

EVALUATING PRESENCE OF TCE BELOW A SEMI-CONFINING LAYER IN A DNAPL SOURCE ZONE

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ABSTRACT: Installation of three dual-stage monitoring wells in a DNAPL source zone was performed at Launch Complex 34, Cape Canaveral Air Station, Florida. The objective of the monitoring well installation was to determine the presence of the DNAPL or dissolved-phase TCE contamination below a relatively thin aquitard. The monitoring wells were installed with a telescopic dual-stage method to isolate the DNAPL in the surficial aquifer and prevent any vertical DNAPL migration into the Deep aquifer. A mud-rotary drilling rig was used to isolate the DNAPL, while a continuous outer casing was keyed into a semi-confining clay unit above the lower (deep) aquifer. The aquitard was determined to be a semi-confining layer with approximately 3 ft in thickness. After the outer surface casing was set and grouted, a continuous smaller inner casing was installed within the outer casing to isolate any DNAPL in the upper aquifer. The inner stainless steel casing penetrated the semi-confining unit to the deep aquifer, with the screen depths at 55 to 60 feet below ground surface (bgs) level. During the well installation, the drilling mud was screened for volatile organic compounds (VOCs) with a photoionization detector (PID) to evaluate any potential drag-down of DNAPL or dissolved-phase contamination from near the bottom of the surficial aquifer to the deep aquifer. At no time did the PID detect VOCs in the drilling mud, indicating that no significant contamination was entering the borehole and migrating downward as the drilling advanced. Soil samples were collected continuously beginning a few feet above the semi-confining clay layer to a few feet below this clay unit into the deep aquifer. These soil samples, as well as groundwater sampling from the completed monitoring wells, indicated that TCE was present both in the clay, as well as in the deep aquifer below the clay layer at some locations. The wells were also used to determine the hydrologic properties of the deep aquifer. The well installation technique provided an effective way of monitoring the deep aquifer in the DNAPL source zone for the presence of contamination.

INTRODUCTION

At Launch Complex 34 there are several layered aquifers, reflecting a barrier island complex overlying coastal sediments. A surficial aquifer comprising of layers of silty sand and shells extends down to about 45 ft below ground surface (bgs), where a semi-confining layer is encountered. The semi-confining unit consists of gray clay with medium to high plasticity. Previous logging and geophysical surveys (Resolution Resources, 2000) suggested that the clay layer is only 1-3 ft thick and discontinuous in areas. A 40-50 ft thick semi-confined aquifer resides under the clay layer and is composed of silty to clayey sand and shells. Underlying the deep aquifer is the Hawthorne forma-

tion, a clayey sand-confining layer, and the limestone Floridan Aquifer which is a major source of drinking water for much of Florida (Shmalzer and Hinkle, 1990).

At the site, TCE DNAPL was detected above and within the semi-confining clay layer at a depth of approximately 45 ft bgs (Battelle, 1999; Eddy-Dilek et al., 1998, G&E Engineering, 1996). As shown in Figure 1, three innovative remediation technologies (Six-Phase Heating™ [SPH™], in situ chemical oxidation, and steam injection technologies), were applied in the surficial aquifer at the site as part of the Interagency DNAPL Consortium (IDC) activities. To determine the competency of the semi-confining layer and whether any contamination migrated through this layer into the deep aquifer, three monitoring wells were completed in the deep aquifer with a dual-stage approach. Figure 1 shows the locations of the semi-confined aquifer wells (PA-20, -21, and -22), surficial aquifer wells, and technology demonstration plots at Launch Complex 34. High concentrations of volatile organic compounds are found in the surficial groundwater throughout the site and two of the wells were installed through the suspected DNAPL zone. Hydraulic testing and groundwater sampling were performed in the semi-confined aquifer wells and nearby surficial aquifer wells. Results were analyzed to further understanding of hydrogeology at the site and determine the nature of DNAPL migration through discontinuous confining layers.

