Hydrogeologic characterization of fractured Abo and Madera Formation aquifers, hydrocarbon contamination and transport along the Zuzax Fault, Tijeras Canyon, New Mexico

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HYDROGEOLOGIC CHARACTERIZATION OF FRACTURED ABO AND MADERA FORMATION AQUIFERS, HYDROCARBON CONTAMINATION AND TRANSPORT ALONG THE ZUZAX FAULT, TIJERAS CANYON, NEW MEXICO

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Abstract—Three separate water producing zones and two localized perched zones were identified within approximately 240 ft of ground surface in the Abo Formation and uppermost Madera Formation during an investigation into gasoline contamination of ground water conducted by the authors for the New Mexico Environment Department (NMED) at the Indian Hills site in the vicinity of Zuzax and Tijeras, New Mexico. Ground-water flow beneath the site occurs in fractured sandstone and limestone beds that are separated by leaky mudstone and shale aquitards. Two separate hydrocarbon plumes located along the Zuzax fault have migrated into both unconfined and leaky-confined aquifers and have contaminated several domestic and commercial wells in the area. A 0.75-mi-long benzene, toluene, ethylbenzene, xylenes (BTEX) and methyl-tert-butyl ether (MTBE) plume and a 500-ft BTEX/EDC (dichloroethane) plume originate from separate locations. Under the influence of down-gradient pumping stresses, contamination of the aquifer located below the BTEX/MTBE source at a depth of 60–80 ft has migrated vertically along a structure perpendicular to the Zuzax fault into a leaky-confined aquifer located at a depth of 110–190 ft below ground surface. The BTEX/MTBE plume has subsequently migrated down-gradient along the northeast trending Juniper Ridge half-graben that parallels the Zuzax fault. Pumping test data and contaminant plume geometry indicate that bounding faults are impermeable or low-permeability barriers to horizontal ground-water flow and contaminant migration, and likely act as pathways for vertical ground-water flow and contaminant migration. Pumping tests conducted on wells completed into each aquifer show strong boundary effects from graben bounding faults, demonstrate communication between the Abo and upper Madera formations aquifers underlying the site, and indicate that the aquifer matrix contributes relatively little water to the aquifer system.

INTRODUCTION

A hydrogeological investigation into hydrocarbon contamination of fractured bedrock aquifers in the lower Abo and upper Madera formations in Tijeras Canyon between Tijeras and Zuzax, NM (Fig. 1) has been conducted by the authors and Glorieta Geoscience, Inc. (GGI) for the New Mexico Environment Department (NMED). The Indian Hills site (Fig. 1) is located approximately 15 mi east of Albuquerque along the Tijeras fault zone, a series of northeast-striking, high-angle faults extending over a distance of more than 50 mi from southwest of Albuquerque to the Cañoncito area south of Santa Fe (Abbott and Goodwin, 1995). The investigation was initiated after a local resident reported tasting gasoline in water pumped from her domestic supply well. Subsequent sampling and water quality testing confirmed the presence of hydrocarbon constituents in several domestic and commercial supply wells in the area. Initial sampling indicated that contaminated domestic wells 120–160 ft deep were located adjacent to relatively shallow (85-ft deep) domestic wells which exhibited little or no hydrocarbon contamination (Drakos et al., unpubl. report for NMED, 1992). Two separate hydrocarbon plumes and sources were identified during the course of the site investigation; (1) a large benzene, toluene, ethylbenzene, xylenes (BTEX) and methyl-tert-butyl ether (MTBE) plume originating from the Canyon Auto source area; and (2) a smaller BTEX/EDC plume originating from the Turner Branch (TB) source area (Fig. 5).

In conjunction with the NMED, GGI conducted an investigation utilizing (1) geologic mapping, (2) measurement of fracture orientations, (3) installation and sampling of monitoring wells, and (4) aquifer testing. The authors supervised a drilling program wherein wells were completed into three separate aquifers and localized overlying perched water zones between 30 and 240 feet below grade. Well screen intervals and surface casing depths were selected based on lithologies and fracture zones observed in continuously cored samples. Wells were drilled and completed into discrete water-bearing zones with overlying aquifers sealed off to prevent cross-contamination of aquifers. Pumping tests ranging in length from one to seven days were then conducted on the three aquifers underlying the site. Water levels were monitored regularly during pilot scale remediation tests up to seven weeks in length.

HYDROGEOLOGIC SETTING

The Indian Hills Site lies along the northeast trending Zuzax and Juniper Ridge faults and is underlain by Quaternary alluvium and upper Paleozoic sedimentary rocks (Fig. 2). Ground-water flow occurs in fractured sandstone and limestone beds that are separated by leaky aquitards composed of mudstone and shale. Due to facies changes and pinching out of channel sandstone beds within the Abo and Madera formations, correlating between individual boreholes, and between boreholes and outcrops, is problematic. Analysis of slickensides in core samples and in outcrops indicates a predominance of normal and right-

