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Date: January 4, 2007
Refer to: EP2006-0966

Mr. James Bearzi
Bureau Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505-6303

SUBJECT: OTOWI 1 ASSESSMENT REPORT PREPARED BY DAVID SCHAFER & ASSOCIATES

Dear Mr. Bearzi:

Enclosed please find two hard copies of the report entitled "**OTOWI 1 ASSESSMENT**" dated December 2006. The report was prepared by David Schafer & Associates in support of Los Alamos National Laboratory's Environmental Programs – Water Stewardship Program. The report documents the results of geophysical logging and water sampling activities conducted at the Otowi-1 water supply well during January, 2006. The enclosed report complements the Kleinfelder report entitled "Flow Temperature, Fluid Resistivity, and Water Quality Testing Report Otowi-1 Water Supply Well Los Alamos National Laboratory Los Alamos County, New Mexico" dated May 2006 which was submitted to NMED on October 25, 2006.

Sincerely,

Andrew Phelps, Associate Director
Environmental Programs
Los Alamos National Laboratory

Sincerely,

David Gregory, Federal Project Director
Department of Energy
Los Alamos Site Office

AP/DG/ME/tml

7803

Enclosure: (1) OTOWI 1 ASSESSMENT

Cy: (w/enc.)
LWSP File, MS M992
RPF, MS M707

Cy: (w/o enc.)
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OTOWI 1 ASSESSMENT

LA-UR-06-8827

Prepared for
Los Alamos National Laboratory
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R E P O R T

December 2006

Otowi 1 Assessment

Los Alamos National Laboratory
Los Alamos, NM

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Otowi 1 Assessment

Los Alamos National Laboratory
Los Alamos, NM

INTRODUCTION

This report examines the results of geophysical logging and water-sampling activities conducted in the Los Alamos County Otowi 1 production well in Pueblo Canyon in January 2006. Low levels of nitrate, tritium, and perchlorate well below U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) for nitrate and tritium and drinking water equivalent level (DWEL) for perchlorate have been detected in Otowi 1. A detailed examination of conditions in Otowi 1 and collection of depth-discrete water samples were undertaken to gain insight into the physical condition of the well and to determine where contaminants were entering the well. This information will be used to guide the design of R-3, a regional sampling/monitoring well proposed to be located near Otowi 1.

The field activities at Otowi 1 have been described in detail in the report entitled "Final Flow, Temperature, Fluid Resistivity, and Water Quality Report Otowi-1 Water Supply Well," (Kleinfelder 2006, 092487). The purpose of the current report is to augment and build on the conclusions presented in the Kleinfelder report.

The Kleinfelder report presented details of the specific field activities, equipment used, and water-discharge setup. It also presented all of the analytical chemistry data obtained from Otowi 1. Therefore, not all of that information is presented here. However, all of the geophysical logs and certain chemistry results are included here, as needed, for discussion purposes.

REGIONAL SETTING

Otowi 1 is located in Pueblo Canyon in the northeast portion of Los Alamos National Laboratory (the Laboratory). Figure 1 shows the laboratory area, with all prominent wells including Otowi 1 (labeled O-1 in the figure).

Figures 2 and 3 show construction details for Otowi 1. As indicated, the well is 2497 ft deep, completed with 16-in. steel casing that includes perforated sections from 1017 to 2477 ft. (As determined from the video logs run in Otowi 1, the uppermost perforations actually start at 1019 ft, 2 ft below the casing joint.)

As shown in Figures 2 and 3, surface casing was grouted to 55 ft below land surface, and an intermediate 28-in. casing was grouted to 664 ft below land surface. Then filter pack was run continuously from the bottom of the well to the base of the 28-in. casing and on up inside the 28-in. casing to near land surface. Thus, the filter-packed annulus below 664 ft provides a continuous conduit for migration of water and dissolved chemicals throughout the entire saturated depth of the well.

The static water level on January 12 before pumping the well was 691 ft below land surface (elevation of 5705 ft). Thus, the filter pack provides a conduit extending from 27 ft above the regional aquifer to the total depth of the well. Following each of several pumping events, water levels failed to return to the previous static water level, suggesting negative boundaries in the area, such as faulting.

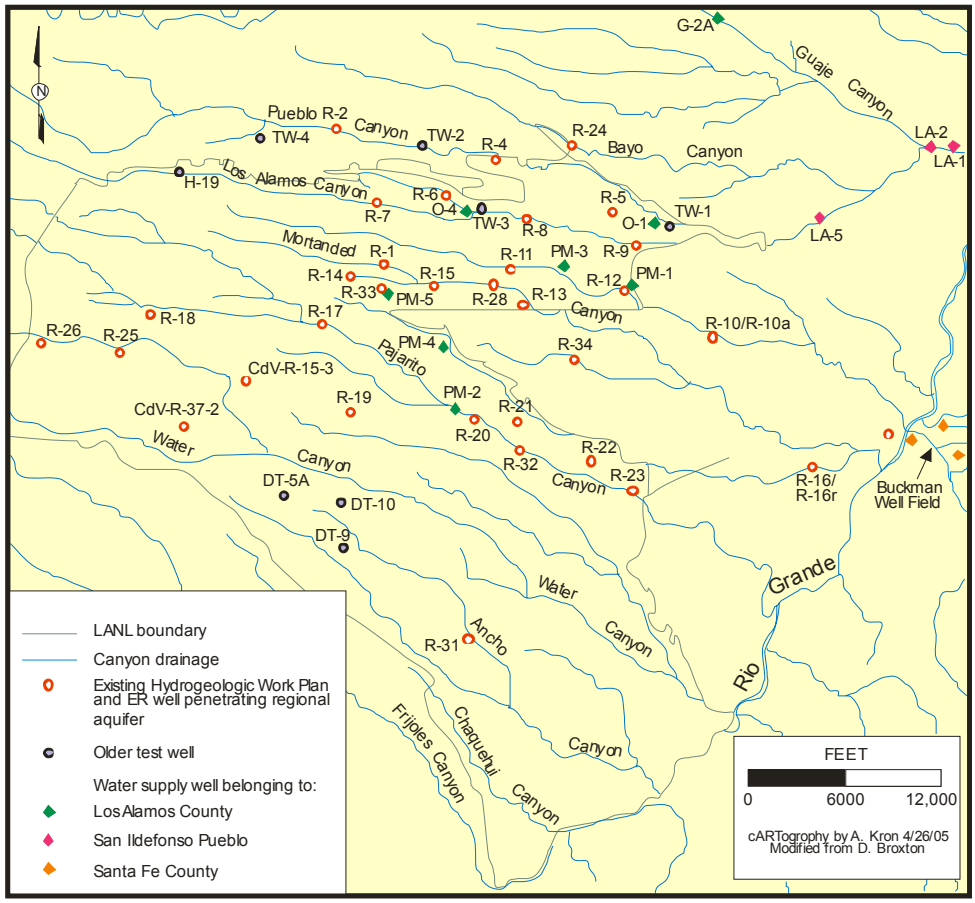


Figure 1. Los Alamos area wells

It is believed that the source of perchlorate in Otowi 1 is former waste discharge far upgradient in Acid Canyon near Pueblo Canyon. This constituent has been observed in regional aquifer wells R-4 and R-5, implying that it has reached the regional aquifer up gradient of Otowi 1.

The nitrates observed in Otowi 1, on the other hand, are thought to be from a different, closer source (a nearby sewage treatment plant) than the source of nitrate contamination seen in R-4. Curiously, tritium has been observed in the perched zone at R-5p but not in the regional aquifer. Therefore, the tritium observed in Otowi 1 may be from yet another source.

