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ARSENIC STRATIFICATION IN THE SANTA FE FORMATION, BERNALILLO, NEW MEXICO

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Abstract—Arsenic is present in ground water from alluvial deposits and the Santa Fe Formation in the Albuquerque basin. Its origin has been attributed to volcanic activity in the Valle Grande and possibly to potassium metasomatism. Stratification of the arsenic has been noted in wells located along the Jemez River and at Bernalillo. Zone sampling and proper well construction can reduce arsenic levels produced from wells, insuring that the supplies will meet drinking-water standards. Zone sampling can also produce cost savings during well construction.

INTRODUCTION

The presence of arsenic in ground water in the Rio Grande basin has been recognized for many years. The vast majority of the state's population resides in this area, and the communities depend almost exclusively on ground water for their source of supply. Thus arsenic is an ever-present threat to wells.

Arsenic is currently regulated under the Safe Drinking Water Act with a maximum concentration limit (MCL) of 0.05 mg/l. Proposed amendments to this act are expected to lower the MCL to 0.02 mg/l or perhaps even lower (Environmental Protection Agency, personal commun., 1996). Currently, January 1996, the amended concentration level of arsenic as well as a timetable for enforcement is being negotiated in the courts with no schedule for the final outcome. Lowering of the MCL for arsenic combined with Albuquerque's reliance on ground water make the understanding of distribution and origin all the more important.

Arsenic has been linked to numerous harmful health effects. Acute doses are known to be fatal. Chronic exposure can result in injury to the liver and peripheral vascular disease (Environmental Protection Agency, personal commun., 1996). Prolonged exposure to even low levels (0.2 mg/l) of arsenic in water has resulted in varying forms of cancer (Brown and Chen, 1994).

The cities of Rio Rancho and Albuquerque have been able to minimize the arsenic problem by blending water from different wells to achieve acceptable levels of arsenic. Most Albuquerque municipal wells are constructed to produce water over a wide stratigraphic interval. The chemical quality of the water produced is a blend of ground water from the screened interval, and this is further blended by mixing water from five to seven wells in a single storage tank. When water from one well has a particularly high arsenic content, production from that well can be regulated to achieve an acceptable mix in the storage tank.

Most smaller communities in the basin depend on only one or two wells for their municipal supply. In these cases it is imperative to obtain an adequate amount of water with acceptable chemical quality. Because a municipal well can expect to produce water for as much as 40 yrs, the pending changes in arsenic limits by the Public Health Service must also be anticipated.

For many years the town of Bernalillo in Sandoval County obtained its municipal supply from two wells located east of Interstate 25. Both wells were less than 500 ft deep and tapped the Santa Fe Formation. Blended samples from these wells frequently exceeded the drinking-water standard of 0.05 mg/l.

SOURCES OF ARSENIC

The town of Bernalillo is located at the north end of the Albuquerque basin, where the arsenic content is rather high. According to Chapin and Dunbar (1995, p. 265), "The arsenic content of the Rio Grande waters increases markedly at the confluence with the Jemez River, due to input of high-arsenic waters from the young Jemez volcanic field." The Valles hydrothermal system is at least 10 Ma, and the high arsenic waters at Soda Dam are part of this system (Goff and Shevenell, 1987). The discharge of large volumes of arsenic-bearing thermal waters into the Jemez River has undoubtedly led to the high levels of arsenic in ground water associated with the river.

High levels of arsenic are frequently associated with rhyolitic volcanics (Chapin and Dunbar, 1995). Much of the region north of the Jemez River is blanketed by the rhyolitic Bandelier Tuff; intermittent streams flowing across the tuff and ground water percolating through the tuff may contribute arsenic to the surface-water system. The possibility of rhyolitic ash deposits interbedded with the Santa Fe Formation cannot be ruled out.

Potassium metasomatism may also contribute arsenic to ground water in the Albuquerque basin. This process is a type of low-temperature alteration that causes enrichment of potassium and other elements in altered rocks, and is common in a closed hydrographic basin in arid or semiarid climates (Chapin and Lindley, 1986). Sediments of volcanic origin are most susceptible to potassium metasomatism because their composition is unstable in an alkaline, saline, oxidizing geochemical environment. Potassium metasomatism is common throughout the southwest and is well documented in the Socorro, New Mexico, area (Chapin and Dunbar, 1995, p. 263).