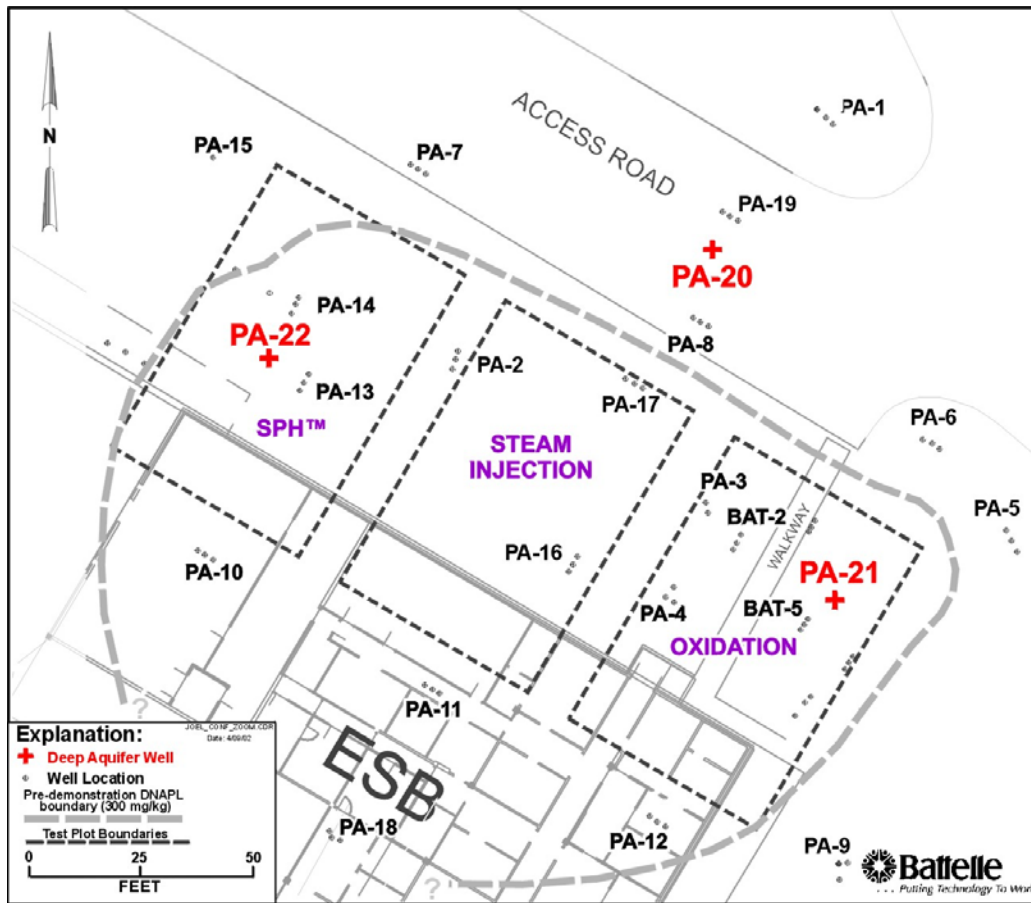


FIGURE 1. Site Map of LC34 Showing Deep Aquifer Wells and Surficial Aquifer Wells in DNAPL Source Zone

WELL INSTALLATION METHODS

A dual-stage approach was used for well installation to prevent the migration of DNAPL from the surficial aquifer to the underlying deep aquifer. To verify the depth of the semi-confining unit at each well location, a 3 7/8-inch pilot hole first was installed to a depth of 40 ft using a tri-cone roller bit. Next, split spoon samples were collected in 2-foot (or 1-foot) intervals from about 36 ft bgs to the top interface of the clay unit. Once the depth of the clay layer was found, a 10-inch borehole was advanced into it and completed with 6-inch stainless steel (surface) casing. The surface casing was advanced until it established a key between the surface casing and the semi-confining unit. The borehole was grouted outside the surface casing and allowed to set. In the second stage of drilling, a 5 7/8-inch borehole was drilled through the inside of the surface casing to a depth of 61 ft bgs. A 2-inch casing with screen was advanced through the deeper borehole to set the well with a sand pack. This borehole also was grouted in the annular space between outside the 2-inch casing and inside the surface casing. Figure 2 shows the well completion diagram for the three deep aquifer wells. The soils were logged for soil type and description, photo-ionization detector (PID) scans were run, and two-foot soil core samples from a split spoon sampler were collected for methanol extraction and VOC analysis.