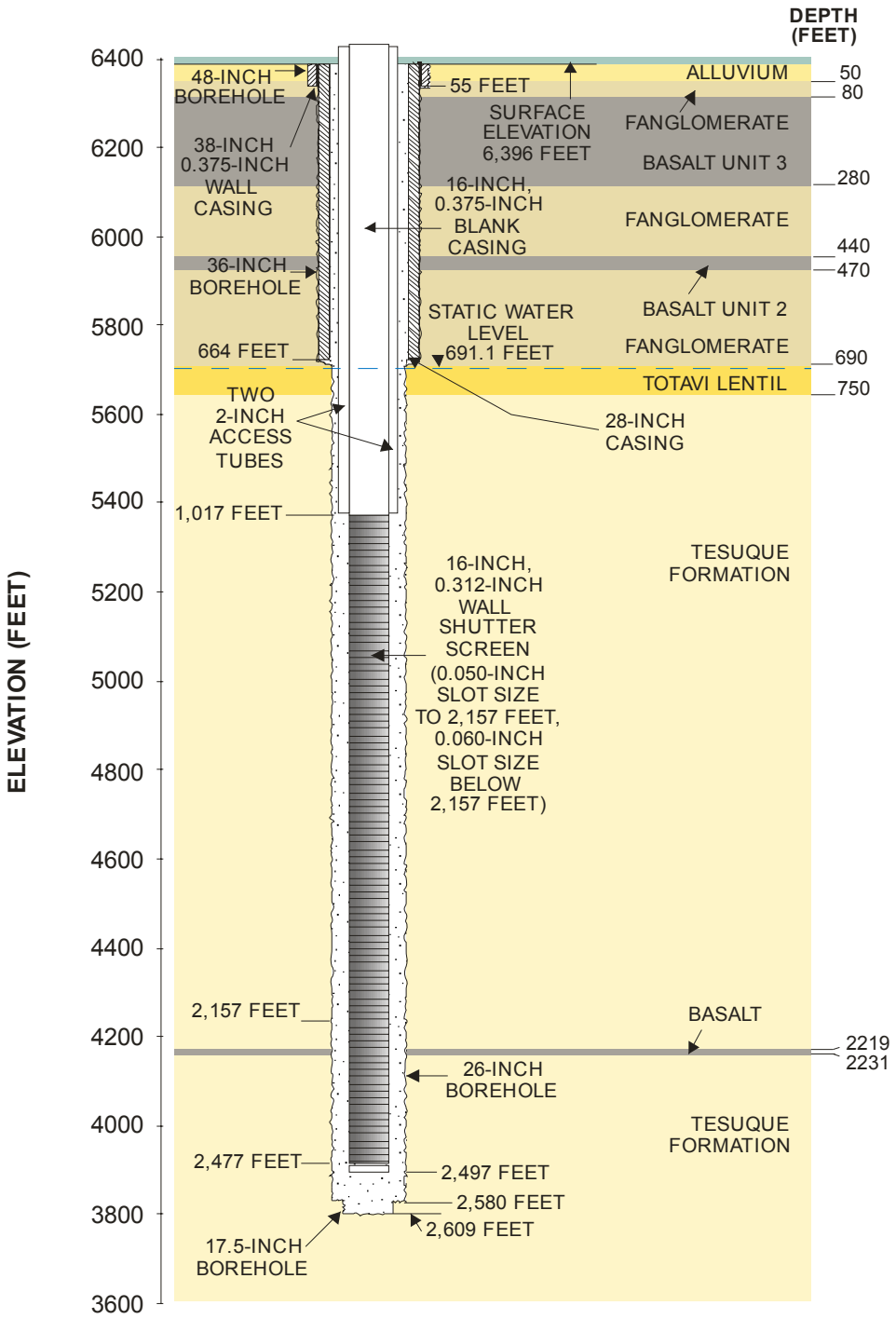


Figure 2. **Well completion diagram for Otowi 1**

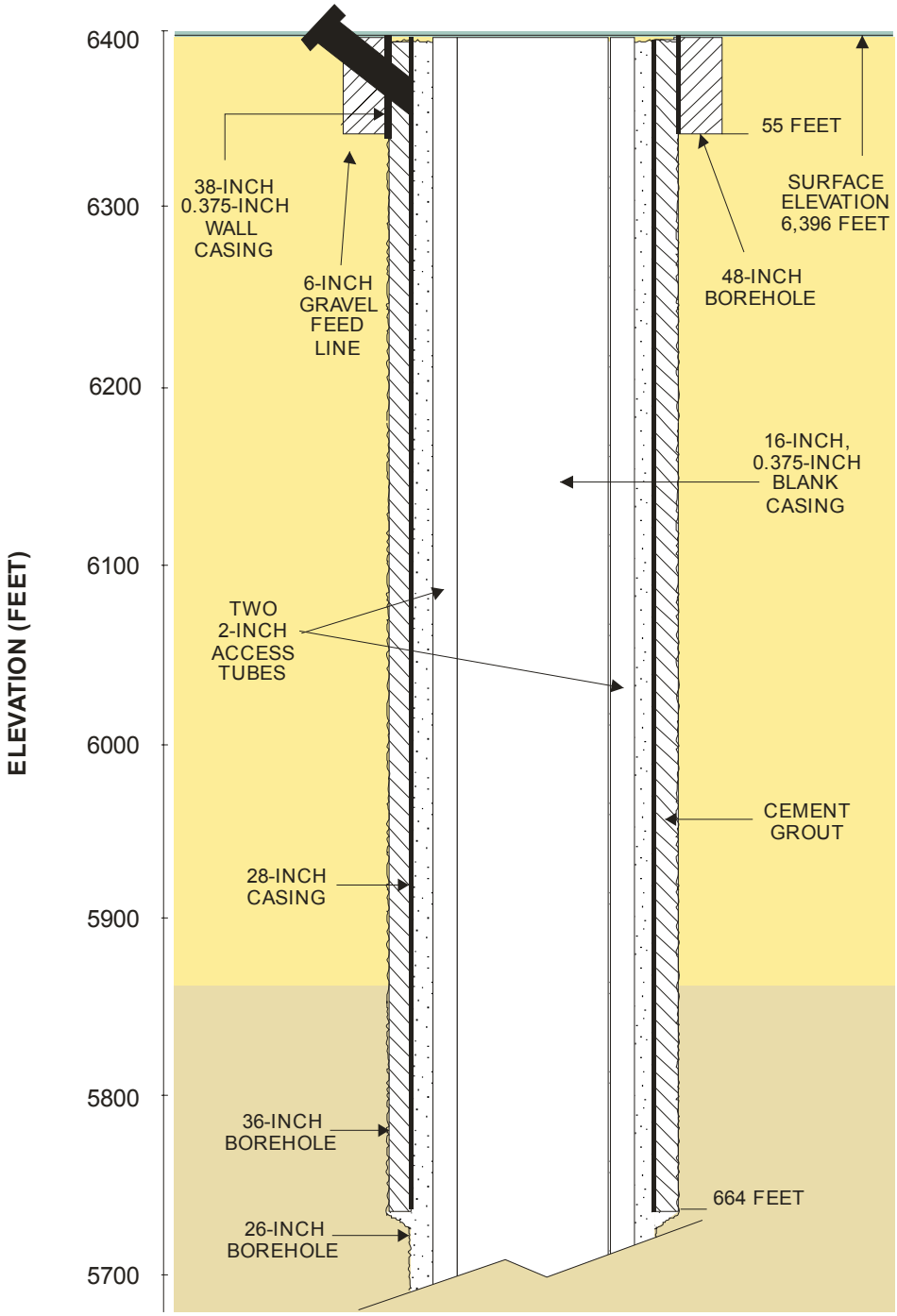


Figure 3. **Grouted portion of Otowi 1p**

Because Otowi 1 incorporates a continuous filter pack from above the regional aquifer to the well screen, as well as a very long screen (1460 ft), it offers the potential of serving as a vertical conduit for groundwater contamination. Therefore, understanding the vertical component of the groundwater gradient near Otowi 1 is important. An inventory of depth-discrete water levels in the regional aquifer was made for all multiscreened regional aquifer wells at the laboratory. A total of 16 such wells, having 49 screens, are within the regional aquifer. Table 1 provides a list of the wells and screen intervals, along with the observed water-level elevation for each screened zone. Most of the data shown represent average 2005 water levels (Allen and Koch 2006, 093652). For wells for which 2005 data were not available, other source data were used, such as water levels measured at the time of well testing (Kleinfelder 2005, 094041; Kleinfelder 2006, 092493).

Table 1
Regional Aquifer Depth-Discrete Water Levels

Well	Screen Zone	Screen Top Elevation (ft)	Screen Bottom Elevation (ft)	Water Level (ft)	Head Difference (ft)
R-5	Screen 3	5795.7	5752.3	5768.4	
R-5	Screen 4	5613.9	5608.9	5754.9	-13.5
R-8	Screen 1	5839.4	5789.0	5854.9	
R-8	Screen 2	5723.4	5716.7	5834.7	-20.2
R-10a	Screen 1	5673.7	5663.7	5741.4	
R-10	Screen 1	5488.3	5465.3	5711.4	-30.0
R-10	Screen 2	5320.3	5297.3	5697.5	-13.9
R-14	Screen 1	5861.5	5828.9	5883.4	
R-14	Screen 2	5775.6	5769.0	5883.1	-0.3
R-16r	Screen 1	5657.0	5639.4	5693.1	
R-16	Screen 2	5393.5	5386.0	5642.2	-50.9
R-16	Screen 3	5242.1	5234.5	5557.9	-84.3
R-16	Screen 4	5019.9	5012.3	5547.1	-10.8
R-17	Screen 1	5869.0	5846.0	5890.6	
R-17	Screen 2	5802.0	5792.0	5888.7	-1.9
R-19	Screen 3	5894.9	5850.9	5887.6	
R-19	Screen 4	5656.1	5648.9	5879.6	-8.0
R-19	Screen 5	5483.7	5476.5	5876.9	-2.7
R-19	Screen 6	5339.5	5332.4	5869.7	-7.2
R-19	Screen 7	5233.9	5226.8	5865.0	-4.7

Table 1 (continued)

Well	Screen Zone	Screen Top Elevation (ft)	Screen Bottom Elevation (ft)	Water Level (ft)	Head Difference (ft)
R-20	Screen 1	5789.8	5782.2	5865.9	
R-20	Screen 2	5547.3	5539.7	5860.5	-5.4
R-20	Screen 3	5365.6	5357.9	5832.7	-27.8
R-22	Screen 1	5778.2	5736.3	5762.2	
R-22	Screen 2	5703.5	5661.6	5756.3	-5.9
R-22	Screen 3	5378.3	5371.6	5699.7	-56.6
R-22	Screen 4	5272.3	5265.6	5694.3	-5.4
R-22	Screen 5	5203.2	5198.2	5694.3	0.0
R-25	Screen 5	6221.4	6211.4	6233.9	
R-25	Screen 6	6111.4	6101.4	6204.9	-29.0
R-25	Screen 7	5911.4	5901.4	6164.2	-40.7
R-25	Screen 8	5721.4	5711.4	6141.3	-22.9
R-26	Screen 1	6989.9	6971.8	7032.5	(perched?)
R-26	Screen 2	6219.9	6196.7	6545.2	-487.3
R-31	Screen 2	5847.5	5816.8	5828.1	
R-31	Screen 3	5696.2	5686.2	5826.8	-1.3
R-31	Screen 4	5535.9	5525.9	5830.2	***3.4****
R-31	Screen 5	5355.4	5345.4	5836.6	***6.4***
R-32	Screen 1	5770.1	5762.4	5859.2	
R-32	Screen 2	5705.8	5702.7	5848.8	-10.4
R-32	Screen 3	5664.7	5657.0	5848.7	-0.1
R-33	Screen 1	5857.8	5834.8	5873.5	
R-33	Screen 2	5740.9	5731.0	5847.2	-26.3
CdV-R-15-3	Screen 4	6023.8	5980.0	6019.9	
CdV-R-15-3	Screen 5	5910.5	5903.6	6020.0	***0.1***
CdV-R-15-3	Screen 6	5621.0	5614.1	5983.0	-37.0
CdV-R-37-2	Screen 2	6141.9	6116.8	6137.4	
CdV-R-37-2	Screen 3	5976.9	5953.5	6136.7	-0.7
CdV-R-37-2	Screen 4	5781.3	5774.6	6135.7	-1.0

*Bold values are positive. All other values are negative.

A cursory examination of Table 1 indicates that groundwater levels at the Laboratory show a substantial downward-gradient component. Only two exceptions to this can be seen in the table: CdV-R-15-3 and R-31. In CdV-R-15-3, screen 5 shows a negligibly higher water level than screen 4, just 0.1 ft, but the substantially lower piezometric level in screen 6 confirms a significant downward component of the gradient at this well location. That leaves well R-31 as the only location not exhibiting a consistent or significant downward-gradient component. As shown in Figure 1, R-31 is the only R well in the southern portion of the Laboratory. At this time, there is not a great deal of hydrogeologic information available from that portion of the Laboratory, and the reason for the gradient having an upward component at R-31 is not understood. However, it is clear from Figure 1 and Table 1 that the hydraulic gradient has a consistent and significant downward component throughout the entire central and northern portions of the Laboratory including the vicinity of Otowi 1. This has implications regarding potential movement of groundwater and chemicals within the Otowi 1 well bore.