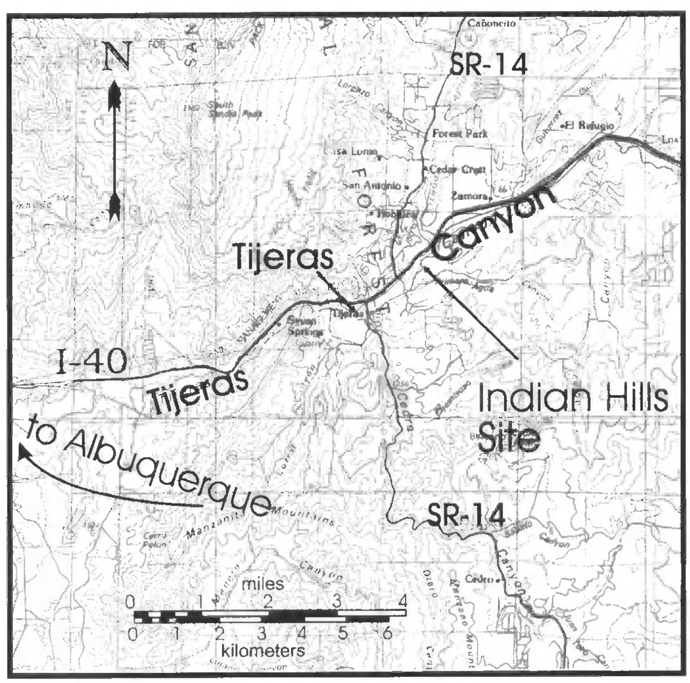

FIGURE 1. Site location map.

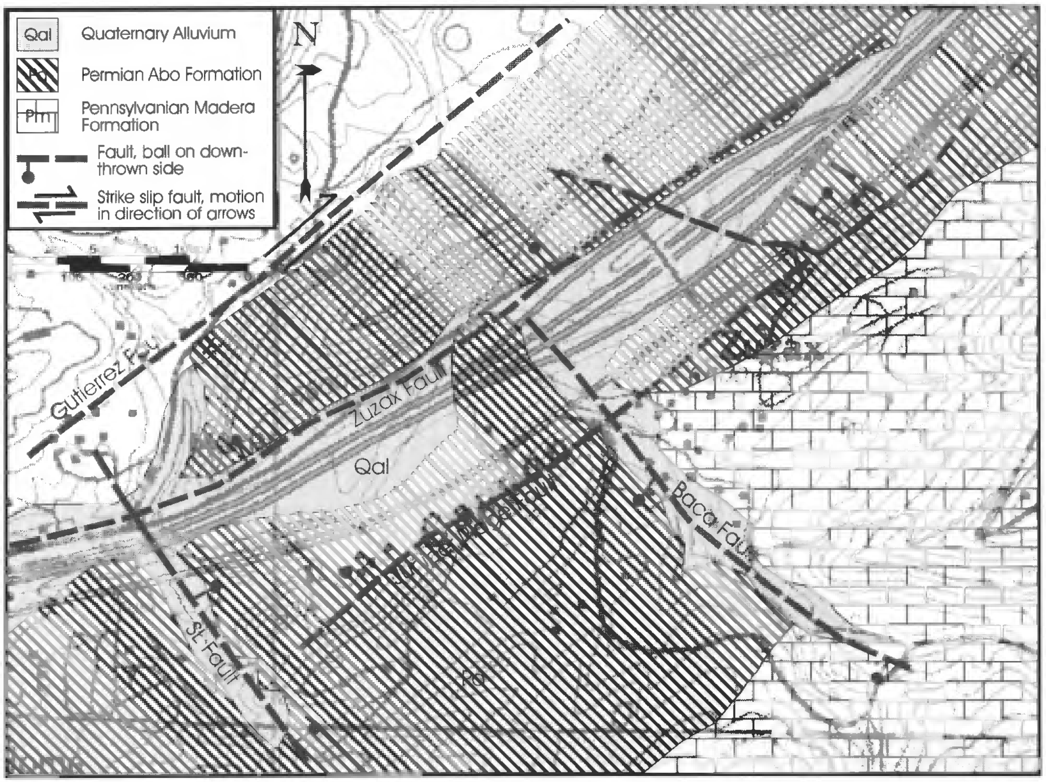

FIGURE 2. Geologic map of the Indian Hills site, Tijeras, New Mexico.

lateral movement. Ground-water flow in the site vicinity is structurally controlled.

Stratigraphy

The study area is underlain by the Pennsylvanian Madera Formation, Permian Abo Formation, and Quaternary valley-fill deposits (Figs. 2, 3). The Abo Formation consists of reddish-brown mudstone and shale with interbedded lenticular arkose beds. Some non-marine limestone beds are present near the base of the Abo Formation (Kelley and Northrop, 1975). The upper Madera Formation consists of interbedded gray limestone, sandstone, and variegated mudstone, with massive marine beds predominating in the lower Madera Formation. The top of the Madera Formation in the Sandia Mountains and the site vicinity is mapped at the top of the highest marine fossil-bearing beds in the Madera-Abo sequence (Kelley and Northrop, 1975). The overlying Permian Yeso Formation, San Andres Limestone, and Glorieta Sandstone are exposed northwest of the study area and are in fault contact with the Cretaceous-age Mancos Shale along the Gutierrez fault.