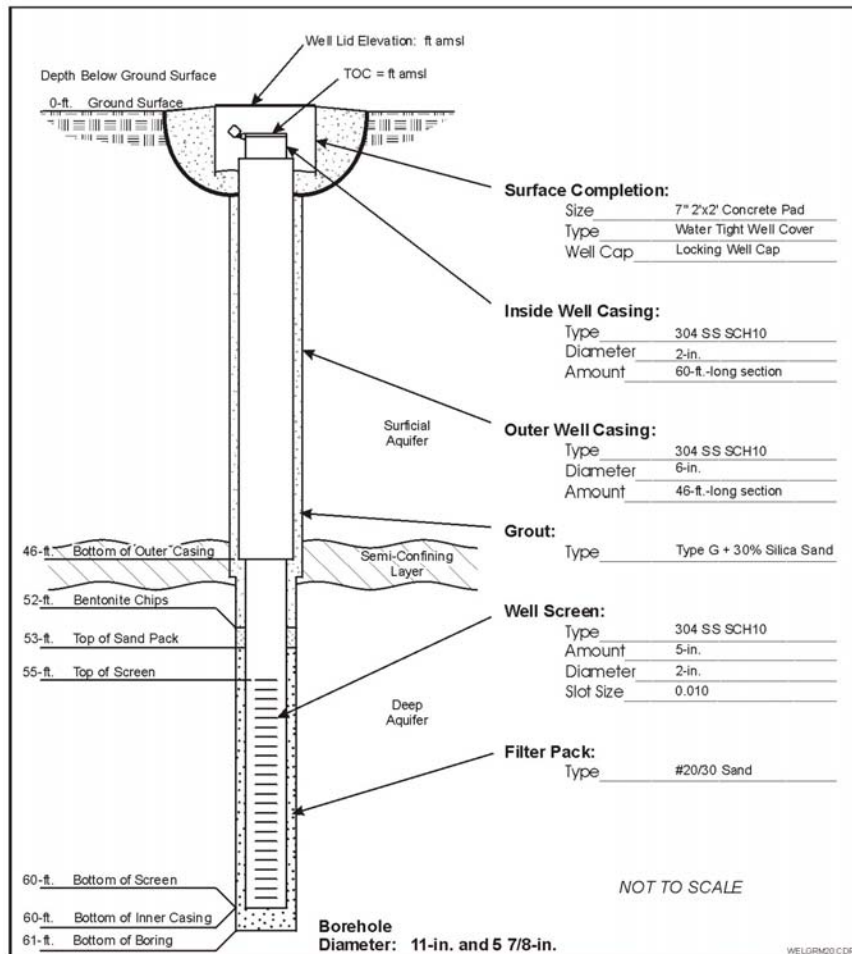


FIGURE 2. Well Completion Diagram for Dual-Stage Well

Drilling mud was used to advance the borehole, to seal the borehole and to prevent DNAPL movement during well installation. The drilling mud was mixed to a density and viscosity that is greater than both groundwater and the bulk density of soil. This mud was pumped down through the drill pipe, out through the drill-bit, and then pushed upward (circulated) through the borehole annulus into the mud pit (open space between drilling rods and borehole wall). Use of the mud stabilizes the borehole, even in sandy soils, enabling advancement of the borehole in depths well below the water table without heaving or caving. The mud seals the borehole walls, preventing the borehole from being invaded by groundwater and potential DNAPL or dissolved TCE contaminants. The mud also lifts all of the cuttings created by the drill bit as the hole is advanced. Once the drilling mud rose to the top of the annulus, it was captured in the mud pit where cuttings were removed by a series of baffles through which the mud was circulated. The mud pit was monitored with a PID throughout the drilling process. At no time did the PID detect VOCs in the drilling mud, indicating that no significant levels of contamination were entering the borehole and being carried downward into cleaner aquifer intervals as the drilling advanced.

Geologic logs of the three semi-aquifer wells show that the aquitard is thinnest in the northwest portion of the site (near PA-22 under the SPH plot), where it is only around 1.5 ft thick. The thickness of the aquitard increases in the eastward and northward directions. A geologic cross-section across the site is shown with the varying thickness of the aquitard in Figure 3. Split spoon samples of the lower clay unit show it to be a gray-colored clay with moderate to high plasticity. The clay is overlain by a silt zone, which in turn is overlain by sand. The entire sand-silt-clay sequence appears to be gradational and fining downward with respect to grain size. In PA-21, the overlying sand and silt intervals were more contaminated than the deep aquifer. Sandier soils were encountered directly below the semi-confining unit. Only at the PA-20 well did soils underlying the clay unit appear to be clean.

