U.S. DEPARTMENT OF THE INTERIOR
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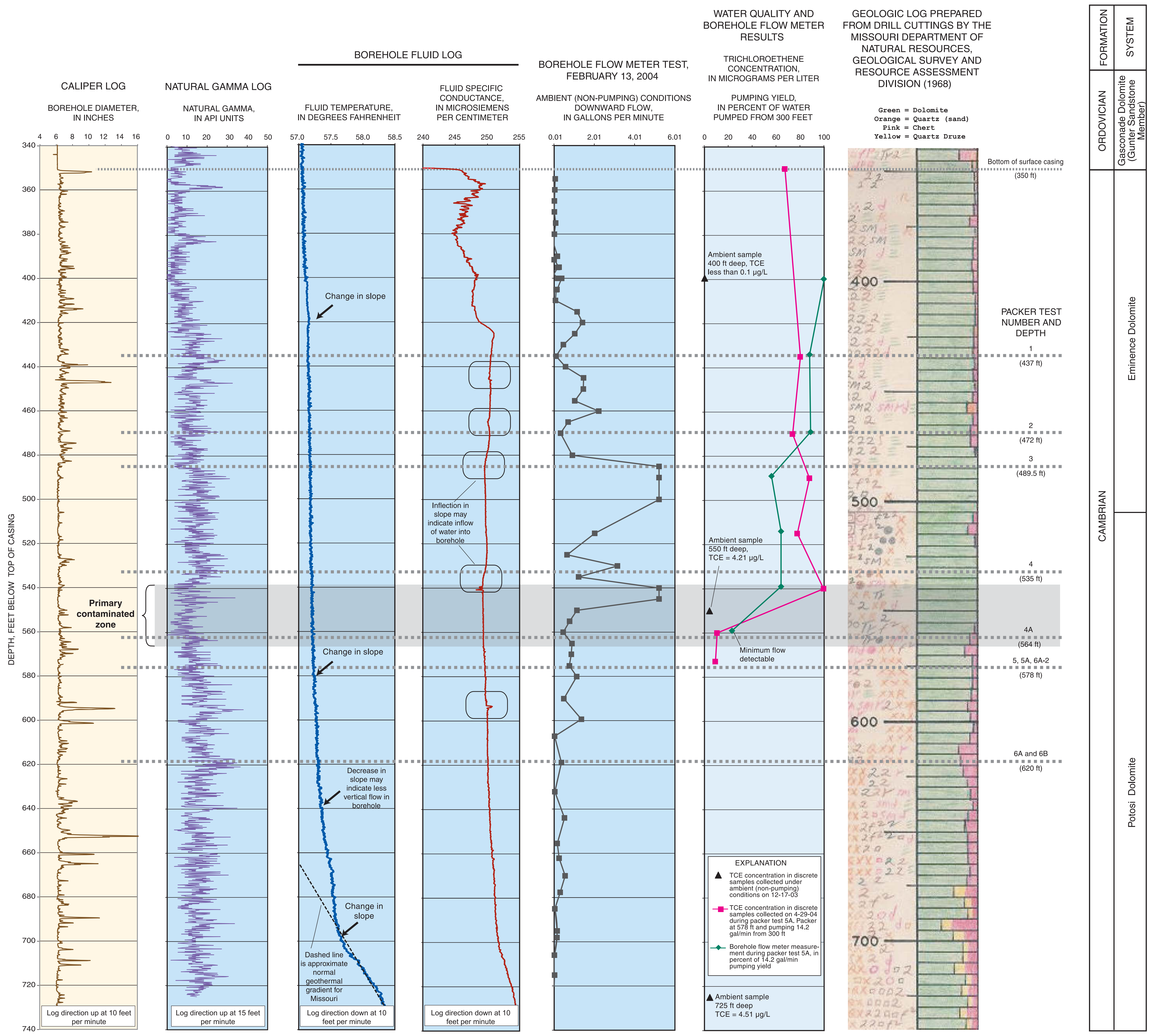
SCIENTIFIC INVESTIGATIONS MAP–2864
Depth of Trichloroethene Contamination
Schumacher, J.G., 2004
Geophysical Logging and Packer Testing to Determine Depth of Trichloroethene (TCE) Contamination in the Vicinity of Oak Grove Village Well 1 (OGV-1), Missouri, 2003–04