Structure

The predominant structural geological feature in the site vicinity is the northeast-trending Tijeras fault zone. The Tijeras fault zone transects the Sandia and Manzano mountains and extends at least 50 mi from the Rio Grande rift to the Cañoncito fault zone in the southern

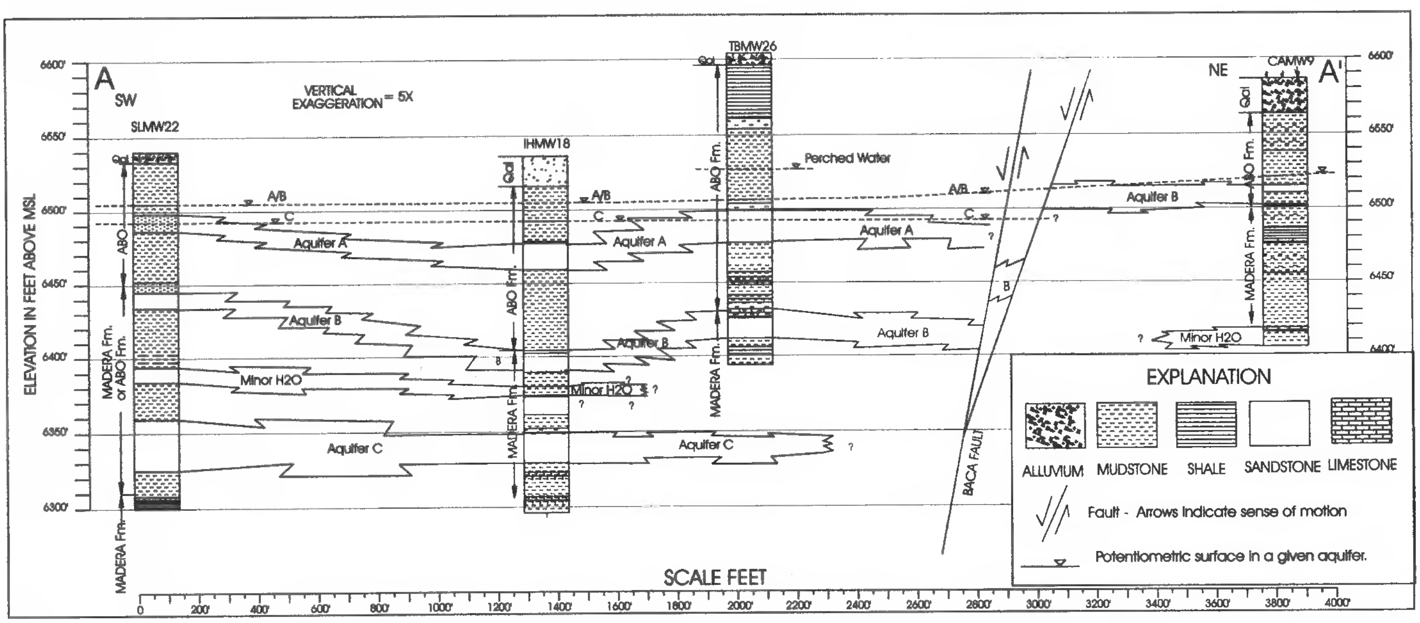

FIGURE 3. Hydrogeologic cross section of the Indian hills site. See Figure 4 for well locations.

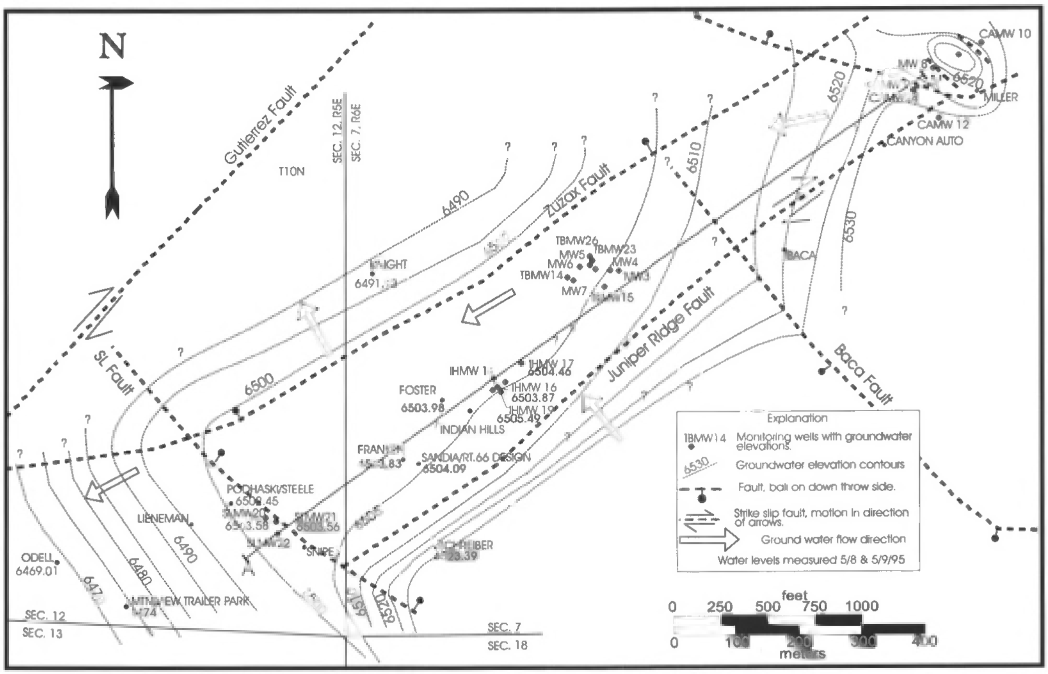

FIGURE 4. Potentiometric surface map for Aquifers A and B.

