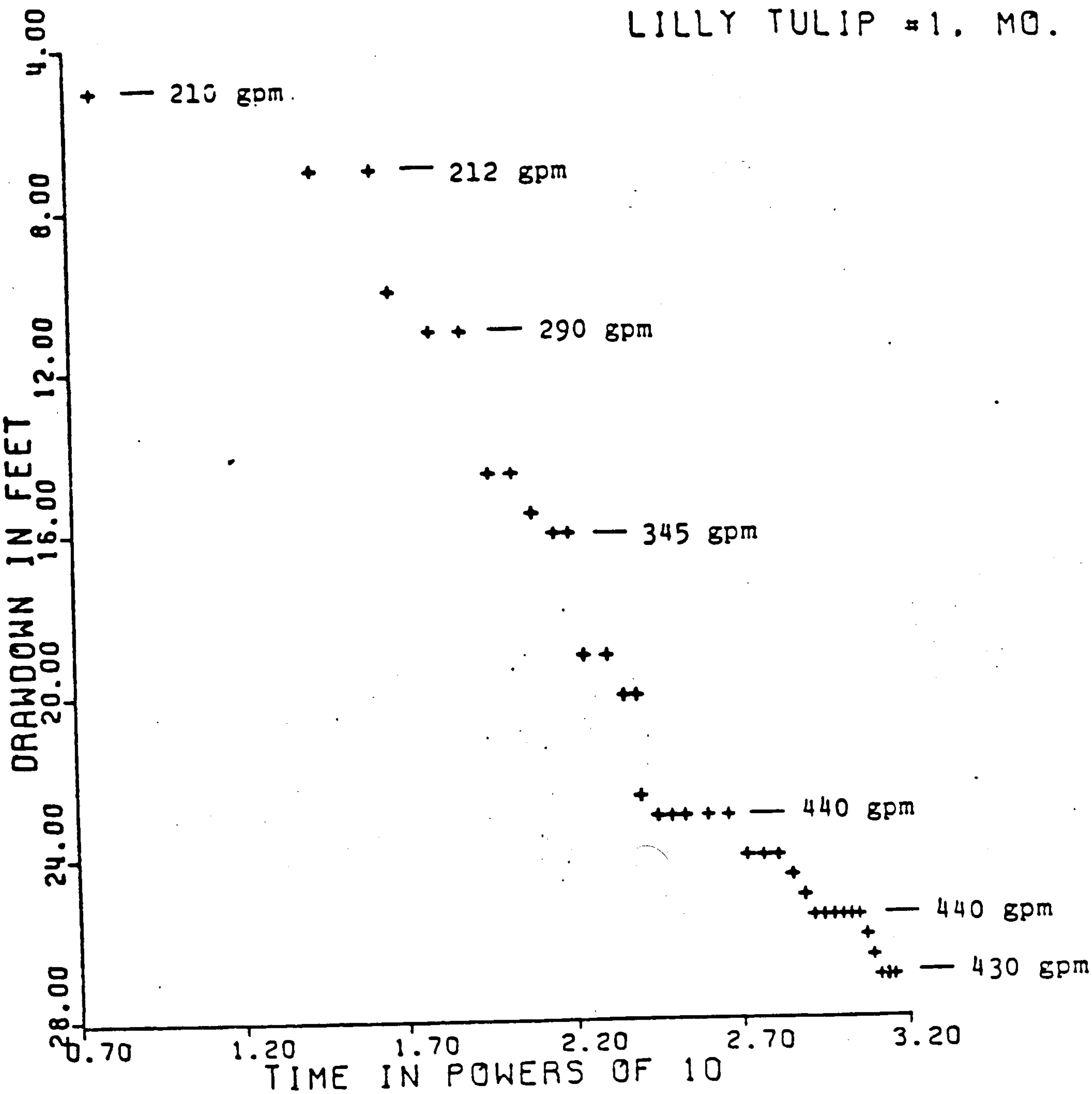

KIMBERLING HILLS, MO
Stone County, Mo.
210 gpm
207 gpm
205 gpm
205 gpm
203 gpm
DRAWDOWN IN FEET
16.00
20.00
24.00
28.00
32.00
36.00
40.00
0.00
0.80
1.60
2.40
3.20
4.00
TIME IN POWERS OF 10