One characteristic of potassium metasomatism is that arsenic is enriched in altered rocks. Another factor that can influence the arsenic content of sediments is the composition of the sediment, and also the oxidizing conditions of the environment. For example, arsenic is strongly sorbed to iron, aluminum, and manganese-bearing sediments in oxidizing conditions, but is not sorbed under reducing conditions (Mok and Wai, 1994). Therefore the major element composition of sediments may influence the arsenic content, and arsenic that is immobile under oxidizing conditions may be remobilized if conditions become reducing (Dunbar, personal commun., 1996).

ARSENIC STRATIFICATION AND ZONE SAMPLING

Water samples collected from wells located in the drainages of the Jemez River and Rio Salado (Fig. 1) show that arsenic is quite variable in location and depth (Table 1). It can also vary with time in a pumping well. In these samples, the arsenic content ranged from less than 0.001 mg/l to 0.182 mg/l. Two of the samples exceeded current drinking water standards. A well located in sec. 7, T14N, R3E contained 0.182 mg/l arsenic between 475 and 495 ft, and 0.034 mg/l arsenic at the 730- to 750-ft interval. A well located in sec. 13, T15N, R2E, was sampled at three different intervals with arsenic ranging from 0.0021 to 0.058 mg/l. Four of the wells listed in Table 1 were sampled during production tests. In three of the wells the arsenic increased during pumping and the arsenic decreased during one test.

All arsenic data presented in this report were determined from unfiltered samples representing total arsenic concentration. Because arsenic has an affinity for suspended sediment, filtered samples generally show lower levels of arsenic than unfiltered samples. However, public supply wells seldom contain suspended sediment, and the water is rarely filtered prior to distribution. Therefore the arsenic levels given here are representative of arsenic concentrations that would be present in drinking water.

There is little correlation between arsenic concentration and duration of pumping prior to collecting zone samples (Table 1). Each zone sample was collected after it was determined from specific conductance measurements that formation water was being produced.

When it became obvious that the town of Bernalillo would be unable to meet water-quality standards, a sampling technique was developed that allowed for specific zones in the aquifer to be sampled prior to comple-

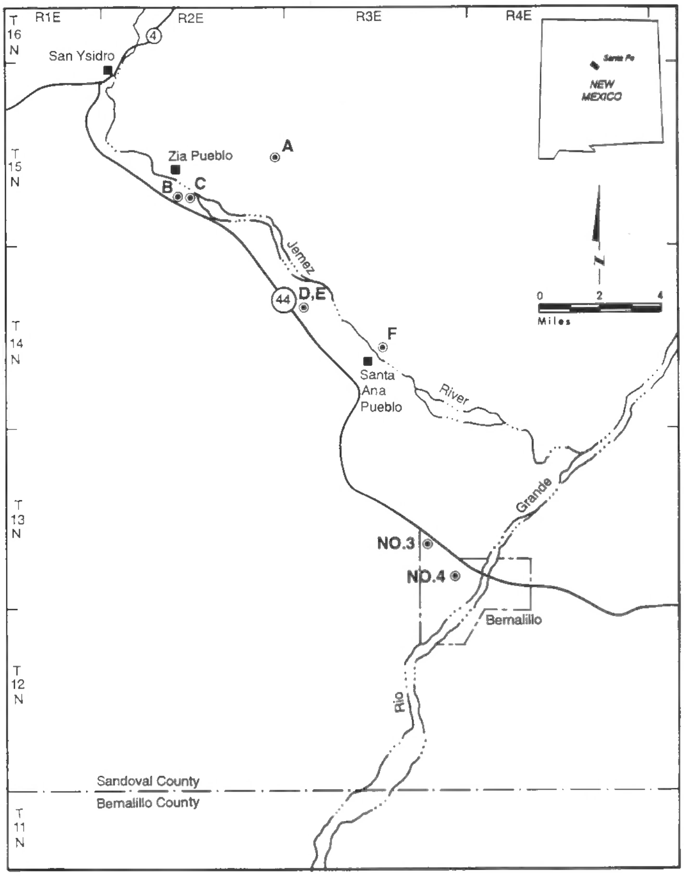

FIGURE 1. Map showing location of arsenic sampling points and town of Bernalillo wells 3 and 4.

