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RECONNAISSANCE OF THE BEDROCK AQUIFERS AND GROUNDWATER CHEMISTRY OF CRAWFORD, FRANKLIN, AND SEBASTIAN COUNTIES, ARKANSAS

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ABSTRACT

A ground water reconnaissance of Crawford, Franklin, and Sebastian counties was performed utilizing 122 wells having drillers' logs from bedrock aquifers. North of the Arkansas River, essentially all bedrock wells produce from the Atoka Formation. There are many low producing aquifers within the Atoka with a range in yield of 0.1 to 55 gpm, but having a median yield of only 2 gpm. Well depths range from 18 to 248 feet with a median of 122 feet. More water is generally obtained from the shale/siltstone aquifers than the sandstones due to more bedding-plane partings and more closely spaced fractures. Greater yields are also found in valleys. South of the Arkansas River, three additional bedrock aquifers are utilized. The aquifers and median yield are as follows: (1) Savannah Sandstone (11.7 gpm), (2) Hartshorne Sandstone (10 gpm), and (3) McAlester Shale (5.2 gpm). Well depths range from 40 to 300 feet.

Seventeen wells in the Atoka were sampled and analyzed. The median iron concentration was 0.15, but four wells had over the 0.3 ppm health limit. Sulfate values ranged from 31 to 125 ppm with a median of 45 ppm. Chloride concentrations ranged from 16 to 58 ppm with a median of 33 ppm. These relatively high values commonly give the water a bitter and strigent taste with some H₂S odor. The source of these ions may be from pyrite weathering or to contamination from the many gas fields in the area.

INTRODUCTION

Ground water is an important resource in Crawford, Franklin and Sebastian counties, Arkansas, and is utilized extensively by rural residents, smaller communities, and the agricultural and other industries of the area. The Fort Smith-Van Buren urban area of west-central Arkansas is the second most densely populated region of the state. Water supplies available for use in this area are proving to be severely inadequate, especially during drier seasons, and appear to worsen yearly. The problem lies basically in the fact that the entire area, rural and municipal, has experienced a sharp rise in population and industrial growth without increasing capacities to deliver more water to the area. Lakes Fort Smith and Shepard Springs presently account for the total of the area's storage and supply, as they have for many years. The extension of water mains to the surrounding rural areas has taxed the existing system further. The construction of new surface impoundment areas has been delayed by opposing interests in the prospective areas. It is obvious that in the near future this area will experience serious shortages which may result in rationing or other extremes.

To date, previous hydrogeologic investigations of this area have been on a regional scale encompassing the Arkansas Valley between Fort Smith and Little Rock. Bedinger et al. (1963) have examined the ground water conditions of the alluvium of the Arkansas River and have provided only general information on the occurrence, availability and chemical quality of ground water in the alluvium. A reconnaissance survey by Cordova (1963) uses sparse data to study the ground water resources of the alluvial and bedrock aquifers of fifteen counties in the Arkansas Valley.

This investigation is intended to serve as a preliminary to more in depth hydrogeologic studies to determine if the study area's ground water supplies are a feasible alternative to building another lake. It provides

the first detailed study of the ground water resources in the important bedrock aquifers in the area, furnishes statistical relationships between several parameters of these aquifers, reviews well drillers' estimates of well yields, and focus' on the ground-water quality north and south of the Arkansas River.

Location and Geology

Crawford, Franklin, and Sebastian counties lie within the extreme west-central portion of the Interior Highlands physiographic province of Arkansas and is within the Arkansas Valley and southern Boston Mountains regions (Figure 1). Structurally, the area lies on the southern flank of the Ozark Dome to the north and the Arkoma Basin to the south. The northern portion of the study area is underlain by nearly horizontal Pennsylvanian aged sandstones, siltstones, and shales. East-west trending normal faults and vertical jointing are the major structures present. The Arkansas Valley area to the south is underlain by Pennsylvanian aged sandstones, siltstones and shale with terrace and floodplain deposits of Quaternary age along the Arkansas River. Extensive folding, faults and jointing with major structural axes oriented nearly east-west are present here. The location and extent of each rock unit, as well as the Arkansas Valley stratigraphy are shown on the "Geologic Map of Arkansas" (Haley, 1976).