Sangre de Cristo Mountains (Lisenbee et al., 1979). The oldest documented activity on the Tijeras-Cañoncito fault system occurred during the Laramide orogeny, during which time the predominant movement was right-lateral slip (Abbott, 1995). The Tijeras-Cañoncito fault system was reactivated during the late Cenozoic in response to regional extension across the Rio Grande rift, and Neogene deformation along the Tijeras fault was characterized by left-lateral slip (Abbott, 1995). Abbott and Goodwin (1995) present evidence that the Tijeras fault has been active during the Quaternary.

The Indian Hills site lies along the northeast-trending Zuzax fault, a splay of the Gutierrez fault located within the Tijeras fault zone. Predominant fracture orientations are primarily oblique (NNW) and secondarily parallel to the Zuzax and Gutierrez faults (Drakos and Lazarus, unpubl. report for NMED, 1991). Several high-angle normal faults are oriented parallel to the dominant NNW fracture orientation and oblique to the Zuzax fault in the site vicinity (Fig. 2).

Within the site, the Juniper Ridge fault parallels the Zuzax fault (Fig. 4). The Juniper Ridge fault is inferred based on the presence of the Juniper Ridge escarpment, a change in water levels across the fault, and the presence of slickensides both in core from the Indian Hills Gallery well nest and in outcrop near Canyon Auto Chevron (Fig. 4). Although slickensides observed in outcrop near Canyon Auto Chevron indicate right-lateral motion for the Juniper Ridge fault, the predominant sense of motion (strike slip vs. dip slip) is unknown. Interpreting movement on the Juniper Ridge fault as down to the northwest (based on the topographic expression of the Juniper Ridge escarpment), the Juniper Ridge and Zuzax faults bound a northwest-tilted half graben.

Although predominant structural elements trend from southwest to northeast, the NNW-trending cross-cutting faults also play an important role in controlling ground-water flow and contaminant migration (both vertical and horizontal) through the site. The crosscutting faults are generally not truncated by the Zuzax and Juniper Ridge faults, indicating that more recent local movement has occurred on crosscutting faults than on the Zuzax and Juniper Ridge faults. The Baca fault is an important secondary structure that crosses the Juniper Ridge fault and offsets the aquifer system by approximately 100 ft (Fig. 3).

Aquifer system

Three aquifers and two separate shallow discontinuous water-bearing zones (referred to as "perched" ground-water in this paper) in the Abo and Madera formations have been defined based on lithology, aquifer characteristics, and the presence or absence of hydrocarbon constituents. Water-bearing intervals within the lower Abo and uppermost Madera formations generally occur in fractured sandstone and limestone, which are separated by mudstone and shale aquitards (Fig. 3). In order from uppermost (nearest to ground surface) to lowermost, the aquifers are referred to as Aquifers A, B, and C (Fig. 3). Discontinuous perched water zones occur in interbedded siltstone, mudstone, and thin sandstone beds located above Aquifer A or B.

Stratigraphically, Aquifer A occurs in a fractured sandstone layer within the Abo Formation, Aquifer B occurs in fractured sandstone and limestone at the Abo/Madera Formation contact or in fractured sandstone within the Abo Formation, and Aquifer C occurs in fractured, parallel-bedded or laminated sandstone within the Madera Formation (Fig. 3). The aquifer system is tilted approximately 15° to the northwest, and is offset across several faults which transect the site. In the area between Canyon Auto and the Baca fault, Aquifer A is absent, Aquifer B is the upper aquifer and is unconfined, and Aquifer C is leaky-confined or confined. Aquifers B and C are downdropped to the southwest across the Baca Fault (Fig. 3). Aquifer B changes from unconfined to leaky-confined across the Baca fault. Aquifer A is present southwest of the Baca Fault. Aquifer A is apparently recharged from Juniper Ridge and receives a small amount of water and MTBE via upward leakage from Aquifer B. Aquifer C is present throughout the site. Based on the absence of any hydrocarbon constituents in Aquifer C, and the difference in water levels between Aquifers B and C, Aquifer C is separated hydrologically from Aquifer B. Aquifer B contains BTEX constituents within the area of the contaminant plume. The perched water zone contains phase-separated hydrocarbons (PSH) in the source areas of the site.