INTRODUCTION

Oak Grove Village, population of about 380, is located about 45 mi (miles) southwest of St. Louis, Missouri (fig. 1). In 1986, the Missouri Department of Natural Resources (MDNR) detected the presence of trichloroethene (TCE) in samples from the Oak Grove Village public water-supply well no. 1 (OGV-1) at concentrations above the U.S. Environmental Protection Agency (USEPA) maximum contaminant level (MCL) of 5 µg/L (micrograms per liter) (USEPA, accessed 2004). The well was drilled to 805 ft (feet) in 1968 and is cased to 350 ft. Water from the well historically has contained TCE concentrations as large as 42 µg/L. In 1991, well OGV-1 was taken off line and Oak Grove Village began purchasing water from the nearby city of Sullivan, Missouri. Because of the marginal condition and limited capacity of the old well, a new well (OGV-2) was drilled in 2003 adjacent to the old well as part of a plan to increase the water capacity for Oak Grove Village. The new well was drilled to 850 ft and cased to 450 ft in an attempt to minimize the TCE contamination. Unfortunately, water from the new well has contained TCE concentrations larger than 80 µg/L (MDNR, written commun., August 2004). Before the new well is placed into service, an air stripper will be installed to remove the TCE contamination.

Currently (2004), the MDNR is conducting a remedial investigation to determine the source of the TCE contamination to well OGV-1. Wells OGV-1 and OGV-2 withdraw water from the Potosi Dolomite and Eminence Dolomite, which compose the lower and most productive part of the Ozark aquifer. The Ozark aquifer is an important regional aquifer in southern Missouri. Several possible sources of the TCE contamination have been identified including an abandoned landfill about 1 mi northeast of Oak Grove Village and an industrial site with known TCE contamination about 1.5 mi southwest of Oak Grove Village in the city of Sullivan (fig. 1). In 2003, the U.S. Geological Survey (USGS), in cooperation with USEPA and MDNR, conducted a study to determine the intervals contributing TCE contamination in well OGV-1. The purpose of this report is to present interpretations of geophysical logging and borehole packer testing in well OGV-1. Results of this investigation will aide the MDNR and USEPA in determining the sources of TCE contamination to the Ozark aquifer and designing monitoring and remedial actions.