FIELD ACTIVITIES

Primary field activities consisted of conducting video and geophysical logs in Otowi 1 during both static and pumping conditions, as well as obtaining depth-discrete groundwater samples from the well while pumping. All work was performed from January 4 to January 20, 2006.

In addition to video logging, geophysical logs included (a) spinner log, (b) temperature log, and (c) fluid resistivity log. Video and geophysical logs were conducted initially under static conditions on January 4. They were repeated on January 18 under pumping conditions, with the well pumping approximately 505 gallons per minute (gal./min). Following the final suite of geophysical logs, a thief sampler was used to obtain depth-discrete groundwater samples while maintaining the 505-gal./min pumping rate.

Pumping was performed using a temporary submersible pump and motor. The pump and motor were set on a 6-in. drop pipe with the pump intake at approximately 854 ft below land surface and the bottom of the motor at 862 ft. A 3-in. slave tube was run alongside the drop pipe to a depth of roughly 883 ft below land surface. The 3-in. pipe accommodated running the video camera and geophysical tools when the well was pumped.

The initial pump installation began on January 6. Pumping was attempted on January 8, but the pump failed to bring water to the surface. The pump was removed and replaced with a different unit that worked successfully.

Pumping occurred in three separate discharge events. Initially, on January 12, the well was pumped at rates ranging from 894 to 840 gal./min. The discharge rate declined continuously during the test, as the increasing drawdown required the pump to operate against steadily increasing head. Pumping continued for about 4 h from 3:00 p.m. to 7:00 p.m. While pumping, water-level measurements were

made manually through one of the 2-in. access tubes installed during well completion (Figure 2) and with an electronic pressure transducer affixed to the bottom of the 3-in. slave tube.

Figure 4 shows the drawdown recorded during the first pumping event. The early data (first few minutes) were affected by a brief pump shutdown. In fact, water levels rose above the static water level (off the scale of the graph) as the partially filled 6-in. drop pipe drained back into the well. Within a few minutes, pumping was restored, and a normal drawdown response was observed.

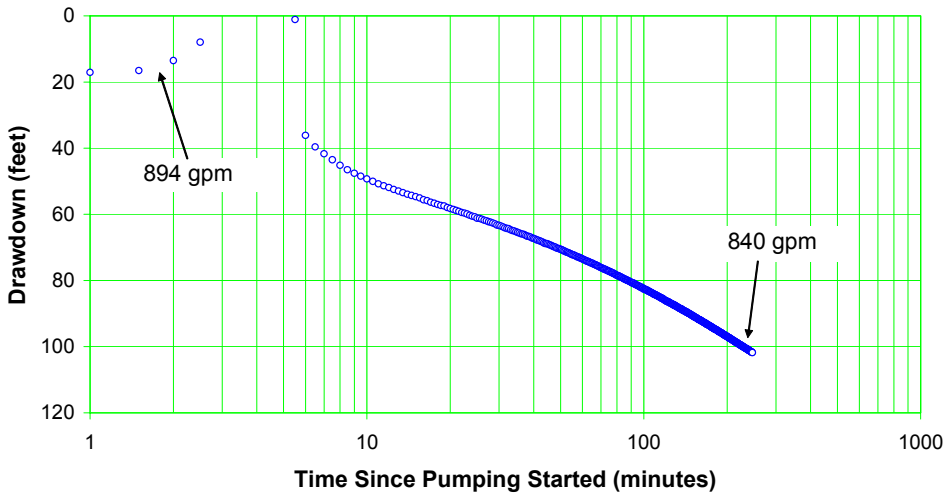


Figure 4. Otowi 1 drawdown on January 12, 2006

The drawdown trend illustrated in Figure 4 suggests that the rate of drawdown was sufficient to bring the pumping water level close to the pump intake after several days of pumping. Therefore, the decision was made to run a second trial pumping event the following day at a reduced rate.

On January 13, the pump was run again for 138 min from 11:55 a.m. until 2:13 p.m. This trial test was performed to adjust the valve in the discharge line to a more acceptable discharge rate. The pumping rate after adjusting the valve was 527 gal./min. Figure 5 shows the resulting drawdown response. The new valve setting and reduced discharge rate ensured that the pump could be operated for several days without drawing the pumping water level near the pump.

The final pumping event began at 8:49 a.m. on January 15 and continued for more than 126 h until 3:00 p.m. on January 20 at an average discharge rate of 505 gal./min. Figure 6 shows the resulting drawdown measured during the pumping period.

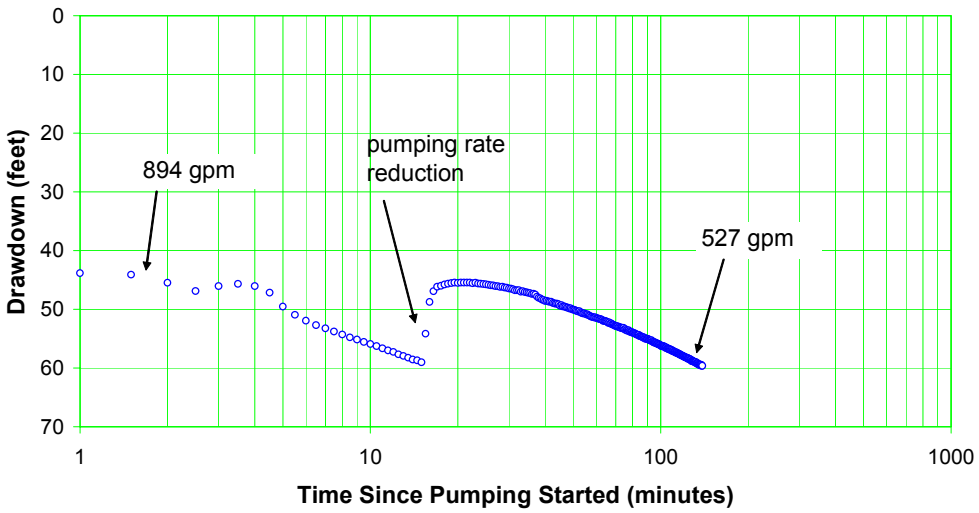


Figure 5. Otowi 1 drawdown on January 13, 2006

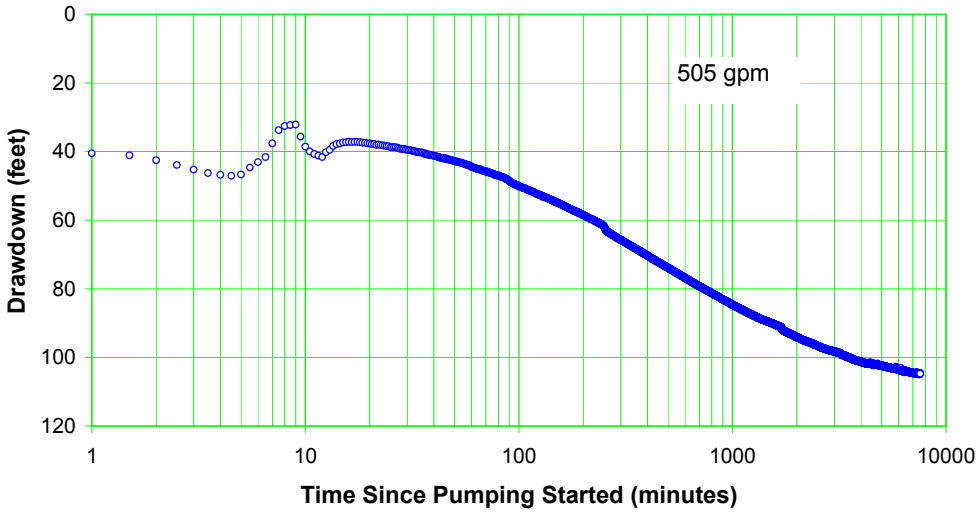


Figure 6. Otowi 1 drawdown on January 15–20, 2006

During pumping, the hydrologic system was allowed to equilibrate from January 15 to January 18 before dynamic (pumping) geophysical logging and sampling were performed. Video logging and geophysics were performed on January 18. The remainder of the pumping period was spent collecting depth-discrete water samples throughout the length of the well.

Pumping rate and drawdown data obtained during the test procedures were compared with previous pumping records to determine if well performance had declined over time. Comparative data were available from 1990, 1999, 2000, and 2001.

Table 2 shows the available pumping-rate and drawdown data. Unfortunately, the previous pumping records did not indicate what the duration of pumping was that corresponded to the drawdown values shown. For this comparison, it was assumed that the old data corresponded to a pumping time of 8 h. This was just an estimate. The actual pumping time could have been shorter or longer than this and could have varied from one test to another.

Table 2
Otowi 1 Specific Capacity Data

Date	Discharge Rate (gal./min)	Drawdown (ft)	Pumping Time (min)	Specific Capacity (gal./min/ft)
1990	1000	123.0	unknown	**8.1**[a]
1999	973	100.3	unknown	**9.7**
2000	973	133.8	unknown	**7.3**
2001	973	141.3	unknown	**6.9**
2006	840	102.0	240	8.2
	840	110[b]	360	7.6
	840	118[b]	480	**7.1**
	516	67.0	360	7.7
	513	71.5	480	**7.2**
	505	103.1	7570	4.9

[a] Bold indicates values from a prescreened duration of 8 h.
[b] Extrapolated value.

Table 2 shows specific capacity readings in bold (pumping rate divided by drawdown) for 1990 through 2001 and for two different discharge rates from the recent testing: 840 and 513 gal./min. The recent specific capacities were calculated for a pumping time of 8 h. Oddly, the data show a specific capacity increase from 1990 to 1999, followed by a decrease in 2000. From 2000 to the present, there was no significant change in reported specific capacity.

The apparent specific capacity increase from 1990 to 1999 seems ostensibly impossible. About the only way this can occur is if a well pumps sand. Sand pumping can contribute to gradual enhanced well development or simply increase the yield by creating a cavity around the screen that gradually enlarges the borehole. There is no evidence of Otowi 1 being a sand pumper. It is more likely that the differences in reported specific capacity are attributable to different pumping times for the 1990 and 1999 tests.

Because the specific capacity values measured in 1990 and 1999 were both greater than subsequent values, it is possible that the data reflect a real reduction in well efficiency after 1999. Nevertheless, the reduction in specific capacity has not been extensive.