tion of the well. After the water analyses were evaluated, the well was designed for maximum water production while sealing off those zones which had inferior water quality (Geohydrology Assoc. Inc., unpubl. reports for Town of Bernalillo, 1992). A total of five samples were collected from well no. 3 and ten samples were collected from well no. 4 (Table 2). In these samples several different analytes were tested in addition to arsenic.

In order to collect zone samples from the Bernalillo wells, a pilot hole was drilled to total depth and a lithologic log was prepared from the drill cuttings. Geophysical logs were run in the pilot hole. After comparing the lithologic and geophysical logs, zones having the greatest water-bearing potential were selected. Water samples were then collected from these zones. The drill pipe, with screen attached, was placed at the lowermost zone and the hole was backfilled with gravel until the screen was covered to a depth of about 5 ft. A bentonite plug was then spotted on top of the gravel. Water was then air-lifted from the drill pipe until a clean sample was obtained. The drill pipe and screen were then pulled up to the next zone and the process repeated until all zones had been sampled.

The zone sampling provided some valuable water quality data from which the final well design was made. In both wells the total dissolved solids decreased with depth and the amount of chloride also decreased (Table 2). Manganese and fluoride were quite variable with depth. Arsenic gradually increased with depth in well no. 3; arsenic also increased with depth in well no. 4 but in a more irregular manner. Significantly more zone samples were collected in no. 4 than in no. 3, allowing for greater variability of arsenic to be detected in no. 4.

On the basis of the lithologic and geochemical data, both wells were selectively screened to maximize water production while isolating the zones containing higher levels of arsenic. The screens were placed opposite those sand and gravel zones with the lowest arsenic content (Fig. 2). In well no. 3 screens were placed in the upper part of the hole in order to avoid the higher arsenic zones with depth. The screens were more widely spaced in well no. 4, where low-arsenic samples had been obtained.

Following completion of the wells, aquifer tests were conducted to determine the production capacity and water quality from each well. Well

TABLE 1. Arsenic concentration in wells located in the Jemez River valley. All samples represent total (unfiltered) concentrations in ground water.

Fig. 1	Location	Date	Sample interval, in feet	As conc., in mg/l	Remarks
A	13, T15N, R2E	9/24/86	356-505, 539-645, 717-780	0.055	
		9/07/86	443-493	0.00210	
		9/07/86	569-619	0.00510	
		9/06/86	750-800	0.0580	
B	28, T15N, R2E	2/20/85	280-300	0.0060	
		2/20/85	480-500	0.0151	
		2/20/85	750-770	0.0208	
C	27,T15N, R2E	8/06/86	120-320	0.0049	After 1 hr @ 37 gpm
		8/07/86	120-320	0.0027	After 24 hrs @ 37 gpm
D	7, T14N, R3E	6/18/86	200-810	<0.001	After 1 hr @ 250 gpm
		6/19/86	200-810	0.0022	After 24 hrs @ 250 gpm
		3/11/85	200-810	0.0029	After 1 hr @ 240 gpm
		3/12/85	200-810	0.0060	After 45 hrs @ 240 gpm
E	7, T14N, R3E	2/05/85	475-495	0.182	
		2/05/85	730-750	0.0346	
F	22, T14N, R3E	6/13/86	200-250, 300-380	0.0034	After 1 hr @ 70 gpm
		6/14/86	200-250, 300-380	0.0047	After 24 hrs @ 70 gpm

TABLE 2. Chemical parameters from zone samples collected from the town of Bernalillo wells 3 and 4. All samples represent total (unfiltered) concentrations in ground water.