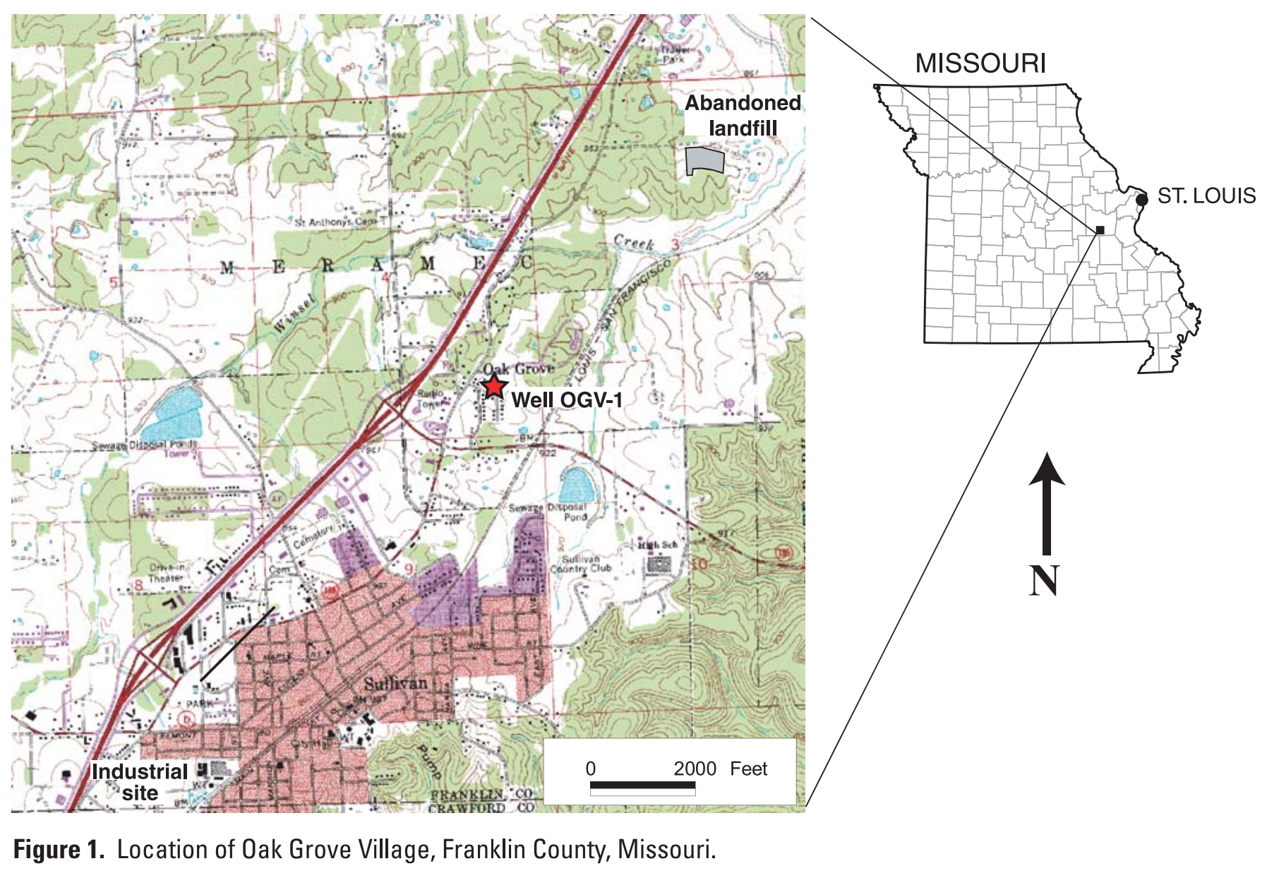


Figure 1. Location of Oak Grove Village, Franklin County, Missouri.

METHODS

Geophysical logging methods and water-quality samples collected during borehole packer tests were used to characterize the geohydrology and water quality in the bedrock aquifer in the vicinity of well OGV-1. Geophysical methods included borehole caliper, natural gamma, fluid resistivity and temperature, and heat-pulse flow meter. The approach used in this investigation was adopted from methods used by Williams and others (2000) in the characterization of a fractured-sedimentary bedrock aquifer in Ventura County, California. The application of borehole geophysical logging methods to ground-water investigations is presented in Keys (1990). Paillet (1998) discusses the application of flow meter logging to detect higher transmissive zones in a borehole.

Borehole packer tests were conducted using an inflatable packer to isolate sections of the borehole and a submersible pump to pump water from the isolated sections. Water-quality samples were collected periodically from the pump outlet and analyzed using a portable gas chromatograph (GC) according to the project Quality Assurance Project Plan (QAPP) by the USEPA (2000). Pumping at each interval continued until TCE concentrations estimated by the portable GC appeared to stabilize, after which, a final split sample was collected and analyzed by the portable GC and submitted to the MDNR for laboratory analysis of volatile organic compounds using USEPA method 524.2. To further identify intervals contributing TCE to the borehole, a discrete sampler was used to collect water samples from specific depths during several packer tests. Discrete samples were analyzed by the portable GC. The accuracy of portable GC was verified by comparing split samples analyzed by both the portable GC and the MDNR. The median relative percent difference (RPD) in TCE concentrations reported by the portable GC were 11.4 percent smaller than the MDNR laboratory.