Investigative Methods

Records of water wells were obtained from the Arkansas Geologic Commission for the counties studied. One hundred twenty-two wells were accurately plotted on topographic maps with the aid of county platt books and rural directors. From the gross lithologic log reported on each record and detailed geologic maps of the area, it was possible to determine the aquifer(s) that supplied water to each well. The

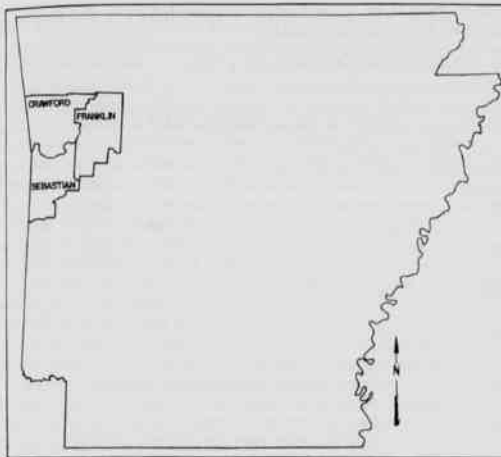


Figure 1. Location of Crawford, Franklin, and Sebastian counties in Arkansas.

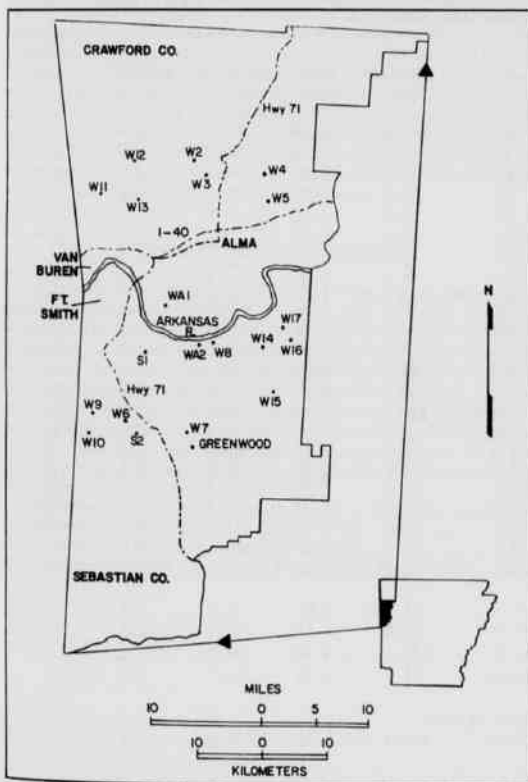


Figure 2. Location of wells and springs sampled in Crawford and Sebastian counties.

alternating nature of the Atoka Formation did not significantly hamper determination of the studied aquifer since the productive unit was easily distinguished from the aforementioned lithologic logs. Other important information provided by each well record was: (1) the static water level of the well, (2) the driller's estimate of yield (gpm), (3) the depth to water and (4) the depth to bedrock. Surveying the driller's records aids in evaluating the productive nature of a particular aquifer prior to "in the field" testing via pumping tests. No pumping tests were performed however, so conclusions on aquifer potential are highly speculative as transmissivity and specific capacity values are not available from this investigation.

The Spearman-Rank Correlation Coefficient test (Seigel, 1956) was then used to make preliminary tests among the following parameters (with computer print out abbreviations in parenthesis): (1) the depth of the well (Depth), (2) the static water level of the well or elevation of the water above sea level (PS), (3) the regolith thickness above the bedrock (REG), (4) estimated well yield in gpm (Q), (5) the depth to water (WTD), and (6) the depth to the producing horizon (DPH).

Water samples were collected in the spring of 1980 from nineteen wells and two springs in the area and tested for their content of sulfate, irons, nitrate and chloride (Figure 2). The samples were processed according to standard Hach procedures (1981).