Ground-water flow direction

Ground-water flow in the Indian Hills site vicinity is structurally controlled. Aquifers A and B have a similar head due to leakage between the aquifers and a composite Aquifer A and B potentiometric surface map shows the overall ground-water gradient in the site vicinity is from northeast to southwest, parallel to Tijeras Canyon (Fig. 4). A second component of ground-water flow is down-dip, with water flowing to the northwest, from Juniper Ridge across the Zuzax fault and toward the Gutierrez fault (Fig. 4). The potentiometric surface is relatively flat within Juniper Ridge graben, between the NW-trending, cross-cutting SL and Baca faults (Fig. 4). The flattening of the gradient within the

Juniper Ridge graben indicates that the Juniper Ridge graben between the Canyon Auto site and the SL fault is an area of relatively high transmissivity. Recharge from precipitation and leakage from ephemeral streams occurs along the Baca and SL faults, along the Juniper Ridge fault, and from the up-gradient (NE) end of Tijeras Canyon.

EXTENT OF HYDROCARBON PLUME

Twenty-five ground-water monitoring wells have been installed to delineate the extent of the hydrocarbon plume beneath the site (Fig. 5). A total of 21 domestic wells have been sampled one or more times to provide additional data on the extent of hydrocarbon contamination in the site vicinity. The geometry of the contaminant plume indicates that contaminant migration is strongly influenced by pumping stresses and by structural geologic controls on ground-water flow. Two separate hydrocarbon sources have been identified at the Indian Hills site: a BTEX/MTBE plume in the perched water zone and in Aquifer B in the vicinity of the Canyon Auto property and a BTEX/EDC plume localized in the vicinity of the TB property in the perched water zone (Fig. 5). The BTEX/MTBE plume extends approximately 0.75 mi down-gradient from the Canyon Auto source area within the Juniper Ridge graben (Fig. 5) and has contaminated leaky-confined Aquifer B at a depth of 110–160 ft below the surface in the vicinity of the TB and Indian Hills gallery sites. Aquifer A is clean or contains only low concentrations of hydrocarbon constituents; therefore, shallow domestic wells completed only into Aquifer A are essentially clean whereas neighboring deeper domestic wells completed into Aquifer B are contaminated. PSH (gasoline floating on top of the water table) is present adjacent to the Canyon Auto source area.

Leaky-confined aquifer B has been contaminated as a result of downward leakage from the perched zone in the Canyon Auto source area and as a result of downward ground-water flow along the Baca fault. It is likely that downward ground-water flow and contaminant migration along the Baca fault was induced by pumping of several domestic wells (Indian Hills Gallery well, Sandia Well Drilling/Sandia Furniture well, Roman Franken well, and several other domestic wells in the area) located down-gradient from and within the same structural block as the Canyon Auto source area (Fig. 5). Aquifer testing data presented below demonstrate that pumping effects from discharge rates of 5–10 gal per minute (gpm) (rates often equaled or exceeded during domestic well use) are observed at distances of 0.5 mi or more.

Contamination of ground water has not been observed on the southeast side of the Juniper Ridge fault, indicating that the fault acts as a barrier to horizontal ground-water flow. The presence of low MTBE concentrations in the Lieneman domestic well suggests that the SL fault is not a strictly impermeable boundary; however, MTBE or BTEX constituents have not been observed down-gradient from the Lieneman well (Fig. 5). The steepening in the ground-water gradient and the absence of hydrocarbon constituents in wells down-gradient of the Lieneman well indicate that the SL fault is a low-permeability zone that inhibits horizontal ground-water flow and down-gradient contaminant migration. Due to the absence of deep wells on the northwest side of the Zuzax fault, data for evaluating the effect of the Zuzax fault on contaminant migration in the site vicinity are lacking. However, the dip of the Abo Formation changes from 10° to 15° to the northwest on the southeast side of the Zuzax fault to 25° to 35° to the northwest on the north side of the Zuzax fault. It is therefore possible that low-permeability mudstone or shale beds are juxtaposed against higher-permeability sandstone beds across the fault and that the Zuzax fault acts as an impermeable boundary.

AQUIFER TESTING RESULTS

Seven-day pumping test on Aquifer B

A seven-day pumping test was conducted in December 1995 using pumping well IHMW17, completed into Aquifer B. Observation wells completed into Aquifers A, B, C, and one perched water zone were monitored during the test (Fig. 6; Table 1). The test was run at an average discharge (Q) of 18.3 gpm. Drawdown was observed in two wells completed into Aquifer A and one perched water zone well in addition to all Aquifer B wells monitored during the test (Table 1). These data demonstrate that leakage occurs between aquifers A and B, and likely from the perched water zones into the underlying aquifers.