Soil samples were collected for lab analysis from each split spoon. Care was taken to collect samples that were most representative of each split-spoon sample. Almost all the soil in an entire vertical half of each split-spoon was collected for the extraction and analysis. Multiple samples were collected in cases where both clays and sand were recovered in a spoon. Field screening with a PID showed readings exceeding 1,000 ppm at both the PA-21 and PA-22 locations both above and below the clay unit.

Figure 4 summarizes the CVOC analysis results of the soil samples collected at depths of approximately 40 to 60 ft bgs where the clay unit is approximately 45 to 48 ft bgs. Soil samples from PA-20 did not show any concentrations approaching the DNAPL threshold of 300 mg/kg (based on the TCE saturation in pore water; Battelle 1999) at any depth. Soil samples from PA-21 indicated the presence of DNAPL in the surficial aquifer and the clay unit, but relatively low levels of TCE in the deep aquifer. PA-22 showed the presence of DNAPL in the lower clay semi-confining unit and deep aquifer; TCE levels were as high as 40,498 mg/kg in the deep aquifer (54-56 ft bgs) at this location. No monitoring was conducted in the lower clay unit or in the semi-confined aquifer before the application of the three remediation technologies due to the concern of breaching the relatively thin aquitard.

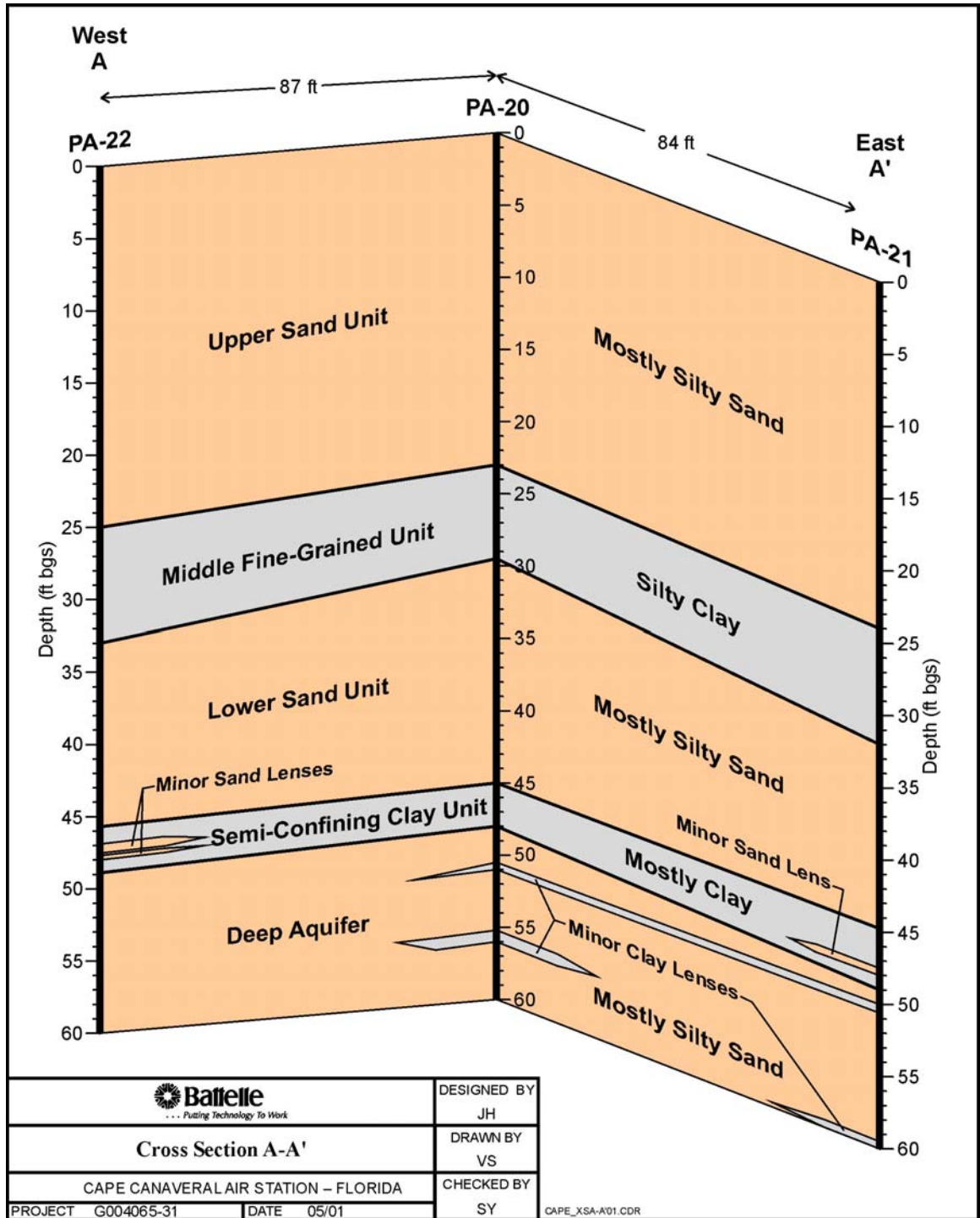


FIGURE 3. Geologic Cross-section View through Deep Aquifer Wells at Launch Complex 34 Showing Semi-Confining Clay Layer Separating Surficial Aquifer from Deep Aquifer

Although the clay unit is approximately 3 ft thick as indicated earlier, it appears to contain sand lenses near PA-22 that reduce the effective thickness of the aquitard to be approximately 1.5 ft. Therefore, the barrier to downward migration is geologically weaker in this region. This corresponds to the geophysical data prepared by RRI (2000) supporting that it is likely to be in a fractured zone. Once geophysical data were obtained (after the SPH and oxidation remediation technologies were demonstrated) showing the possible presence of DNAPL in the semi-confined aquifer, there was renewed interest of investigating below the semi-confining clay layer.