RESULTS

Four bedrock aquifers were found to be used in the study area. North of the Arkansas River, essentially all bedrock wells produce from the Atoka Formation. The Atoka Formation was found to contain several water bearing horizons utilized most extensively in Crawford County to meet various water needs (only three wells were located in the Atoka in Franklin County). The Atoka Formation consists of alternating beds of sandstone, siltstone, and shale, and reaches a maximum surface thickness of 9,400 feet in Perry County. Since these units alternate with each other, there are many water producing horizons within the Atoka. A single well usually will penetrate more than one producing horizon to meet the necessary production. A total of 58 wells were investigated which were found to be under unconfined conditions. Of the 58 wells, 41 were found to be producing from shales or siltstones and 17 were found to be producing from the interbedded sandstones. The hydrologic interaction of the shales and siltstones can only be speculated upon, but, in many wells, several horizons of low yield had to be intersected to produce sufficient quantities of water.

Depths for drilled wells in the Atoka aquifer range from 18 to 248 feet and have a median depth of 122.5 feet (Table 1). The greater depths represent those wells that had been drilled through the horizons of low productivity. The range in yield for this aquifer is 0.1 to 55 gpm, but having a median productivity of only 2.25 gpm (Table 1).

Table 1. Ranges and medians of depth and yield of the wells studied in Franklin and Crawford counties.

AQUIFER	FRANKLIN COUNTY		YIELD (GPM)	
	RANGE	MEDIAN	RANGE	MEDIAN
SAVANNAH	44-250	134	1.5-33	11.7
McALESTER	40-220	122	0.5-13	5.2
HARTSHORNE	50-300	83	3.3-33.7	10
ATOKA	66-148	73	2.0-16.7	16.7
CRAWFORD				
ATOKA	18-248	122	0.1-55	2.3

South of the Arkansas River three additional bedrock aquifers are utilized. The aquifers are all of Pennsylvanian age. The more shallow aquifer is the Savannah Sandstone. Measured sections indicate thicknesses ranging from 1,140 to 1,610 feet. The Savannah consists mainly of shale and sandstone with six coal beds and one lenticular bed of limestone (Cordova, 1963). The range in yield for the 17 wells located in this unit is from 1.5 to 33.3 gpm; the median productivity is 11.7 gpm. Depths for these wells range from 44 to 250 feet (Table 1). This aquifer may act as a confined or as an unconfined aquifer, depending on the occurrence of a confining shale unit above a saturated sandstone.

The McAlester Shale underlies the Savannah Sandstone, and in the study area its range in thickness is from about 500 to about 1,820 feet. The McAlester mainly consists of dark, gritty shale and minor sandstone, siltstone and coal. Individual sandstone beds are generally less than 50 feet thick and lenticular (Cordova, 1963). Eleven of the wells plotted are located in the McAlester Shale. These wells showed a range in yield from 0.5 to 13.3 gpm and represent the least productive wells with a median value for yield of only 5.2 gpm. Well depths for this aquifer zone range from 40 to 220 feet with a median depth of 122 feet (Table 1). The Atoka Formation underlies the McAlester Shale.

The third bedrock aquifer found to be utilized in Franklin County is the Harshorne Sandstone. Thickness range from about 10 to about 300 feet in the study area. The Harshorne is mostly thick bedded sandstone, but shales may attain significant thickness locally. This aquifer was found to be used by twenty of the located wells. The range in yield is from 3.3 to 33.7 gpm, with a median value of 10 gpm. The range in depth is from 50 to 300 feet, and the median is 83 feet (Table 1).

Ground-water samples from nineteen wells and two springs were retrieved and analyzed for chemical content of sulfate (SO₄) iron (Fe), chloride (Cl), and nitrate (NO₃). The Environmental Protection Agency has established limits on these chemical constituents for drinking purposes (1976). These are, respectively, (measured in parts per million) 250 ppm, 0.3 ppm, 250 ppm, and 45 ppm. Analysis results are shown in Table 2 as are the range, median, and mean of each parameter.

Most samples tested on these parameters were found to be well within established guidelines for safe drinking water. Some samples were found to have exceeded the limit set for iron, but this limit is based on aesthetic and taste considerations and not toxicity.