Bernalillo Well No. 3	Constituents						
Zone Depth (feet)	**Arsenic**	**Chloride**	**Fluoride**	**Iron**	**Manganese**	**TDS**	**Conductance**
420	0.009	220	0.29	<0.05	0.03	880	1400
560	0.020	220	0.39	<0.05	0.05	620	1100
730	0.022	160	0.29	***1.40**	0.05	620	1000
863	0.023	190	0.42	<0.05	<0.02	550	920
970	0.029	150	0.38	<0.05	<0.02	510	910
Bernalillo Well No. 4							
340	0.009	***370**	0.63	<0.05	***0.45**	***1100**	1800
470	0.007	***320**	0.69	<0.05	***0.24**	850	1400
555	<0.005	210	0.46	<0.05	<0.02	750	300
615	0.012	150	0.42	<0.05	<0.02	580	990
680	0.021	110	0.37	<0.05	0.11	490	830
740	0.019	110	0.29	<0.05	0.14	480	830
890	0.012	150	0.23	<0.05	0.11	560	920
995	0.028	150	0.33	<0.05	0.08	440	800
1050	0.039	150	0.35	<0.05	0.05	420	790
1150	***0.052**	77	1.50	<0.05	<0.02	340	530

*Indicates analyte in excess of New Mexico Water Quality Control Commission standard.

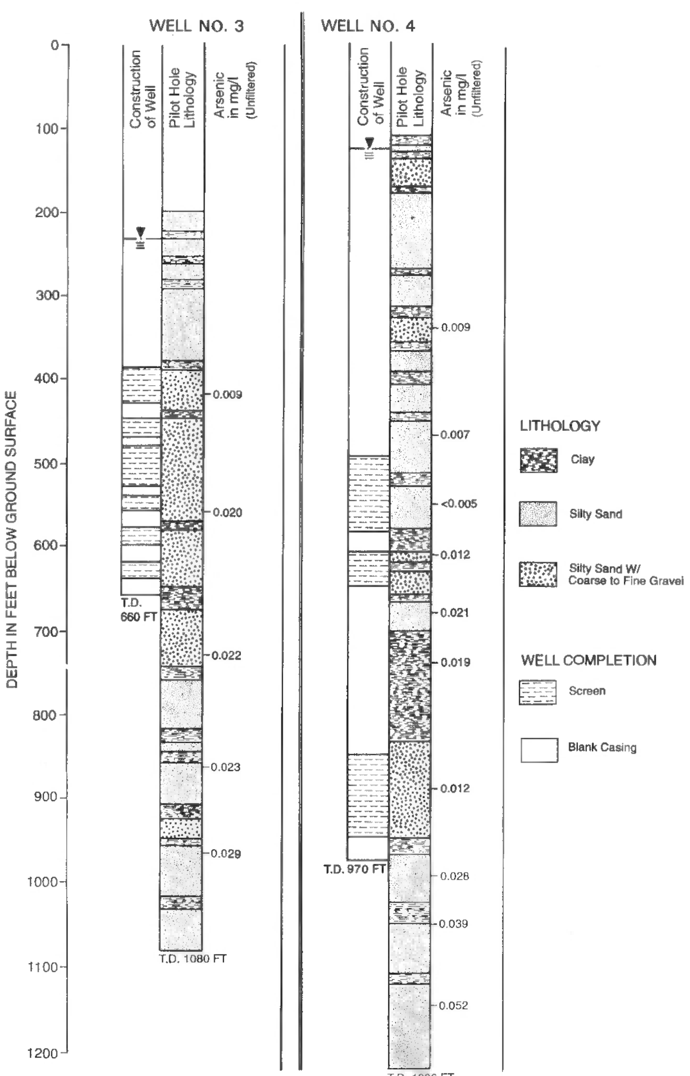

FIGURE 2. Diagrams of town of Bernalillo wells 3 and 4, showing lithology of pilot holes, stratified arsenic content, and final well construction.

no. 3 was pumped at the rate of 733 gpm for 24 hrs. At the conclusion of the test, a sample was collected and analyzed for drinking-water standards. The arsenic level was 0.03 mg/l, which was higher than any of the concentrations identified by the zone sampling. Well no. 4 was pumped at the rate of 1457 gpm for 24 hrs. The sample collected at the end of the test contained less than 0.02 mg/l, which was higher than in samples collected during sampling of the producing zones, but well within the range indicated by the zone sampling overall. Pumping these zones may be pulling water from finer-grained sediments and smaller pores where water has been in contact with mineral grains longer and more intimately, thus increasing the arsenic content somewhat.