Analysis of drawdown data is complicated by recharge derived by leakage from Aquifer A and by impermeable boundary effects caused by the Juniper Ridge and Zuzax faults. Transmissivity (T) of 400 ft^2/day and storage coefficient (S) of 1.5×10^{-4} that are likely representative of the fracture permeability of the aquifer were calculated from the early-time data from observation well TBMW26 (Fig. 7). Using an average aquifer thickness of 15 ft for Aquifer B, the hydraulic conductivity (K) of the fractured sandstone aquifer is approximately 27 ft/day. The impermeable boundary effects illustrated in Figure 7 are typical of the response of Aquifer B observation wells during the pumping test and indicate dewatering of the aquifer during the test. The 1:1 slope of

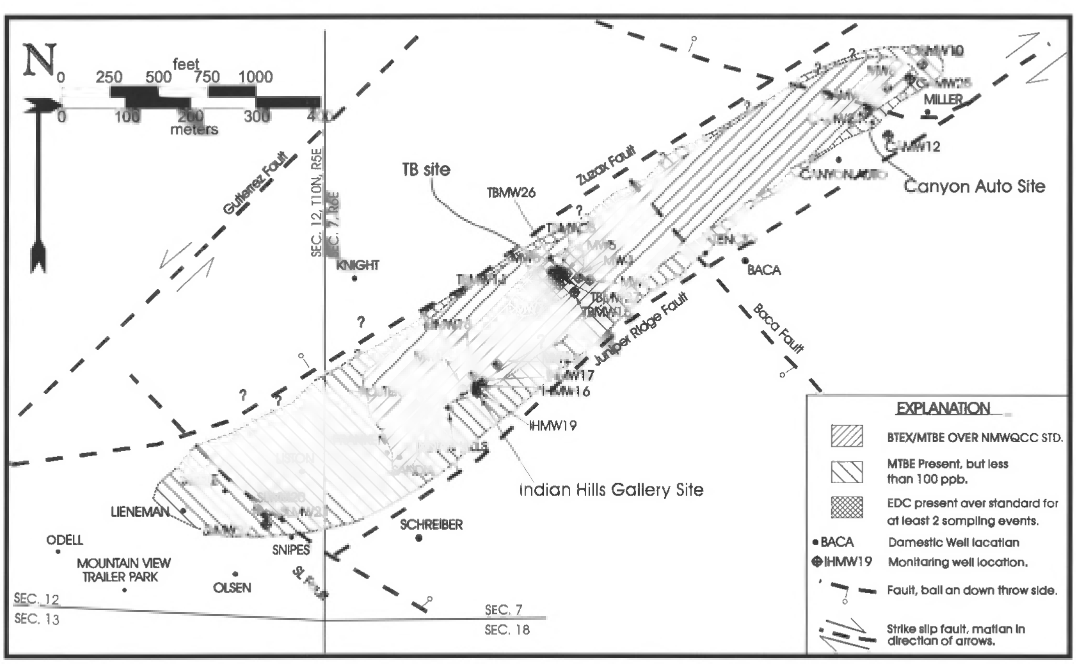

FIGURE 5. Extent of hydrocarbon contamination of ground-water, Indian Hills site.

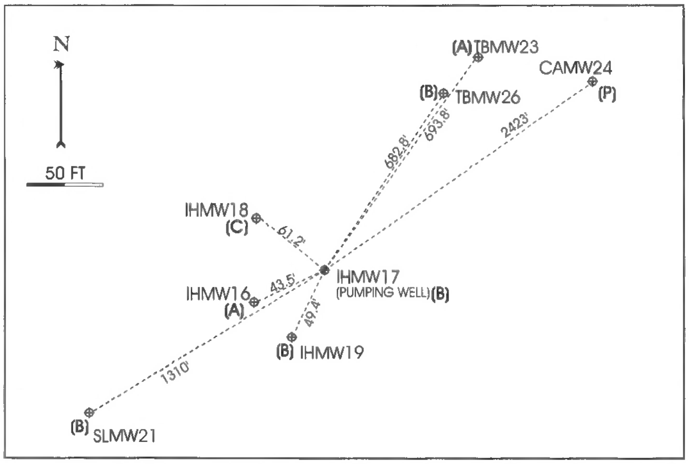

FIGURE 6. Schematic map showing distances in feet of observation wells from pumping well for seven-day Aquifer B pumping test.

the late time drawdown data observed in all Aquifer B wells is similar to well-bore storage effects typically observed in early-time pumping test data (Kruseman and de Ritter, 1990, p. 219). These data suggest that the fractured Aquifer B sandstone between the Baca and SL faults is laterally confined and limited by faults, and acts as one large well bore during the later part of the test. This conclusion is supported by the similar drawdowns observed in other Aquifer B wells (pumping well, IHMW17, IHMW19, and TBMW26) located between the SL and Baca faults, and the much smaller total drawdown observed in SLMW21, located west of the SL fault (Table 1; Fig. 5). Although significant drawdown is observed in Aquifer A wells, the volume of water supplied to Aquifer B via leakage from Aquifer A must be relatively small in comparison to effects of the impermeable boundaries of the Juniper Ridge and Zuzax faults. The lack of any flattening in the curve observed for the late-time data indicates that the sandstone matrix contributed very little water during the course of this pumping test and that this aquifer cannot be characterized as a dual porosity system on the basis of the tests conducted.