BOREHOLE GEOPHYSICAL LOGS AND FLOW MEASUREMENTS

Caliper log

The caliper log measures the diameter of the borehole using a set of spring-loaded mechanical "arms". The arms ride along the side of the borehole as the caliper tool is pulled up the borehole. A sharp increase in the borehole diameter indicates the presence of a solution enlarged bedding plane or "void". Softer rocks, such as shale and mudstone, are eroded by the drilling process and can be recognized by an increase in borehole diameter coupled with an increase in the natural gamma. Although the borehole was reportedly drilled to 805 ft deep, the caliper and other logs indicated that the open borehole is only about 735 ft deep and the borehole possibly has collapsed or is filled with debris below this depth.

Natural gamma log

The natural gamma log records the gamma rays emitted from the radioactive decay of naturally occurring radioisotopes in the bedrock. In carbonate rocks in the Oak Grove Village area, most gamma rays are the result of the radioactive decay of uranium, thorium, or potassium-40 (^{40}K) isotopes. Clay minerals contain substantial quantities of potassium in their crystal lattice. Trace elements such as uranium also adsorb preferentially to clay minerals. An increase in natural gamma generally indicates an increase in clay minerals, such as a shale or mudstone bed or clay-filled solution opening. Uranium and thorium also may adsorb to iron oxides, and an increase in natural gamma could indicate the presence of iron-oxides containing these trace elements. The low natural gamma counts in the log reflect the predominant carbonate lithology of the bedrock.

Borehole fluid log

The temperature profile of water in an open borehole under ambient and pumping conditions provides information about the vertical flow of water in the borehole. The average geothermal gradient in Missouri is an increase of about 2 ºF (degrees Fahrenheit) per 100 ft of depth. Static water in the borehole will be in thermal equilibrium with the bedrock and the temperature profile will reflect the geothermal gradient. Water moving vertically in the borehole will not be in thermal equilibrium with the bedrock and the temperature profile will be nearly vertical. The steep slope of the ambient temperature profile between about 420 and 580 ft reflects the vertical movement of water in the borehole. Decreases in slope of the ambient temperature profiles at 580 ft and 640 ft deep probably indicate decreasing rates of vertical flow in the borehole. Below about 700 ft deep, stagnant conditions exist in the borehole and the temperature profile approximates the normal geothermal gradient.

The specific conductance log indicates the amount of dissolved solids in the borehole water. Specific conductance is a measure of the capacity of water to conduct an electrical current, and this capacity is a function of types and quantities of dissolved substances. Values are not adjusted for temperature changes and will increase as borehole fluid temperature increases. Inflections in the specific conductance log may indicate inflow of water of different specific conductance values into the borehole. The variation in specific conductance values between the bottom of the surface casing (350 ft deep) and about 420 ft deep indicate mixing of stagnant water from inside the casing with water of varied specific conductance in this interval. The increase in specific conductance at 425 ft deep indicates inflow of slightly higher specific conductance formation water. This increase is followed by a trend of slight decreases in specific conductance values at 445, 465, 485, and 535 ft deep, suggesting inflow of slightly "fresher" water at these depths. Below 535 ft, specific conductance values increase with increasing depth. The increase in specific conductance at 594 ft is unusual and may indicate inflow of water with a slightly larger specific conductance into the borehole. The trend of increasing specific conductance below 600 ft and sharper increase below 700 ft is caused mostly by increases in water temperature and may reflect relatively stagnant conditions in the bottom of the borehole.

Borehole flow measurements

Flow measurements in the borehole made using a heat-pulse flow meter under ambient conditions indicate that water is moving downward throughout the open interval of the borehole. Ground-water movement in the borehole is caused by the borehole intersecting geohydrologic units, zones, or fractures within units that have different potentiometric heads and permeabilities. The downward movement of water indicates that shallower formations have higher potentiometric heads than deeper formations. Notable increases in downward flow occurred at 420, 460, 485, 540, and 594 ft, and these depths generally correspond to depths where inflections in the specific conductance log occur. A substantial quantity of water, estimated at nearly 5 gal/min (gallons per minute), enters the borehole at about 485 ft deep. Most of this flow exits the borehole between 545 and 550 ft deep. Below 600 ft deep, downward flow decreased with increasing depth, and no flow was detected below 700 ft deep. The stagnant conditions below 700 ft correspond to the sharp increase in borehole fluid temperature.