Although it is frequently difficult to correlate individual lithologic units in the Santa Fe Formation, there appears to be good correlation between the two wells in three different horizons (Fig. 3). The correlation can be made with the geophysical logs and the arsenic content. This would indicate that individual sand deposits may have a predictable arsenic content. Several zones of high arsenic were sampled near the bottom of well no. 4. It is possible that these zones would have been penetrated by well no. 3 if it had been drilled and sampled at greater depth.

COST EFFECTIVENESS

The cost of drilling and completing a municipal well varies a great deal, depending on geology, location, depth, and size of the well. Wells in the Bernalillo area may cost about $250/ft for a large-capacity well. Zone sampling at Bernalillo cost approximately $5000 per sample. While this may seem like a very expensive water sample, the availability of the zone sampling actually saved the town a considerable amount of money. In well no. 3 the pilot hole was drilled to a depth of 1080 ft. The zone samples showed that the lower part of the hole was high in arsenic, so the production well was completed at a depth of 660 ft (Fig. 2). This was 414 ft shallower than the pilot hole. This was a savings to the town of Bernalillo of $103,500 in construction costs, less $25,000 for zone sampling. Not only was there a net savings of $78,500, the town was assured of obtaining acceptable water quality before final construction of the well. The net savings in well no. 4 was about $14,000 after 10 zone samples had been collected.

Zone sampling is not limited to arsenic. It has been successfully used to evaluate total dissolved solids at Sunland Park, New Mexico (Geohy-

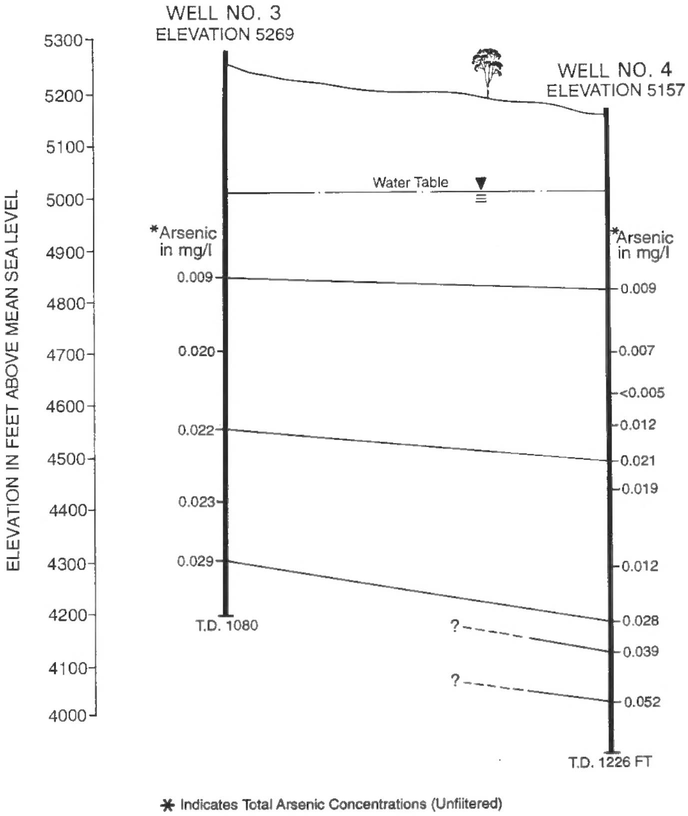

FIGURE 3. Diagram showing correlation and stratification of arsenic levels in town of Bernalillo wells.

drology Assoc., Inc., unpubl. report for City of Sunland Park, 1993) and was recommended for use in evaluating high fluoride levels in the Columbus water system (Geohydrology Assoc., Inc., unpubl., 1994). As shown in Table 2, these parameters can also be stratified and quite variable in the geologic environment.

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