WATER-SAMPLING RESULTS

Following several days of purging Otowi 1 at 505 gal./min, down-hole water samples were collected at 22 discrete depths from 890 to 2400 ft while the pump was running. In addition, three samples (Otowi 1-1, Otowi 1-2, and Otowi 1-3) were collected from the surface discharge line. The samples were tested for cations, anions, metals, perchlorate, tritium, and stable isotopes of nitrogen. In addition, field parameters were measured including temperature, specific conductance, dissolved oxygen, pH, and oxidation reduction potential. All analytical testing results are presented in the "Final Flow, Temperature, Fluid Resistivity, and Water Quality Testing Report Otowi-1 Water Supply Well Assessment Report" (Kleinfelder 2006, 092487). Certain key parameters are included here for discussion purposes.

Down-hole samples were collected by running a Mount Sopris Fluid Sampler (also known as a thief sampler) on a wire line cable through the 3-in. slave tube. The sampler was open ended so that water flowing up the borehole could pass through it until valves in the unit were closed remotely, thus containing the sample. The sampler was allowed to equilibrate (with well water passing through it) for 15 min for shallow settings and 45 min for deep settings before closing the valves. Once the sample was contained, the sampler was brought to the surface to test for field parameters and prepare samples for Laboratory submittal. Then the thief sampler was rerun to gather the sample from the next horizon.

In theory, the water sample collected at a particular depth represents a weighted average of the constituents entering the well at all points beneath the sampler location. This assumes that complete mixing occurs within the borehole as deeper water moves upward and mingles with new water entering the well. Under this assumption, for successive sample locations *A* and *B*, where observed constituent concentrations are C_A and C_B, respectively, the constituent concentration of the water entering the well in the interval between points *A* and *B* can be calculated as follows:

$$C_{AB} = \frac{f_A C_A - f_B C_B}{f_A - f_B}$$

Where,

C_{AB} = constituent concentration of the water entering the well in the interval between points *A* and *B*
C_A = observed concentration in sample collected at point *A*
C_B = observed concentration in sample collected at point *B*
f_A = fraction of flow entering the well below point *A*
f_B = fraction of flow entering the well below point *B*

If the fractional flow contribution from various portions of the well can be determined (from a spinner log, for example), it is possible to compute the interval concentration, C_{AB}, for each sampling interval. It also follows that once the thief sampler rises above the uppermost perforations (1019 ft), all samples should show identical constituent concentrations.

In practice, however, a uniform sampling environment is not necessarily achieved using this sample-collection method. First, mixing water entering the well with water from below is not instantaneous. It can be expected that water entering the well at a particular horizon initially will travel upward as a thin "shell" of fluid surrounding the deeper water moving up the well bore from below. The degree of mixing will be a function of the amount of turbulence in the water stream and the distance traveled. Second, the position of the sampler, relative to the casing wall, changes with depth. Because the well is not straight and plumb, the thief sampler at times will drag along the casing wall and at other times will be suspended off the side wall of the casing by varying distances.

When the sampler rests on the side wall, it is possible that the collected sample could be biased by water entering the well at that particular depth. Conversely, when the sampler is more centrally located within the well casing, the collected sample could more likely represent a mix of deeper water, excluding contribution from the sampled depth. Because of this, there can be some apparent nonrepresentative scatter and inconsistency in the measured data.

Table 3 shows the analytical chemistry results for perchlorate, nitrate, and tritium for the 22 down-hole samples collected from Otowi 1. Figures 7, 8, and 9 show graphical representations of the reported constituent concentrations for perchlorate, nitrate, and tritium, respectively, as well as estimates of background levels of these chemicals in the regional aquifer beneath the Laboratory.

Perchlorate concentrations ranged from 0.367 to 2.52 ppb. Levels were exceedingly low below 1120 ft, gradually increasing from 1120 to 1020 ft at the top of the screen. As expected, concentrations observed at and above the top of the perforations were similar. It is believed that there are natural background concentrations of perchlorate in the regional aquifer. They are estimated to be about 0.27 ppb as indicated in Figure 7 (LANL 2005, 090580). Therefore, the perchlorate concentrations observed at most depths in Otowi 1 (greater than 0.27 ppb) are interpreted to be anthropogenic.

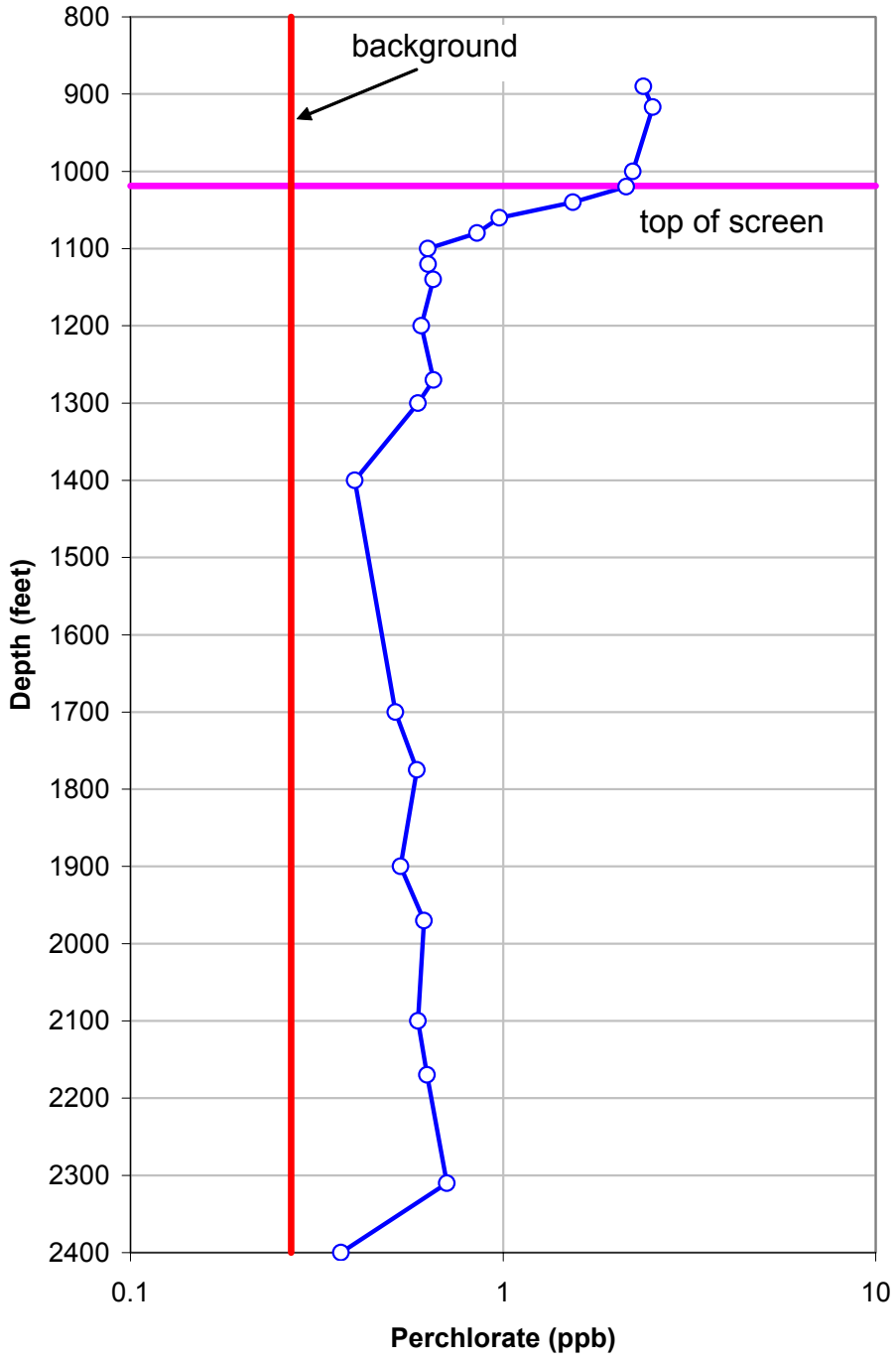
Nitrate concentrations ranged from 0.51 to 1.62 ppm, consistently greater than the estimated background concentration range of 0.3 to 0.5 ppm. The concentration pattern was similar to that observed for perchlorate in that levels were very low below 1120 ft and increased steadily from 1120 to 1020 ft.

Table 3
Otowi 1 Analytical Chemistry Results

Sample ID	Depth (gal./min)	ClO_4 (ppb)	NO_3 (ppm)	Tritium (TU)
CAPU-06-66567	890	2.38	1.55	11.8
CAPU-06-66546	917	2.52	1.62	12.6
CAPU-06-66547	1000	2.23	1.57	12.1
CAPU-06-66552	1020	2.14	1.46	10
CAPU-06-66553	1040	1.54	1.15	6.39
CAPU-06-66554	1060	0.977	0.82	2.77
CAPU-06-66555	1080	0.851	0.75	2.18
CAPU-06-66548	1100	0.628	0.54	1.74
CAPU-06-66556	1120	0.629	0.65	1.94
CAPU-06-66557	1140	0.65	0.65	2.18
CAPU-06-66549	1200	0.603	0.6	1.88
CAPU-06-66558	1270	0.651	0.64	2.14
CAPU-06-66550	1300	0.591	0.6	1.93
CAPU-06-66551	1400	0.4	0.54	0.73
CAPU-06-66559	1700	0.514	0.58	1.32
CAPU-06-66566	1775	0.587	0.62	1.39
CAPU-06-66560	1900	0.531	0.6	1.25
CAPU-06-66565	1970	0.613	0.63	1.85
CAPU-06-66561	2100	0.591	0.64	2.09
CAPU-06-66562	2170	0.625	0.64	2.14
CAPU-06-66563	2310	0.706	0.72	2.54
CAPU-06-66564	2400	0.367	0.51	0.71

Tritium concentrations ranged from 0.71 to 12.6 tritium units (TU), substantially greater than typical background levels, and exhibited the same concentration pattern as perchlorate and nitrate.

Two key conclusions can be drawn from the analytical data. First, it is readily apparent that all three contaminants were observed at low levels throughout the entire length of the well. Given the vast aquifer thickness and the extreme heterogeneity and vertical anisotropy of the formations, it is unlikely that natural groundwater movement between the source areas and Otowi 1 accounted for the observed distribution of contaminants. Perhaps the only mechanism that can explain such pervasive contamination presence over nearly a third of a mile of aquifer thickness is the continuous open well bore in Otowi 1 combined with the downward component of the hydraulic gradient that is known to exist throughout the northern and central portion of the laboratory. The Otowi 1 filter pack and well screen apparently served as a conduit for movement of shallow, contaminated regional aquifer water to greater depths.