The unconsolidated alluvium along the Arkansas River is used extensively for irrigation and is known to be capable of sustained high yields (Bedinger et al., 1963). Two samples (WA1 and WA2, Table 2) were taken from the alluvium. WA1 was found to have high sulfate and iron content. Although not sampled, many other wells in the alluvium were said to be high in these ionic constituents by the well owners. The presence of iron and sulfate is probably controlled by the iron pyrite in the sediments. The presence of iron pyrite is a function of the paleo-environment and in particular, where reducing conditions occurred. A well-flushed, paleo-environment that formed under oxidizing conditions will yield water of better quality. An in depth study of the alluvial wells utilizing water quality analyses and remote sensing, could designate the areas of best water quality for the development of well fields.

Geostatistical Relationships

The Spearman-Rank Correlation Coefficient test was used with the aid of computer SAS procedures (Barr et al., 1976) to compare the various parameters taken from the well reports. For the Atoka aquifer, eight relationships between the various parameters were found at an $\alpha = 0.1$ significance level or better (Table 3). Two of these comparisons displayed expected aquifer conditions, while the remainder enabled the construction of an hydrogeological model that could prove to be important in future water well prospecting.

A positive correlation resulted from the comparisons between well depth (DEPTH) vs. depth to water (WTD) and well depth vs. depth to the producing horizon (DPH). This simply shows that when a water bearing horizon is at a great depth, the well will be deep as will be the resulting piezometric surface. Positive relationships were also found between regolith thickness (REG) vs. DPH and between REG vs.

Table 2. Results of water analysis of sampled wells and springs in Crawford and Sebastian counties.

	MEAN	PS	REG	Q	WTD	DPH
DEPTH	130	-0.286 0.029	0.296 0.024	-0.433 0.001	0.309 0.018	0.513 0.001
PS	882	-	-0.357 0.006	-0.029 0.829	-0.142 0.287	-0.286 0.030
REG	13	-	-	-0.009 0.949	0.065 0.626	0.294 0.025
Q	6.3	-	-	-	-0.151 0.258	-0.111 0.401
WTD	28	-	-	-	-	0.257 0.051
DPH	71	-	-	-	-	-

DEPTH = DEPTH OF WELL (FT)
 PS = PIEZOMETRIC SURFACE LEVEL (FT ABOVE MSL)
 REG = REGOLITH THICKNESS (FT)
 Q = DRILLERS' ESTIMATED YIELD (GPM)
 WTD = DEPTH TO WATER FROM SURFACE (FT)
 DPH = DEPTH TO PRODUCING HORIZON (FT)

Table 3. Correlation matrix and means for depth, piezometric surface, regolith thickness, yield, depth to water, and depth to producing horizon of the Atoka Formation.

SAMPLE NO.	SULFATE (PPM)	IRON (PPM)	CHLORIDE (PPM)	NITRATE (PPM)	ESTIMATED YIELD (GPM)
W1	53.0	0.16	27.5	4.4	1.5
W2	56.4	0.02	48.7	0.3	10
W3	35.4	0.03	54.7	0.6	15
W4	38.5	0.03	56.2	2.8	5
W5	54.1	0.10	27.6	1.2	0.5
W6	34.7	0.03	54.5	0.0	20
W7	37.6	0.03	52.5	0.0	25
W8	32.5	0.05	51.8	0.7	5
W9	45.4	1.30	16.5	3.4	0.5
W10	53.4	0.65	24.4	1.7	7
W11	75.5	0.15	36.8	3.8	2.5
W12	73.4	0.08	37.9	4.4	5
W13	38.4	0.34	26.3	0.0	15
W14	125.4	0.23	33.4	11.3	10
W15	43.4	0.24	24.4	0.8	5
W16	36.5	3.80	58.0	0.0	5
W17	31.5	0.00	36.4	0.3	15
WA1	163.4	0.55	8.5	13.7	225
WA2	37.5	0.09	17.5	6.4	175
S1	54.4	0.25	26.5	0.0	---
S2	52.3	4.40	27.4	10.5	---
MEAN	51.1	0.63	37.9	2.4	
MEDIAN	45.4	0.15	33.4	0.8	
MAXIMUM	125.4	4.40	58.0	11.3	
MINIMUM	31.5	0.00	16.5	0.0	
E.P.A. HEALTH LIMIT	250.0	0.30	250.0	45.0	