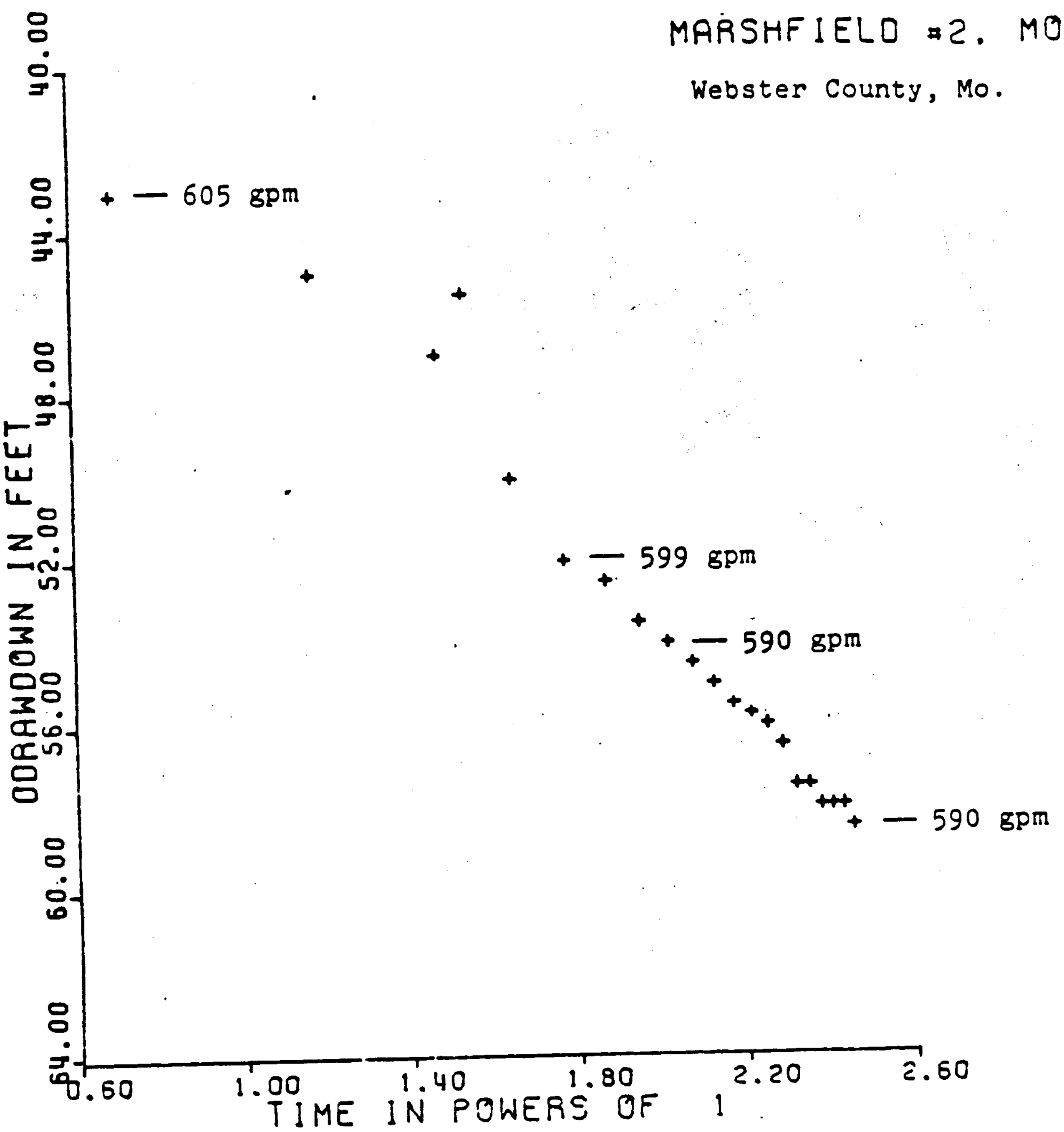

KIMBERLING HILLS.MO
Stone County, Mo.
Recovery curve.
Pump off.
DRAWDOWN IN FEET
465.00
466.00
467.00
468.00
469.00
470.00
471.00
0.40
0.80
1.20
1.60
2.00
2.40
TIME IN POWERS OF 10

LAKE ST. LOUIS #2 MO

St. Charles County, Mo.




LILLY TULIP #1, MO.
210 gpm
212 gpm
290 gpm
345 gpm
440 gpm
440 gpm
430 gpm
DRAWDOWN IN FEET
4.00
8.00
12.00
16.00
20.00
24.00
28.00
0.70
1.20
1.70
2.20
2.70
3.20
TIME IN POWERS OF 10


MARSHFIELD #2, MO
Webster County, Mo.
605 gpm
599 gpm
590 gpm
590 gpm
DRAWDOWN IN FEET
40.00
44.00
48.00
52.00
56.00
60.00
64.00
0.60
1.00
1.40
1.80
2.20
2.60
TIME IN POWERS OF 1