Flow measurements in the borehole also were made under pumping conditions during packer test 5A on April 29, 2004. For this test, the packer was set at 578 ft deep and the borehole was pumped at 14.2 gal/min from a pump set at 300 ft. Flow in the borehole exceeded the standard operating range of the flow meter, and the meter was calibrated to the known pumping rate of 14.2 gal/min inside the surface casing at 345 ft deep. Flow was expressed at a percentage of the total flow being pumped from the borehole. Because of the higher flow rates, the sensitivity of the flow meter (normally around 0.01 gal/min) was decreased to about 20 percent of the pumping rate or about 2.8 gal/min. No measurable inflow was detected in the interval between the bottom of the surface casing and 400 ft deep. During pumping, about 33 percent (about 4.7 gal/min) of the yield was obtained from the interval between 469 and 489 ft deep, and more than 40 percent of the yield (about 5.9 gal/min) was obtained from the interval between 539 and 559 ft deep. Results of the flow meter measurements made under both ambient and pumping conditions indicate that the borehole intersects two high permeability zones (469 to 489 ft deep and 539 to 559 ft deep) that yield most of the water to the borehole at a pumping rate of 14.2 gal/min.

BOREHOLE PACKER TESTS AND WATER-QUALITY SAMPLING

Water-quality samples were collected and analyzed for TCE and other volatile organic compounds under ambient (non-pumping) and pumping conditions. Samples were collected at specific depths using a discrete sampler, and composite samples from the entire pumped interval were collected from the pump outlet.

Under ambient conditions, TCE concentrations in discrete samples collected at the beginning of the study (December 17, 2003) increased from less than 0.1 µg/L at 400 ft deep to 4.21 and 4.51 µg/L at 550 ft and 724 ft deep. These results indicate that TCE enters the borehole between 400 and 550 ft deep.

Beginning in March 2004, packer tests were conducted by pumping the borehole above an inflatable packer set at various depths. During the initial tests, the borehole was pumped at 8.9 gal/min and the packer was placed at depths of 437, 472, 489.5, 535, 564, and 578 ft (fig. 2, table 1). At each test depth, the pump was run from 24.5 to 77 hours before the final laboratory sample was collected from the pump outlet. Results from initial tests conducted at 8.9 gal/min indicate a gradual increase in TCE concentrations with increasing packer depth with the maximum concentration of 6.36 µg/L obtained at a packer depth of 564 ft deep. Subsequent packer tests conducted at higher pumping rates generally resulted in higher TCE concentrations with the maximum concentration of 67.3 µg/L detected in packer test 5A [packer at 578 ft and pumping at 14.2 gal/min (fig. 2, table 1)].