Permeability testing of core samples

Additional data on matrix porosity is provided by permeability testing of core samples conducted by Sandia National Laboratories (V. Tidwell, unpublished report to Glorieta Geoscience, 1997). All permeabilities of the sandstone matrix were near the lower detection of the instrument (1 x 10–15 m^2), and ranged from 9.12 x $10^{-15}m^2$ to 2.01 x $10^{-14}m^2$ (V. Tidwell, unpublished report to Glorieta Geoscience, 1997). These values represent a range in matrix hydraulic conductivity from 2.5–5.6 x 10^{-2} ft/day, several orders of magnitude less than the estimate of fracture K calculated from the early-time pumping test data. The permeability of a sample of mudstone aquitard was below the detection limit of the instrument, or less than to 1 x $10^{-15}m^2$ (V. Tidwell, unpublished report to Glorieta Geoscience, 1997). These data support inferences made from the pumping tests that the aquifer matrix exhibits low

TABLE 2. Summary of aquifer test analysis for December 1995 seven-day pumping test in Aquifer B and April 1994 24-hour pumping test on Aquifer A.

Well name	Radial Distance, ft	T (ft^2/day)	Storage Coefficient
	Aquifer B pumping test results		
TBMW26	680	400	1.5 x 10^{-4}
	Aquifer A pumping test results		
TBMW15	705	2500	8 x 10^{-4}
IHMW2	139	2100	3 x 10^{-3}
IHMW1	39	3200	9 x 10^{-3}
IHMW16	0	3000	
Average values, Aquifer A test		2700	

TABLE 1. Drawdown at end of seven-day pumping test in Aquifer B; time (t) = 10,060 min., Q = 18.3 gpm.

Well	Distance from pumping well (ft)	Aquifer	Total drawdown (ft)
IHMW17	0	B	43.83
IHMW19	49	B	40.46
TBMW26	680	B	36.62
SLMW21	1310	B	2.72
IHMW16	44	A	3.32
TBMW23	700	A	2.92
CAMW24	2420	P	1.75
IHMW18	6	C	0.01

permeability, and that relatively little water is contributed to the aquifer system from the aquifer matrix.

Twenty-four hour pumping test on Aquifer A

A separate 24-hr pumping test was conducted on well IHMW16 completed into Aquifer A in April 1994. The test was run at an average discharge (Q) of 30 gpm. Drawdown was observed in well IHMW17, completed into Aquifer B, in addition to wells completed into Aquifer A. Analysis of drawdown data is complicated by impermeable boundary effects caused by the Juniper Ridge and Zuzax faults. Analysis of early-time aquifer test data indicates a relatively higher fracture T value of 2700 ft^2/day (K = 110 ft/day) compared to T and K values calculated for Aquifer B, and a wide range of S from 8 x 10^{-4} to 9 x 10^{-3} (Table 2). It is likely that at the shallow depth of Aquifer A (40–70 ft), fractures have a greater aperture and therefore T and S values are higher than observed for Aquifer B, encountered at a depth of 110–178 ft below surface throughout the site. These data indicate a decrease in fracture aperture and/or decreasing interconnectedness with depth.

Twenty-four hour pumping test on Aquifer C

The decrease in T with depth is further substantiated by data from a 24-hour pumping test conducted on Aquifer C well IHMW18 in April 1994 at an average Q of 15 gpm. Aquifer C was encountered in IHMW18 from 189–215-ft below ground surface. Observation wells were not available for this test. A fracture T of 310 ft^2/day and a K of 12 ft/day were calculated from this test. Due to the relatively short test duration and low discharge rate, boundary effects were not observed during the Aquifer C pumping test.

CONTAMINANT TRANSPORT INDUCED BY PUMPING STRESSES

Contaminant transport through the aquifer system in the site vicinity is strongly influenced by pumping stresses. The seven-day pumping

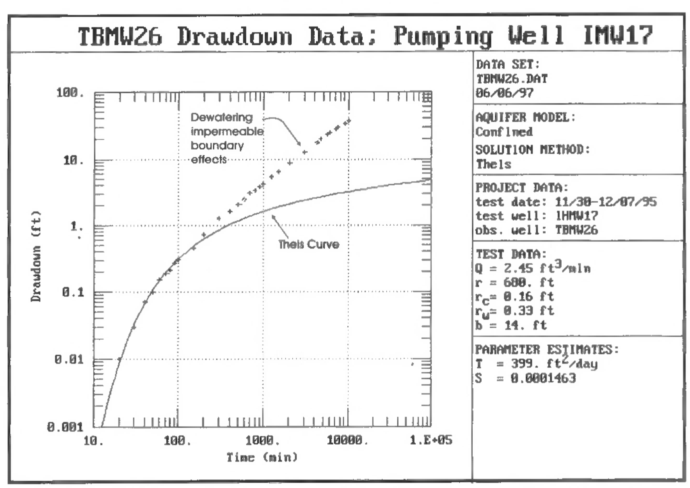

FIGURE 7. Data plot from observation well TBMW26 showing early-time Theis curve-match solution.

test resulted in significant dewatering of wells completed into Aquifer B in addition to several feet of drawdown in Aquifer A wells located within the Juniper Ridge half-graben (Table 1; Fig. 4). The drawdown observed in CAMW24, completed into the leaky perched water zone above Aquifer B in the Canyon Auto source area, indicates that vertical ground-water flow and contaminant migration can be induced in the source area by pumping in Aquifer B from IHMW17, located 2400 ft away in the down-gradient direction. Vertical ground-water flow along the Baca fault is likely induced by pumping from leaky-confined Aquifer B in the area down-gradient from the fault. The initial vertical migration of hydrocarbon contamination from the perched water zone into Aquifer B and subsequently downward along the Baca fault was likely a result of pumping from the domestic wells located in the vicinity of IHMW17 (e.g., Indian Hills, Sandia, and Franken domestic wells; Fig. 4).