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Los Alamos, NM

Figure 7. Perchlorate concentrations in Otowi 1

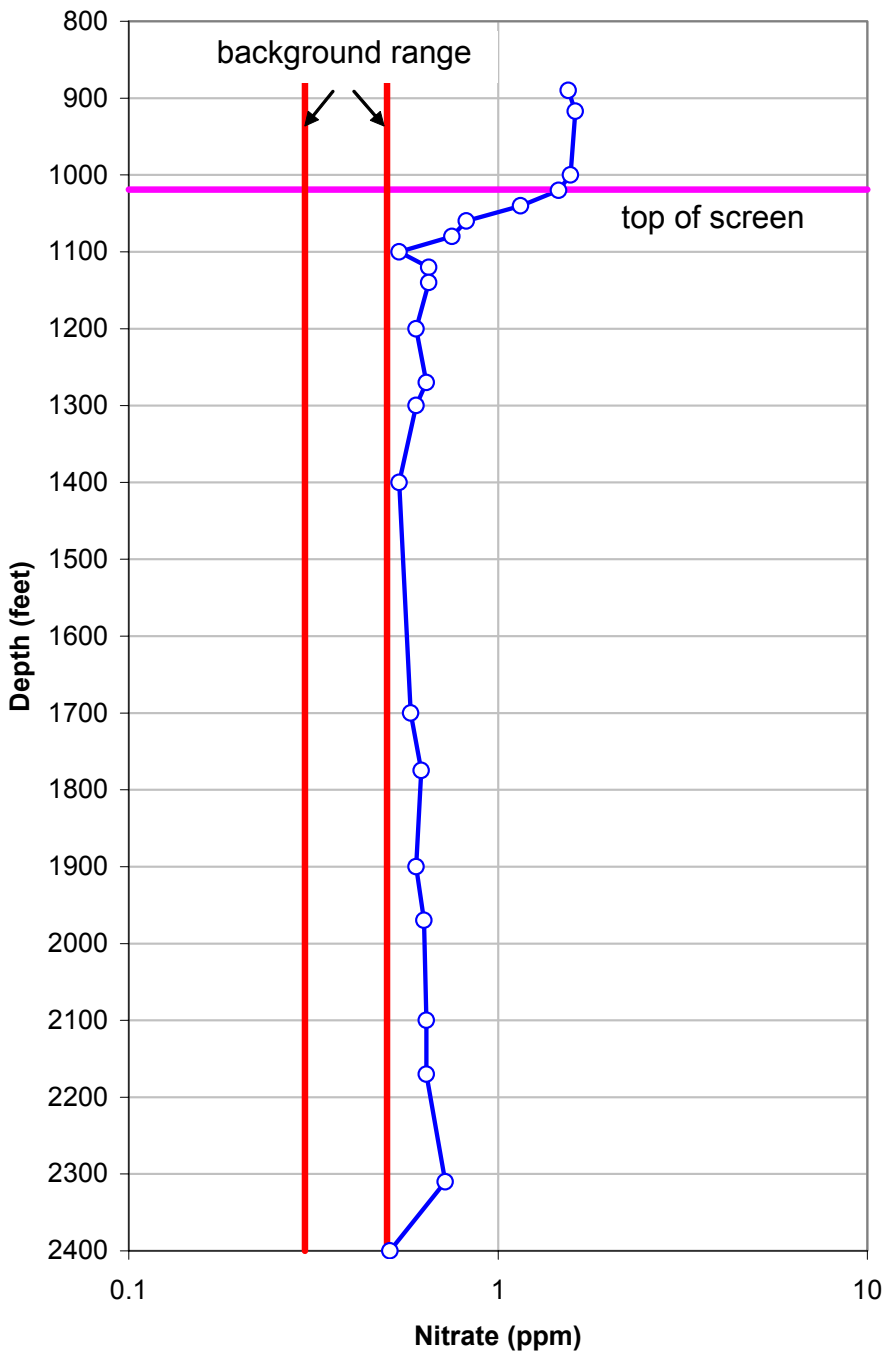

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Figure 8. Nitrate concentrations in Otowi 1

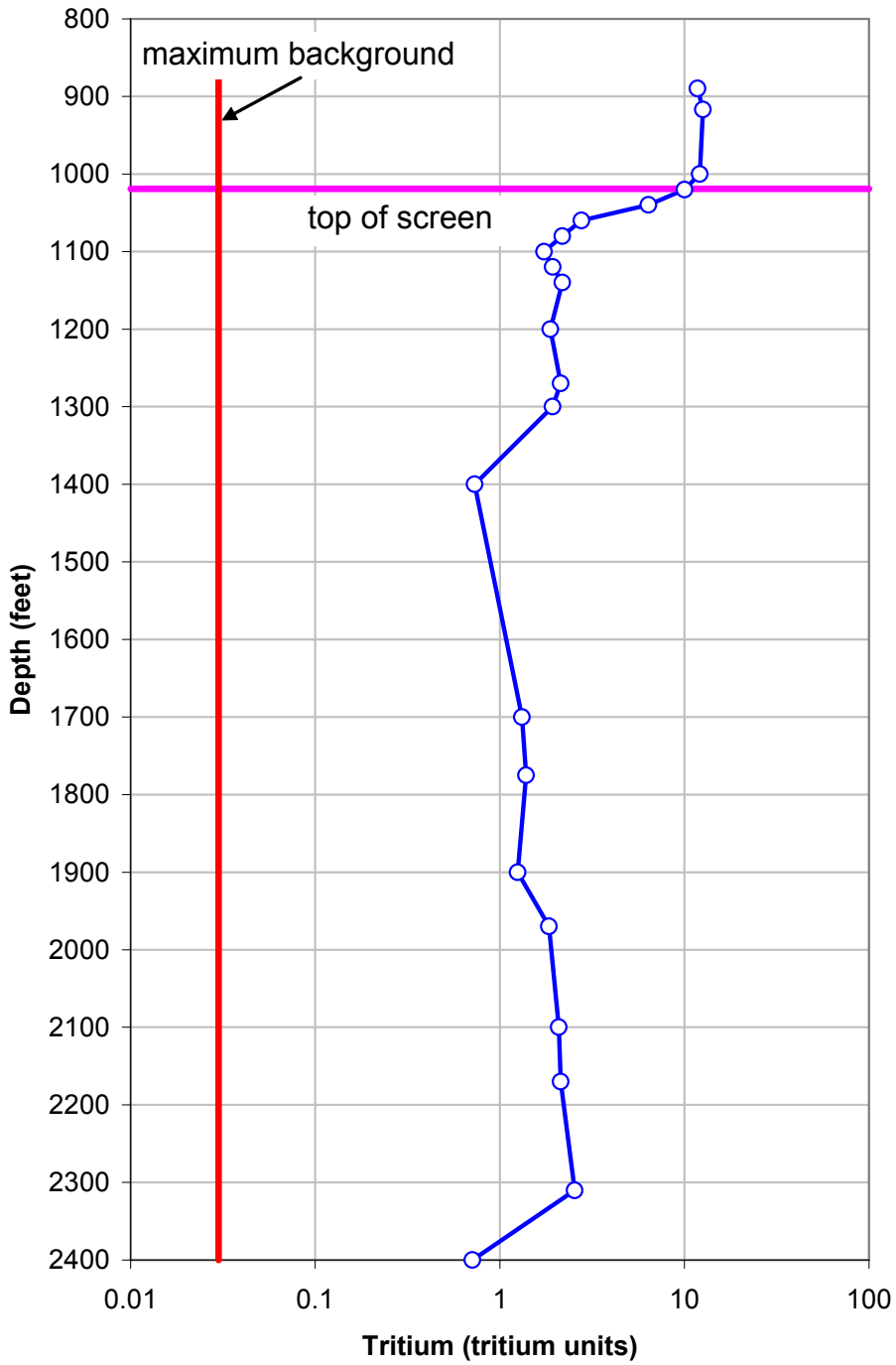

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Figure 9. **Tritium concentrations in Otowi 1c**

Second, the steady and significant increase in concentrations from about 1120 ft up to the top of the casing perforations indicates that the source of the chemicals lies somewhere above 1019 ft, behind the blank portion of the casing. It is probable that the filter-packed annulus that runs along the entire saturated portion of the casing served as a conduit connecting the chemical plume to the well screen. The prevailing downward gradient likely caused a slow but steady flux of contaminated groundwater down the filter pack and through the well screen and then down the well interior throughout the rest of the well.

Given the Otowi 1 configuration, this downward flux will continue uninterrupted into the future.

An attempt was made to investigate whether the observed contaminant concentrations could provide insight into the likely concentrations that exist in the plume(s) in the shallow portion of the regional aquifer above the top of the casing perforations. Unfortunately, correlating observed and plume concentrations accurately would require knowing the exact vertical distribution of heads within all portions of the aquifer, the vertical distribution of aquifer hydraulic conductivity, the conductivity of the filter pack, the vertical position and thickness of the plume, and the horizontal hydraulic gradient. Lacking this information, it was not possible to estimate the plume concentrations with a high degree of certainty.

Nevertheless, very rough estimates of chemical concentrations can be made as follows. For some of the municipal wells on the Pajarito Plateau, estimates of the vertical flux within the filter pack have been made. For Otowi 1, it is estimated that the downward flux outside the well casing is on the order of 10 gal./min under static conditions and perhaps double this under pumping conditions (Vesselinov, personal communication, 2006, 094260). Assuming that the downward flux was 20 gal./min while pumping the well at 505 gal./min, it is clear that the downward moving chemicals would have been diluted by about 25:1 by the production from the well.

According to the data in Table 3, the average concentrations of perchlorate, nitrate, and tritium observed in the three samples collected above the perforations in Otowi 1 were 2.38 ppm, 1.55 ppm, and 12.2 TU, respectively. Based on a dilution factor of 25:1, the concentrations of perchlorate, nitrate, and tritium in the water moving down the filter packed annulus could be 25 times greater, or about 600 ppm, 400 ppm, and 3000 TU, respectively.