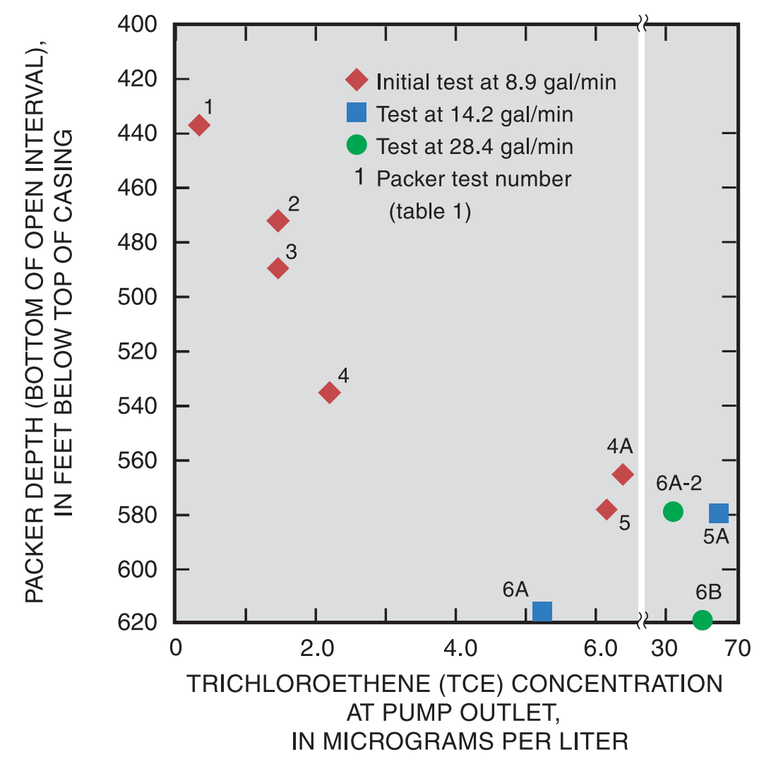


Figure 2. Summary of final trichloroethene (TCE) concentrations in samples collected from the pump outlet during packer tests. The top of the open interval was the bottom of surface casing at 350 ft deep. The pump was set at 300 ft and water was pumped at 8.9 to 28.4 gal/min. Laboratory analyses were done by the Missouri Department of Natural Resources.

Water samples were collected using a discrete sampler from various depths in the borehole during several packer tests to determine the distribution of TCE concentrations in the borehole with depth. The largest TCE concentrations were detected in discrete samples collected on April 29, 2004, during packer test 5A (pumping 14.2 gal/min from the borehole above 578 ft deep). Samples collected during this test indicate a gradual increase in TCE concentrations with increasing depth (see chart to left). TCE concentrations increased from 67.3 µg/L at 350 ft deep to 99.6 µg/L at 540 ft deep, then rapidly decreased to less than 10 µg/L at and below 560 ft deep. These results indicate that the zone of largest TCE contamination present in the bedrock strata intersected by well OGV-1 is between about 540 and 560 ft deep. At depths above 540 ft, concentrations of TCE gradually decreased with decreasing depth as uncontaminated water entered the borehole—diluting water obtained from the more contaminated 540 to 560 ft deep interval. Packer test 5A was a repeat of an earlier test (test 5) where the pumping rate was 8.9 gal/min (fig. 2, table 1). After 43 hours of pumping, the maximum TCE detected in the earlier test was only 6.15 µg/L. The smaller TCE concentration in the earlier test indicates that the most contaminated region of the aquifer is not directly intersected by the OGV-1 borehole. The higher pumping rate draws more contaminated water from the aquifer to the well.