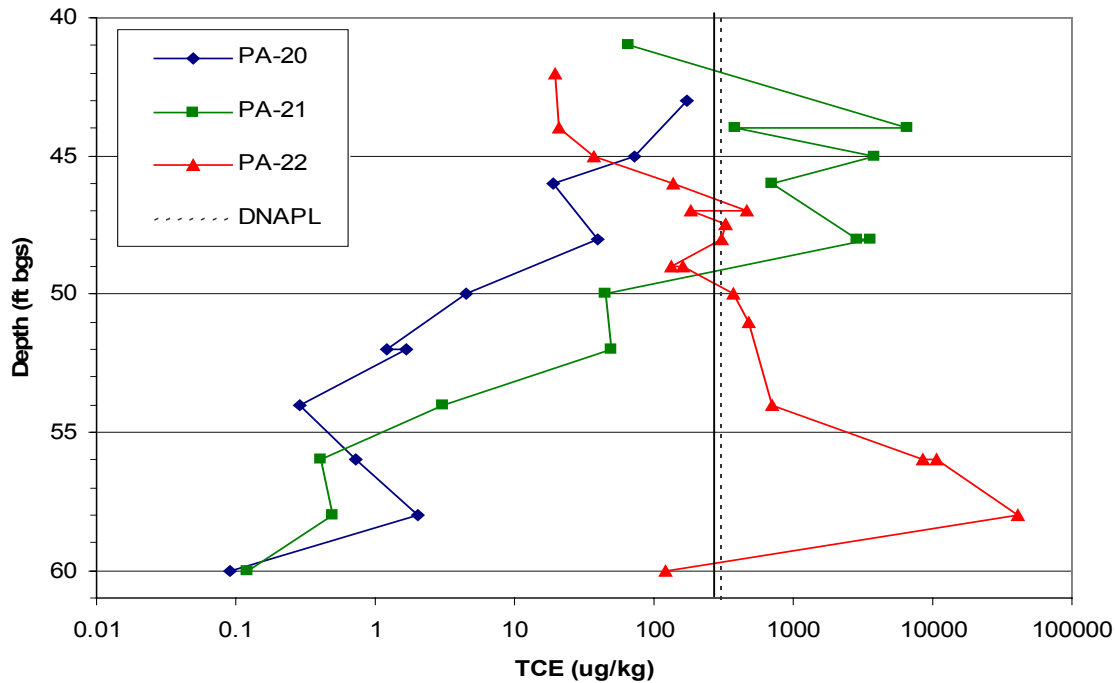


FIGURE 4. TCE Concentrations in Soil with Depth in Deep Aquifer Soil Borings

Groundwater samples from the deep aquifer wells reinforce the soil sampling results. High levels of TCE approaching solubility were observed in PA-22 where high soil concentrations were also observed. In wells PA-20 and PA21, lower VOC concentrations were measured, suggesting that the semi-confining clay layer is more competent in these areas and free phase contamination has not migrated it into the deep aquifer in this area. Overall, VOC concentrations are declining or stable in wells PA-20 and PA-21, while they are increasing slightly in well PA-22 suggesting a potential DNAPL vertical migration in this area due to the fractured zone. Figure 5 summarizes TCE concentrations over time in the deep aquifer wells.