The chemical concentrations in the plume itself would in turn be even greater. The downward flux of water in the filter pack outside the casing is contributed from a 328-ft thickness of sediments between the static water level of 691 ft and the top of the perforations at 1019 ft. Most of this interval is presumably contaminant free, and only the portion corresponding to the location of the plume is contaminated. For example, if the plume were about 30 ft thick (10% of the thickness of the contributing zone) and if the hydraulic conductivity and driving heads were uniform, the water moving down the filter-packed annulus would be composed of about 10% contaminated water and 90% clean water. This would imply a plume concentration about an order of magnitude greater than the estimated average

concentration in the water flowing down the filter pack. Based on the figures presented above, this could imply concentrations of perchlorate, nitrate, and tritium in the plume on the order of 6000 ppm, 4000 ppm, and 30,000 TU, respectively.

While the foregoing estimates are somewhat conjectural, they suggest that the plume concentrations could be a couple of orders of magnitude greater than the chemical concentrations measured in water samples collected from Otowi 1.

One other point worth mentioning is the apparently anomalously low tritium reading obtained from 1400 ft. The observed value was about half that observed at greater depths. Yet, as discussed later in this report, the well produced little water between 1400 ft and the next sampling location at 1700 ft. Therefore, the expected concentration at 1400 ft would have been the same as those of the deeper samples. It is not known whether the unusual reported value was related to lateral movement of the thief sampler within the borehole, sample handling, lab error, or some other cause.

Mineral and pH data recorded from Otowi 1 were used to assess the potential of the groundwater to either corrode or encrust steel well screens. As described below, video logging of the well showed considerable buildup of foreign material on the inner wall of the well casing and screen.

The parameter used to assess the corrosive versus encrusting nature of the water was the Ryznar Stability Index (Ryznar 1944, 094246). This index is based on an analysis of the relative amounts of calcium and alkalinity compared with the pH of the water, and it can indicate the tendency for either corrosion of the steel or precipitation of calcium carbonate scale. Thus, the Ryznar Stability Index addresses calcium carbonate precipitation but not other forms of encrustation (Ryznar 1944, 094246).

The Ryznar Stability Index is equal to the pH of the water minus two times Langelier's Index (Larson and Buswell 1942, 094251). A Ryznar Stability Index less than 7 suggests encrusting conditions (calcium carbonate scale formation potential); an index between 7 and 9 suggests neutral to mildly corrosive conditions; and an index greater than 9 suggests the potential for severe corrosion of steel materials (Ryznar 1944, 094246). An elevated Ryznar Stability Index, indicative of corrosive conditions as opposed to encrusting conditions with respect to calcium carbonate, does not preclude the possibility of other forms of encrustation (Ryznar 1944, 094246).

Table 4 summarizes the constituent values used to compute the Ryznar Stability Index along with the calculated results. Two sets of pH values were available—field and laboratory—so two values of the Ryznar Stability Index are shown for each sample (Ryznar 1944, 094246). The computed values ranged from a little more than 8 to more than 10, implying moderate to severely corrosive groundwater. This makes it unlikely that the scale observed in Otowi 1 is composed of calcium carbonate. It is more likely to include corrosion products, that is, redeposition of iron-bearing compounds from iron removed from the well casing through corrosion attack.

Table 4
Otowi 1 Ryznar Stability Indices
(Ryznar 1944, 094246)

Depth (ft)	Lab pH	Field pH	Alkalinity ($CaCO_3$)	Calcium (Ca++)	TDS (mg/L)	Lab Ryznar Stability Index	Field Ryznar Stability Index
Otowi 1-1	8.36	NS[a]	102	14.5	255.7	8.37	n/a[b]
Otowi 1-2	8.32	NS	101	14.8	253.3	8.40	n/a
Otowi 1-3	8.37	NS	99.4	15.2	256.9	8.34	n/a
890	8.19	7.95	97.9	15.8	250.6	8.50	8.74
917	8.16	8.10	100	15.2	253.7	8.54	8.60
1000	8.05	8.48	101	14.5	252.8	8.69	8.26
1020	8.14	8.59	101	13.9	249.9	8.63	8.18
1040	8.24	8.52	105	12.7	252.2	8.58	8.30
1060	8.31	8.51	111	10.5	254.0	8.62	8.42
1080	8.32	8.52	112	10.4	257.2	8.62	8.42
1100	8.30	8.53	115	9.36	254.3	8.70	8.47
1120	8.45	7.98	120	7.9	262.2	8.67	9.14
1140	8.56	7.70	123	5.57	260.3	8.84	9.70
1200	8.59	8.45	125	4.89	264.1	8.91	9.05
1270	8.59	7.94	133	4.56	268.6	8.92	9.57
1300	8.59	8.53	124	4.82	260.4	8.93	8.99
1400	8.67	7.63	130	3.02	262.2	9.21	10.25
1700	8.66	7.86	129	3.19	263.6	9.18	9.98
1775	8.65	7.99	129	3.24	259.4	9.18	9.84
1900	8.61	7.88	129	3.23	262.5	9.22	9.95
1970	8.69	7.97	131	3.54	262.8	9.05	9.77
2100	8.63	7.87	128	3.47	264.3	9.15	9.91
2170	8.57	8.05	128	3.66	265.9	9.16	9.68
2310	8.53	7.91	129	4.26	275.5	9.06	9.68
2400	8.65	7.95	147	3.2	298.3	9.09	9.79

[a] NS = Not sampled.
[b] n/a = Not applicable.

The observed scale also may include silicon compounds. Table 5 shows the measured silicon content of the groundwater samples, expressed as parts per million silica. The observed concentrations ranged from 35.6 to 62.8 ppm, averaging 49.0 ppm. These values are somewhat high, as most natural groundwaters contain less than 30 ppm silica (Hem 1970, 094155).

Table 5
Otowi 1 Silica Content

Sample ID	Depth (gal./min)	Silica (ppm SiO_2)
Otowi 1-1	NA*	58.7
Otowi 1-2	NA	59.7
Otowi 1-3	NA	62.8
CAPU-06-66567	890	61.1
CAPU-06-66546	917	60.6
CAPU-06-66547	1000	59.6
CAPU-06-66552	1020	59.2
CAPU-06-66553	1040	58.6
CAPU-06-66554	1060	57.3
CAPU-06-66555	1080	58.2
CAPU-06-66548	1100	55.0
CAPU-06-66556	1120	51.2
CAPU-06-66557	1140	43.9
CAPU-06-66549	1200	42.1
CAPU-06-66558	1270	39.9
CAPU-06-66550	1300	40.9
CAPU-06-66551	1400	36.5
CAPU-06-66559	1700	37.0
CAPU-06-66566	1775	35.6
CAPU-06-66560	1900	36.8
CAPU-06-66565	1970	37.3
CAPU-06-66561	2100	39.8
CAPU-06-66562	2170	40.7
CAPU-06-66563	2310	47.1
CAPU-06-66564	2400	44.9
	Average	49.0

*NA = Not analyzed.

Furthermore, it has been reported that silica encrustation is common in Los Alamos area wells (Purtymun 1994, 058233). This is likely the result of abundant rhyolite glass below the water table, with high silicon solubility.

To confirm the nature of the buildup on the well casing, it would be necessary to obtain a sample for chemical analysis. No such samples were obtained from Otowi 1 because this was beyond the scope of the investigation.

DOWN-HOLE LOGS

Down-hole logging performed in Otowi 1 consisted of (a) video inspection, (b) spinner survey, (c) temperature log, and (d) fluid resistivity log. Each log type

was conducted under both static (nonpumping) and dynamic (pumping) conditions. Initially, logs were run under static conditions on January 4. Later on January 18, they were repeated while pumping the well at approximately 505 gal./min.

The video logs were run to inspect the condition of the well materials and to look for defects, damage, evidence of corrosion, and the like. They also were used to provide evidence of zones of water contribution to the well. The spinner, temperature, and fluid resistivity logs were run primarily to identify vertical flow within the well and zones of water contribution.

Video Logs

Video logging was performed using a standard down-hole video logging camera with both down and side view capability, with 360 degree rotation. Logging was performed top to bottom at a descent rate of 40 ft/min. Periodically, the camera was stopped, and side views were used to examine the condition of the casing and screen in greater detail. A DVD containing the down-hole video was provided with the Kleinfelder report (2006, 092487).

The video showed that the inner wall of the well screen was covered with light-colored scale and nodules from top to bottom. The degree of chemical buildup worsened with depth, with the bottom half of the screen being particularly encrusted. It is reasonable to expect that any chemical reactions causing mineral buildup would be speeded up by the warmer groundwater conditions at greater depths. In most cases, side-view shots of the perforations suggested that they were plugged, that is, they showed only chemical imprints of where the perforations had been, but the perforations themselves were not visible.

As discussed previously, it is unlikely that the encrustation includes significant calcium carbonate scale because of the elevated Ryznar Stability Index of the groundwater (Ryznar 1944, 094246). It is more likely that the encrustation includes silicon-based compounds as well as iron compounds consisting of redeposited corrosion products.

Despite the massive amounts of severe chemical buildup observed in the well, pumping and drawdown data presented earlier showed that not much well capacity had been lost since it was drilled. Indeed, the past pumping records and the current drawdown data shown in Figures 4, 5, and 6 suggest that most of the drawdown is aquifer related and that only a modest component is attributable to well inefficiency. Thus, rehabilitation work applied to improve well capacity probably would not provide large yield increases.

It was hoped that the static video log might provide evidence of vertical groundwater migration within the well. However, there was no visible evidence of this. The dynamic log, on the other hand, clearly showed upward flow in response to pumping, even at depths below 2000 ft, implying that the lower reaches of the perforations, where encrustation was most severe, produced significant water volumes.

Visual examination of the casing and screen showed no evidence of damage of any kind. All joints were secure, and there were no obvious defects or corrosion holes at any depth.

Spinner Logs

Spinner logs were conducted in Otowi 1 during both static and pumping conditions. For each condition, logs were conducted both downward and upward at tool speeds of 40 ft/min.

Figure 10 shows the upward and downward spinner logs for static conditions. It was hoped that vertical flow of water within the well would be observable as a change in relative velocity of the water compared with that of the spinner tool from the top of the screen to the bottom. For example, downward flow of water would result in lower relative velocities (and reduced counts per second) near the top of the screen, with gradually increasing relative velocity toward the bottom of the screen. The resulting downward spinner log should drift to the right with increasing depth. Similarly, on the upward log, the relative tool/water velocities would be a minimum at the bottom of the well and increase gradually toward the top of the screen. This would yield a spinner log showing a mirror image of the downward log, resulting in increasing counts per second with *decreasing* depth.

Rather than a mirror image response, however, the spinner logs in Figure 10 are parallel and thus give contradictory (opposite) results. Therefore, the apparent trends on these logs were deemed insignificant and nonrepresentative. It is possible that the trends on both logs were simply thermal effects, with progressively warmer water at depth affecting the tool output.