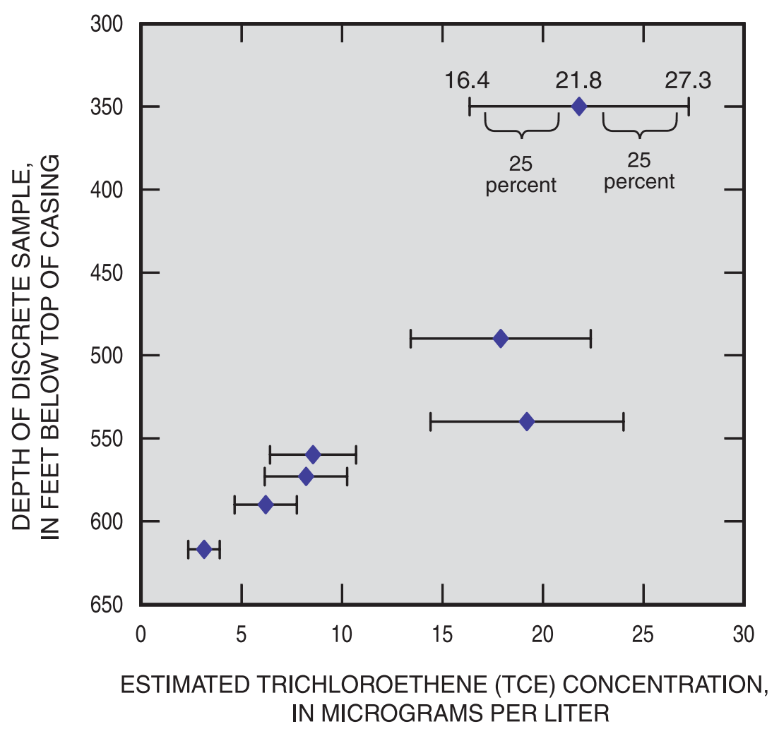


Figure 3. Estimated TCE concentrations in discrete samples collected during packer test 6B (May 13, 2004) and analyzed by a portable gas chromatograph. The packer was set at 620 ft deep. The top of the open interval was the bottom of surface casing at 350 ft deep. Pump was set at 300 ft and borehole was pumped at 28.4 gal/min for 21 hours before sample collection. Error bars represent 25 percent error in replicate sample analyses.

The final packer test (test 6B) was run for 5 days at 28.4 gal/min (packer at 620 ft deep) to test if water with substantial TCE concentration was entering the borehole between 578 and 620 ft deep, and to determine if the sustained higher pumping rate would result in even larger TCE concentrations than previously detected. The maximum TCE concentration of 46.9 µg/L detected at the pump outlet in this test was smaller than the 67.3 µg/L detected in test 5A (table 1). The smaller TCE concentrations in test 6B compared to test 5A and smaller drawdown (2.66 ft compared to 5.08 ft), despite a doubling of the pumping rate, suggest that the interval between 578 and 620 ft deep yields significant quantities of relatively uncontaminated water. Discrete samples collected 21 hours after the beginning of test 6B and analyzed by the portable GC confirm smaller TCE concentrations in the lower part of the borehole. Concentrations of TCE increased from less than 10 µg/L at depths below 560 ft to about 20 µg/L at depths of 540 ft and shallower indicting that most TCE enters the borehole between 540 and 560 ft deep (fig. 3).

SUMMARY AND CONCLUSIONS

Results of water-quality samples collected during the borehole packer tests and the borehole geophysical logging indicate that the largest trichloroethene concentrations are entering the borehole in the interval between 540 and 560 feet deep. This same interval appears to have a larger permeability as it contributes about 40 percent of the yield under pumping conditions of 14.2 gallons per minute. Compared to this interval, other intervals appear to contain smaller quantities of trichloroethene.

Table 1. Summary of Borehole Packer Tests

Packer test number	Packer depth, in feet below top of casing	Pumping rate, in gallons per minute	Drawdown after 24 hours	Trichloroethene (TCE) concentration in pumping sample at end of test, in micrograms per liter	Packer test date
1	437	8.9	15.54	0.35 J	3-24-04 to 3-25-04
2	472	8.9	6.84	1.47	3-25-04 to 3-27-04
3	489.5	8.9	7.86	1.47	3-29-04 to 3-31-04
4	535	8.9	7.18	2.20	3-31-04 to 4-02-04
4A	564	8.9	no data	6.36	4-13-04 to 4-14-04
5	578	8.9	2.01	6.15	4-19-04 to 4-21-04
5A	578	14.2	5.08	67.3	4-26-04 to 4-29-04
6A-2	578	28.4	5.95[a]	37.0[a]	5-17-04 to 5-19-04
6A	620	14.2	4.62[b]	5.04[e]	5-05-04 to 5-12-04
6B	620	28.4	2.66	46.9[e]	5-12-04 to 5-17-04

[J] Estimated concentration below the laboratory reporting level, Missouri Department of Natural Resources.
[a] Measured after 46.3 hours of pumping, pressure tank low and packer only partially inflated and leaking.
[b] Measured after 18.3 hours of pumping.
[e] Estimated concentration reported by the portable gas chromatograph.

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