W = WATER SAMPLE FROM WELL IN CONSOLIDATED BEDROCK AQUIFER
 WA = WATER SAMPLE FROM WELL IN UNCONSOLIDATED ALLUVIAL AQUIFER
 S = WATER FROM SPRING AT POINT OF EMERGENCE

DEPTH. This suggests that there is a greater thickness of regolith on upland surfaces (remnants of the Boston Mountain Plateau) where the aquifers are deeper. A negative relationship between these same factors is usually found in karst areas where weathering has taken place much deeper along solution-enlarged fractures that produce great yields at shallower depths than wells not located on fracture zones (Ogden et al., 1979). Negative correlations were found between DEPTH vs. elevation of water above sea level (PS), REG vs. PS, and DPH vs. PS. These relationships state that the piezometric surface is higher beneath alleys than hills. If the valleys represent fracture zones, then most recharge may be taking place along the valleys causing the piezometric surface to slope downward away from the valleys. Also, it is important to remember that most water comes from the siltstones and shales that are less resistant to erosion and weathering, and thus underlie valleys. Resistant sandstones cap the hills with the siltstone-shale aquifers beneath at great depth and lower pressure head.

A second model that can be visualized to explain these correlations is based on the "multi-level" aquifer characteristic of the Atoka Formation. A near surface aquifer along a valley (fracture) may produce water, but the same rock unit may produce no water in an unfractured uplands area. Therefore, the well must be drilled deeper to a water producing horizon of lower pressure head.

Finally, a negative correlation between DEPTH vs. yield (Q) was found. This suggests that joints and fractures close with depth due to increasing lithostatic pressure. Thus, drilling deep will probably not give greater yield. Another possible explanation is that a well drilled on a fracture zone will produce sufficient quantities of water at little depth, but if the well is not sited on a fracture, a sufficient yield will not be obtained at any depth due to low porosity and permeability.

The results of the statistical comparisons in the three non-Atokan aquifers indicate that nearly all the variables under consideration (except well depths and water table depths and well depths with depth to producing horizons) were not statistically related within the conditions of this study. Well depth was statistically ($\alpha = 0.1$) related to water table depth and depth to producing horizon, but these are obvious relationships expected for all aquifers.

SUMMARY AND CONCLUSIONS

Ground water is extensively used by rural residents, small communities and the industries of Crawford, Franklin, and Sebastian counties, Arkansas. The most important bedrock aquifer of this area is the Atoka Formation, an extensive formation of Pennsylvanian age consisting of alternating shales, siltstones, and sandstones. Three additional bedrock aquifers utilized by residents south of the Arkansas River are the Harishore, McAlester, and Savannah formations. These aquifers cannot match the yield of the alluvial aquifers in the Arkansas Valley region, but the alluvium is commonly high in sulfate and iron. A more detailed study of the water quality in the alluvium with respect to the paleo-depositional environment is needed.

Geostatistical correlations show that yield in the Atoka aquifer is topographically controlled since greater yields were found in wells drilled in valleys. In addition, the shale/siltstone aquifers appear to be more productive than sandstones emphasizing that bedding plane

partings and closely-spaced fractures common to thin bedded rocks are more important than intergranular porosity and wide-spread fractures found in massive bedded, tight sandstones. The hypothesis is that fractures close with depth and that wells not drilled on fractures must go deeper was substantiated by the fact that yield decreases statistically with depth.

Most of the water samples collected for chemical analyses were found to be well within established limits of safety with regard to sulfate, iron, nitrate, and chloride. Further water chemistry tests should be performed involving more parameters such as bacteria to determine the factor controlling water quality of the Atoka in the Fort Smith vicinity. Numerous pumping (aquifer) tests should be performed to determine the range in transmissivity and specific capacity of the aquifer. Finally, the relationship of well yield to fold axis proximity and yield to fault proximity should be determined to aid in ground water exploration.

The results of this study indicate that the quantity and quality of ground water in Crawford, Franklin, and Sebastian counties is highly variable. Presently, some industries in the Fort Smith area use large quantities of ground water, thus demonstrating the possibility of developing city well fields. A more thorough study involving extensive field work could determine the factors that control production and water chemistry, thereby allowing the development of one or more well fields to meet the growing needs of the Fort Smith area at much less expense than a surface impoundment.

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