Note also that any prominent deflections on either of the logs were not reproduced on the other. Thus, none of the apparent “spikes” on the plots is significant. The numerous deviations shown in the log are simply noise registered by the tool.

There was a clear difference in the measured counts per second between the downward and upward logs in Figure 10, with a slower propeller speed (fewer counts per second) seen in the upward log. This was caused by the geometry of the tool and the presence of the bulk of the electronic components being positioned above the propeller. This configuration makes it easier to focus flow through the propeller when water is moving upward relative to the tool (the *downward* log), compared with when water is moving downward relative to the tool (the *upward* log).

Figure 11 shows the upward and downward spinner logs for pumping conditions. Sections where the traces are steep imply little water entering the well, whereas flat portions of the trace show large contribution zones. The two plots seem to yield similar results.

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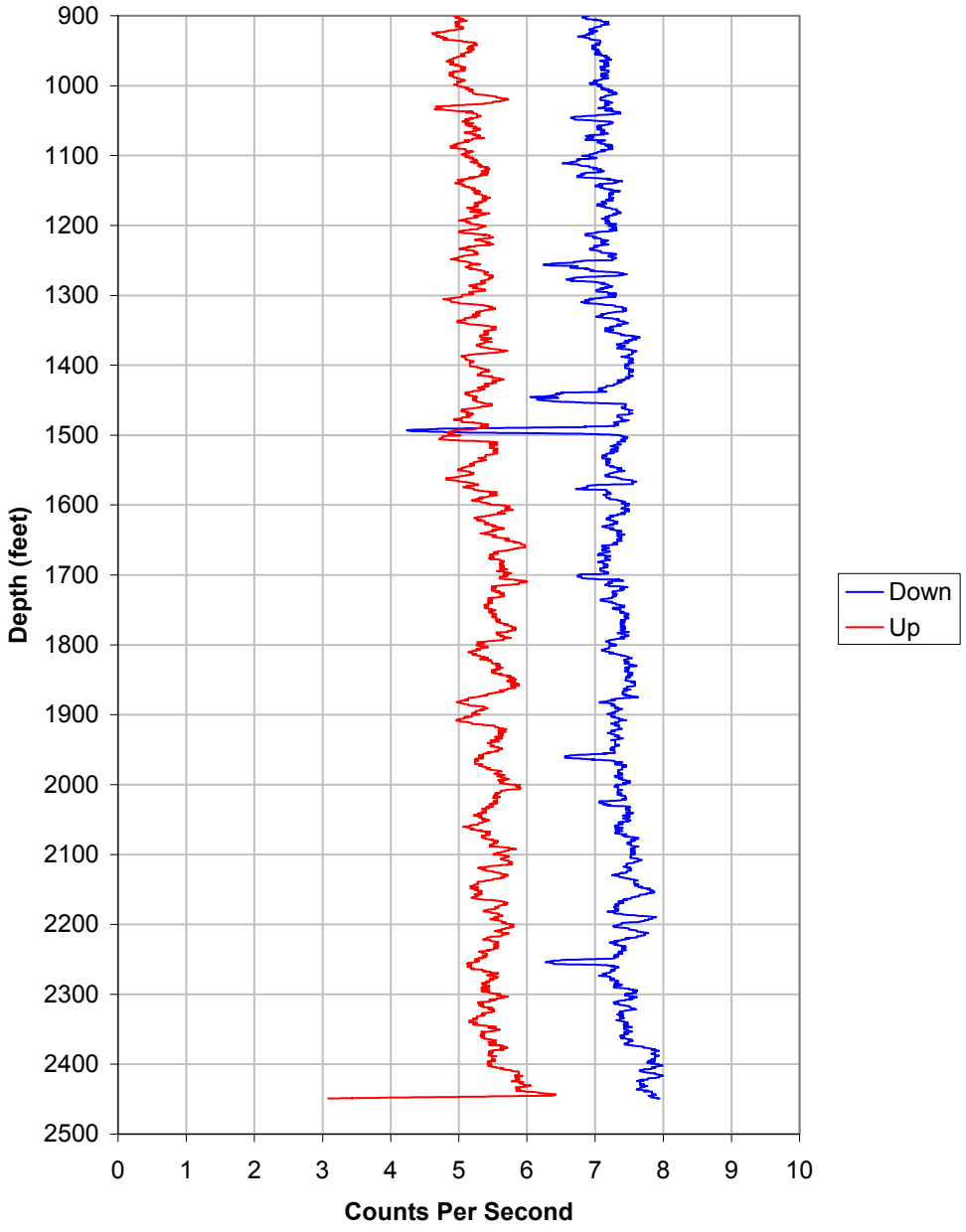

Figure 10. Spinner log—static conditions

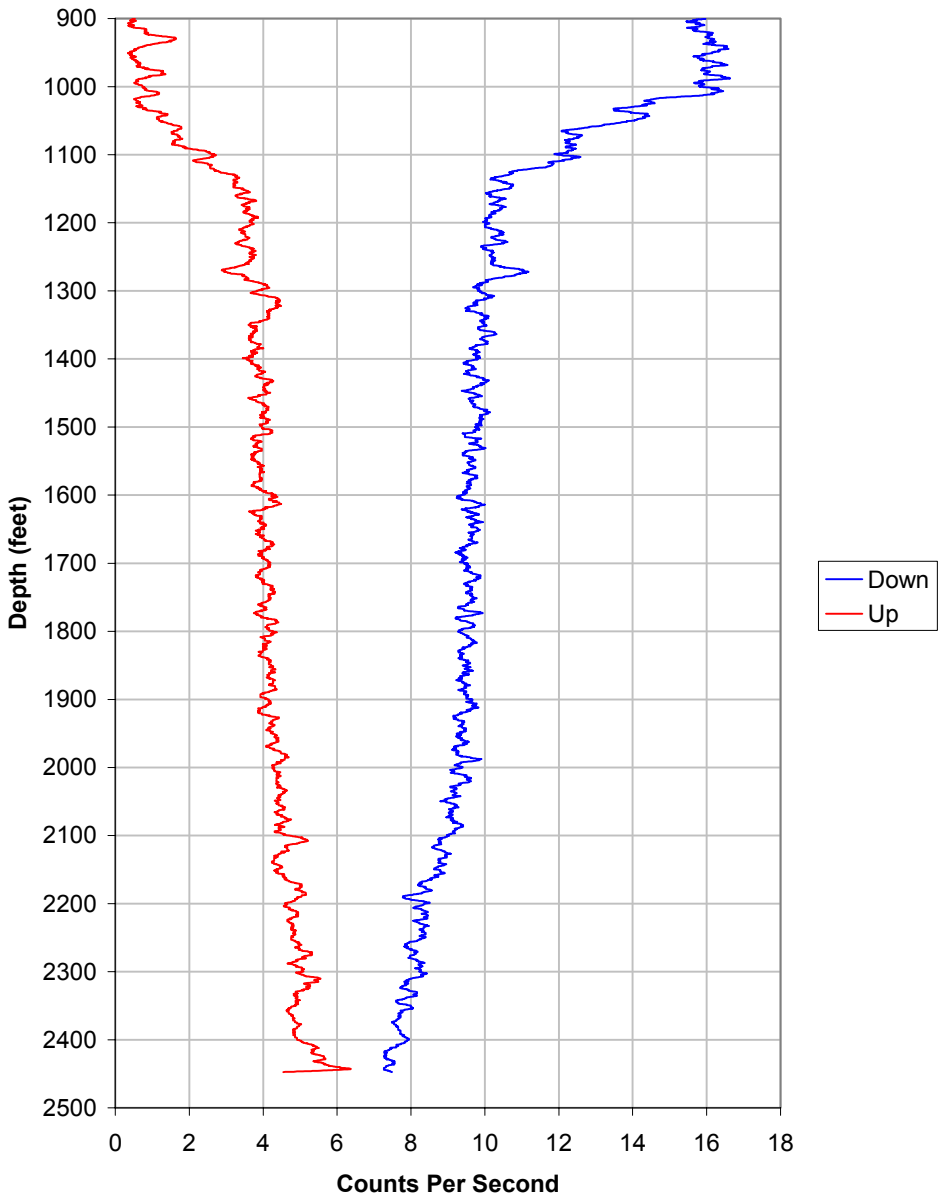

Figure 11. Spinner log —pumping conditions

It is important to point out that the output curve range shown near the top of the upward log is attenuated somewhat because of the inability of the tool to report negative counts per second. The tool speed of 40 ft/min was less than the maximum upward water velocity, which was either 48.4 ft/min (16-in. inside diameter casing) or 52.3 ft/min (16-in. outside casing). (Note: The supplier of the

pipe and louvers manufactures casing in both sizes. However, the manufacture of the pipe was so sloppy that the measured diameter of the top of the casing at the wellhead fell between these size dimensions, making it impossible to know which size had been installed in Otowi 1.) Nevertheless, regardless of casing size or slight diameter reduction caused by scale buildup, the tool speed was roughly 80% (plus or minus) of the maximum upward water velocity. Thus, the counts per second decreased steadily as the tool was moved up the well; when the tool was positioned so that 80% of the water entering the well came from beneath the tool (at approximately 1040 ft), the tool speed matched the water velocity, and the counts went to zero.

As the tool was raised further, the propeller shifted direction and rotated the opposite way. However, counts per second were still reported as positive numbers. Thus, the counts per second on the upward log above approximately 1040 ft should be plotted as the negative of the values shown on the graph. This change would have increased the data range spanned by the curve and provided a more representative log. (Note that the noise in the output prevented observing an actual count of zero, making it difficult to identify the transition point exactly.)

Because the downward log did not have this shortcoming, it was used to estimate relative flow contribution along the perforated casing. Figure 12 shows a breakdown of the log into eight individual segments. Assuming that the propeller speed was directly proportional to the water velocity, it was possible to compute the percentage yield contributions shown on the graph. Table 6 summarizes the respective depth intervals, thicknesses, and yield contributions.