Slug tests were also performed in the deep aquifer wells and analyzed with the Bouwer (1989), Bouwer and Rice (1976), and Hvorslev (1951) methods for slug tests. Overall, the hydraulic conductivity estimates range from 0.4 to 29.9 ft/day. It appears that the aquifer conductivity near well PA-20 is greater than near PA-21 and PA-22. The

hydraulic conductivity of wells PA-21 and PA-22 is lower and reflects the silty-clayey sands that were observed during drilling. The conductivities in the deep aquifer are similar to the conductivities measured in the surficial aquifer wells.

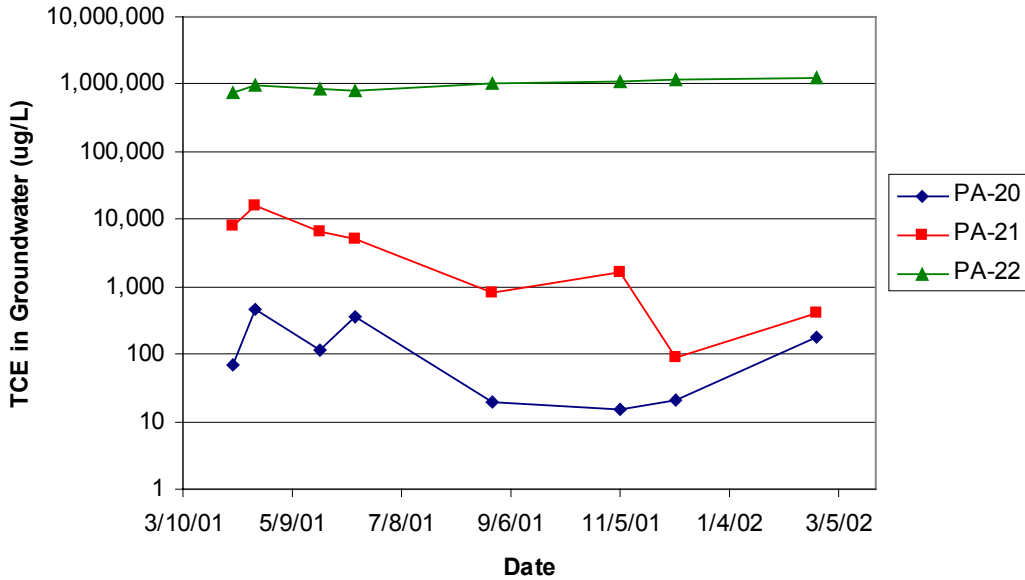


FIGURE 5. TCE Concentration Changes in Groundwater Within Deep Aquifer Wells

Several water level surveys were performed in the deep aquifer wells. Table 1 summarizes gradients observed in the deep aquifer wells. Overall, the surveys indicate that there is an eastward or northeastward gradient at 0.001 to 0.005 ft/ft, similar to the site-wide gradient observed in the surficial aquifer.