PILOT SCALE REMEDIATION SYSTEM TESTING

Two separate pilot-scale remediation tests were conducted, using: (1) IHMW17 as a down-gradient plume containment/dissolved phase constituent remediation system, and (2) CAMW24 as a source area PSH recovery and dissolved phase constituent remediation system (Fig. 5; Drakos, unpubl. report to NMED, 1997). Test duration ranged from 10 days to seven weeks. Test results indicate that the most effective site remediation is likely free product recovery and dissolved phase treatment and reinjection in the Canyon Auto source area. IHMW17 can be used effectively as a dissolved phase plume containment well, but continuous pumping at a Q of 5–10 gpm may result in dewatering of Aquifers A and B throughout the site.

IHMW17 (Aquifer B) was pumped for seven weeks at discharge rates ranging from 5.1 to 11.3 gpm. IHMW18 (Aquifer C) exhibited approximately 8 ft of drawdown during the seven-week pilot test, providing the first clear evidence that Aquifers B and C are hydrologically connected. Water level declines were also observed in Aquifer A and in some wells completed into perched water zones throughout the site. Based on water level recovery measurements collected following system shut-down, due to boundary effects, complete water level recovery had not occurred in Aquifers A, B, or C seven weeks after the cessation of pumping. Five months after system shut down, all wells in Aquifer A and B had fully recovered, but IHMW18 (Aquifer C), still exhibited 13 ft of residual drawdown. The sustainable pumping rate of Aquifer B alone is likely in the range of 2–4 gpm. A pumping rate of 2–4 gpm is likely sufficient to contain the Aquifer B BTEX/MTBE plume but would have the undesired effect of moving contaminants long distances horizontally and vertically through the aquifer system.

Pumping of CAMW24, located in the Canyon Auto source area (Fig. 5), at a Q of around 2 gpm was sufficient to lower the water level in the well to a depth at which PSH would flow from fractures into the well and be recovered. PSH was recovered from an area with a radius of over 155 ft. Pumping and injection tests conducted on nearby well CAMW25, completed into Aquifer B, demonstrate that CAMW25 is capable of accepting an injection rate of 2–4 gpm. Water levels in the overlying perched aquifer will likely not be significantly affected.

Because matrix porosity appears to contribute very little water to this aquifer system, it is likely that the volume of hydrocarbon constituents absorbed within the aquifer matrix pore spaces is negligible. A conventional pump and treat remediation system or an in situ air stripper system located in the source area may be an effective remediation tool for this particular hydrogeologic system. Down-gradient plume containment is not an option at this time because increased risk to domestic water supplies may result from moving contaminants through the aquifer system.

WATER SUPPLY IMPLICATIONS

The pumping test and pilot scale remediation testing results indicate that very little water is derived from the fractured aquifer matrix and the entire aquifer system within approximately 250 ft of ground surface in the Juniper Ridge graben is capable of long-term production of 10 gpm or less. At present, at least eight domestic wells are completed to a depth of less that 250 ft in this area. The NMED has been supplying water to several of the domestic well users. Once all wells are brought back into production, the potential exists for significant dewatering of the aquifer system and drying up of wells in the area.

CONCLUSIONS

Aquifer testing and contaminant plume geometry demonstrate that contaminant migration through aquifers in the vicinity of the Zuzax fault northeast of Tijeras, NM, is structurally controlled. Aquifer test and permeability testing data are indicative of a fracture-flow aquifer system wherein water is derived from fractures with very little water contributed from matrix porosity. The aquifer test data demonstrate a decrease in fracture T with depth. Testing data also demonstrates that leakage occurs between aquifers A, B, and C, and likely from the perched water zones into the underlying aquifers.

Movement of contaminants through the aquifer system in the site vicinity is strongly influenced by pumping stresses. The initial vertical migration of hydrocarbon contamination from the perched water zone into Aquifer B and subsequently downward along the Baca fault was likely a result of pumping from the domestic wells located in the vicinity of IHMW17. The BTEX/MTBE plume extends approximately 0.75 mi down-gradient from the Canyon Auto source area within the Juniper Ridge graben which parallels the Zuzax fault (Fig. 5) and has contaminated leaky-confined Aquifer B at a depth of 110–160 ft below the surface in the vicinity of the TB and Indian Hills gallery sites.

The entire Aquifer A and B system in the Juniper Ridge graben between the Baca and SL faults can be dewatered by pumping continuously from Aquifer B at discharge rates of 10 gpm or less. A conventional pump-and-treat remediation system or an in situ air stripper system located in the source area may be an effective remediation tool for this particular hydrogeologic system. However, once remediation is complete and all wells are brought back into production, the potential exists for significant dewatering of the aquifer system and drying up of wells in the area.

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