TABLE 1. Summary of Gradient Direction and Magnitude in the Deep Aquifer

Date	4/19/01	5/24/01	7/2/01	8/28/01	11/8/01	12/4/01	1/21/02	1/25/02	2/20/02
Direction	ENE	E	ENE	SW	NE	NW	ESE	ESE	ENE
Magnitude (ft/ft)	0.0046	0.0056	0.0052	0.0033	0.0028	0.0013	0.0014	0.0013	0.0026

Water levels were compared in deep aquifer wells paired with nearby surficial aquifer wells in order to evaluate vertical gradients between the surficial aquifer and deep aquifer. Figure 6 summarizes vertical gradients. A positive vertical gradient suggests upward flow from the deep aquifer to the surficial aquifer, which would inhibit downward migration of contamination. A negative gradient would promote downward migration. As shown, it appears that the vertical gradient fluctuates, beginning as upward

when the wells were installed, changing to a downward gradient in the Fall of 2001, and finally recovering to an upward gradient.

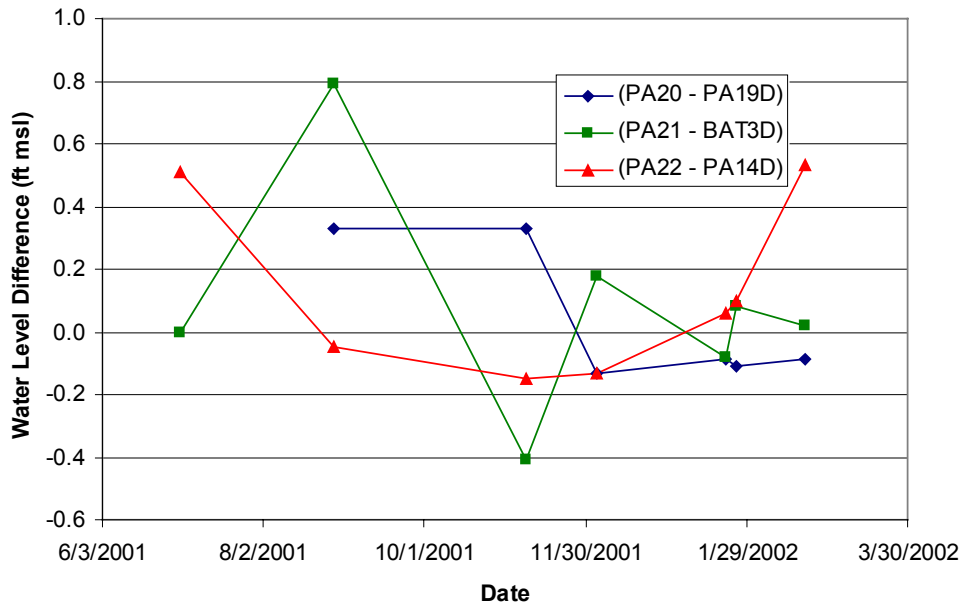


FIGURE 6. Vertical Gradients Between Paired Wells

CONCLUSIONS

Three semi-confined aquifer wells were completed under a DNAPL zone using a dual-stage drilling method to ensure that they were sealed from the surficial aquifer above while evaluating the semi-confining clay layer and deep aquifer. A semi-confining clay unit occurs at approximately 45 ft bgs and is 3 ft thick but was found to contain sand lenses that appeared to reduce the effective thickness of the aquitard in one location. Soil and groundwater sampling indicated the presence of DNAPL in the deep aquifer in the area where the clay layer was less continuous. In the other areas, the DNAPL was only present above the clay layer. It appears that the sand lenses reduce the effective thickness of the aquitard to approximately 1.5 ft in portions of the DNAPL source area. Therefore, the barrier to downward vertical migration is geologically weaker in this section along with the fracture zone. Hydraulic measurements in the deep aquifer indicate an eastward gradient similar to the overlying surficial aquifer. Vertical gradients fluctuate between the deep aquifer and the surficial aquifer. As the semi-confined aquifer extends as much as approximately 120 ft bgs, additional investigation of the deeper geologic strata would be required to obtain an understanding of the VOC distribution in the semi-confined aquifer. Three semi-confined aquifer wells installed in this effort penetrated to a depth of only 60 ft bgs. The nature of clay layers is a key feature at DNAPL sites where discontinuous clay layers may lead to a variable DNAPL distribution. Determination of the vertical, as well as lateral, extent of contamination should be included in site characterization where uncertainty exists regarding a confining layer.

ACKNOWLEDGMENTS

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