Table 6
Otowi 1 Dynamic Spinner Log Results

Top Depth (ft)	Bottom Depth (ft)	Thickness (ft)	Production (%)
1019	1060	41	41.6
1060	1100	40	2.2
1100	1130	30	21.3
1130	1260	130	1.7
1260	1330	70	5.1
1330	1890	560	3.4
1890	2100	210	5.6
2100	2463	363	19.1

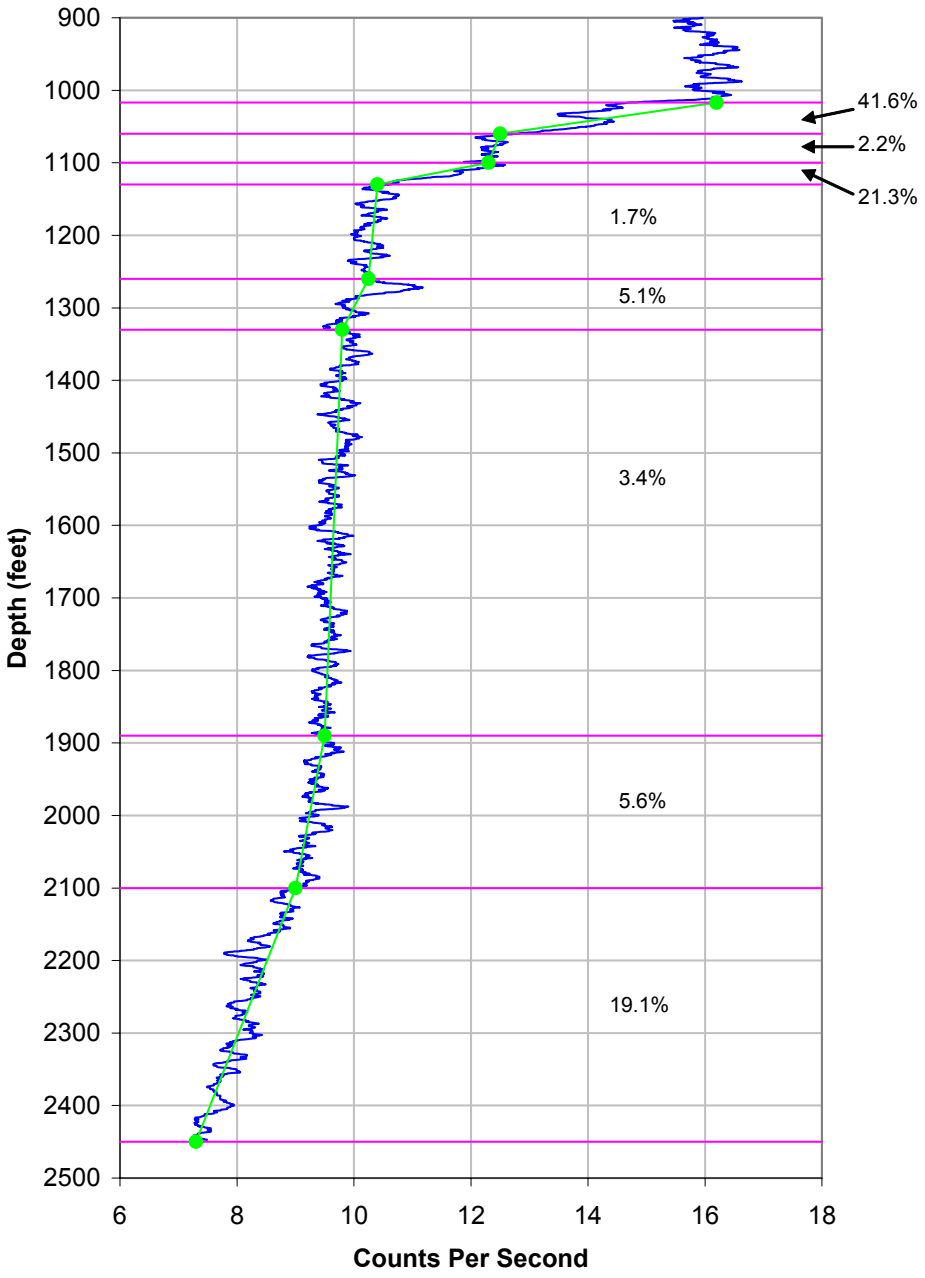

Figure 12. Relative yield contributions inferred from dynamic spinner log

The spinner log showed that about 65% of the well yield came from the upper 111 ft of perforations (1019 to 1130 ft) and that a significant portion of the production (about 19%) came from below 2100 ft. A large interval from 1330 to 1890 ft (560 ft thick) produced only 3.4 % of the production to Otowi 1. (Note that

the 65% production from the upper portion of the screen likely includes a few percent contributions from the vertical flux in the filter pack above the screen.)

Temperature Logs

Temperature logs were conducted in Otowi 1 for both static and pumping conditions. The log results are plotted in Figure 13.

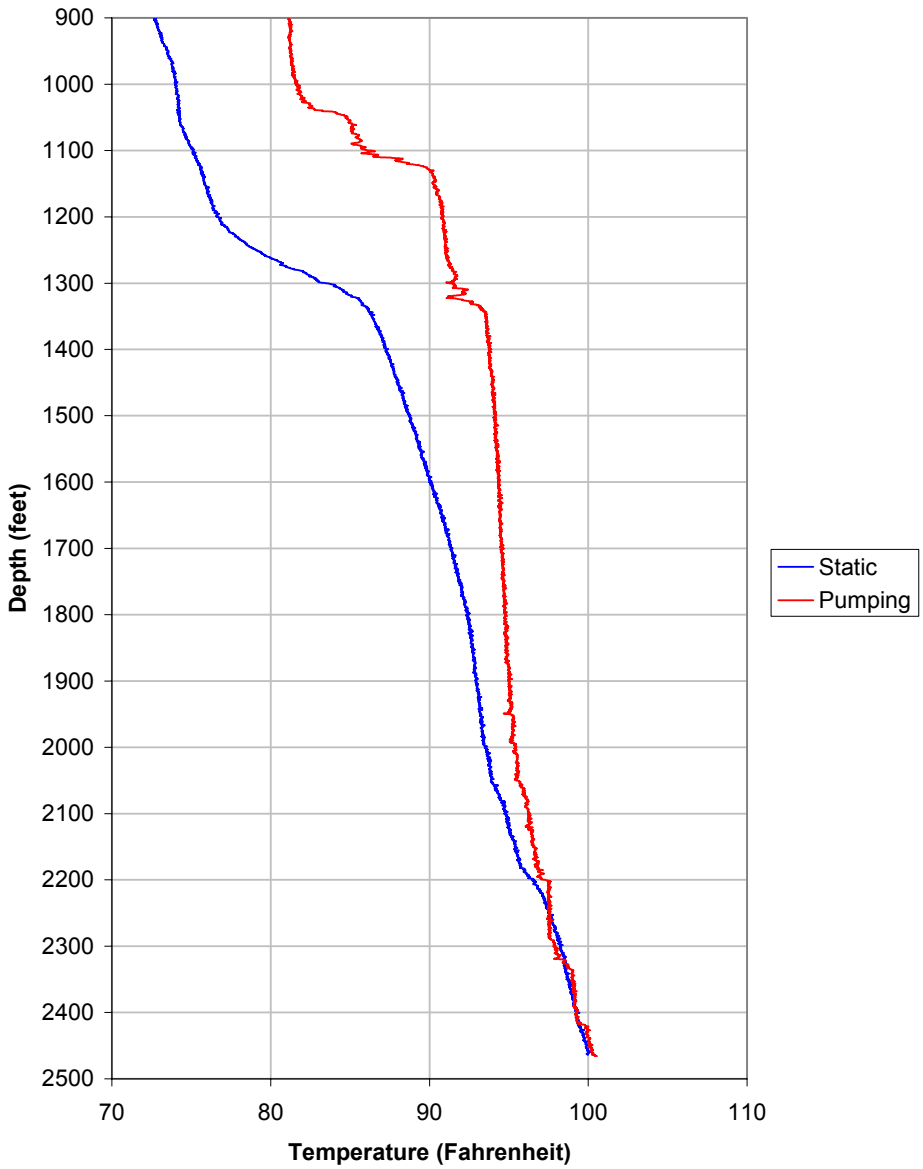

Figure 13. Static and dynamic temperature logs

The static log showed that water temperatures within the perforated zone ranged from about 74 degrees Fahrenheit at the top to 100 degrees at the bottom of the well. It also provided additional evidence of downward migration of groundwater.

Normally, the temperature slope is somewhat uniform. However, above 1320 ft, instead of a gradual increase in temperature with depth, the water temperature increased only slightly from 1019 ft to about 1220 ft then increased sharply from 1220 ft to 1320 ft. Presumably, downward flux of a small quantity of cooler water from the top of the perforations provided a cooling effect that persisted for some distance. As the downward moving cooler water gradually moved out into the formation, a steadily decreasing quantity was left to continue migrating down the screen.

At about 1320 ft, the cooling effect seemed to have dissipated. Any further migration down the well is apparently at too low a rate to significantly cool the deeper portions of the aquifer.

A perplexing aspect of the static temperature plot is that the reverse argument could be made about warm water at the bottom of the well rising and causing a warming effect some distance up the borehole, suggesting the presence of an *upward* gradient in the deeper portion of the borehole. This idea is illustrated in Figure 14. The straight line on the graph shows a typical linear temperature gradient that might be expected in the absence of groundwater movement within the well bore. Just as temperatures at the top of the screen appear to be cooled relative to the theoretical trend line by a downward flux, it could be argued that a similar upward flux of warm water caused the static temperature curve to deflect above the linear gradient trend line. Note that having both a downward gradient and an upward gradient in the same well is not impossible, if the discharge point (Rio Grande) falls in the middle of the well screen and is nearby.

There are several problems, however, with the interpretation of an upward gradient in the lower portion of the borehole. First, the Rio Grande is not nearby but is about 4 mi away. Second, the source of the warm water flux appears to be between 2000 and 2100 ft, an area where the sediments are not high yielding. One would expect the warming effect to have originated from deeper than this where the temperatures are greater and the formation is more permeable. Finally, if there really is an upward gradient in the bottom 1000 ft of the aquifer penetrated by Otowi 1, it is difficult or impossible to explain how contaminants could have reached the deeper portions of the well and aquifer. Unless the observed contaminant concentrations can be considered background levels, a downward gradient would be necessary to have created the observed chemistry.

Perhaps an alternate explanation is that the natural temperature gradient is segmented as shown in Figure 15. The figure suggests gradual cooling with increasing elevation from the bottom of the well to a depth of 1330 ft and more rapid cooling above 1330 ft. Sediments below 1330 ft are tight; thus, the flux of groundwater is low. Above 1330 ft, the sediments are more permeable, so groundwater flow in that area is substantially greater. It is possible that significant

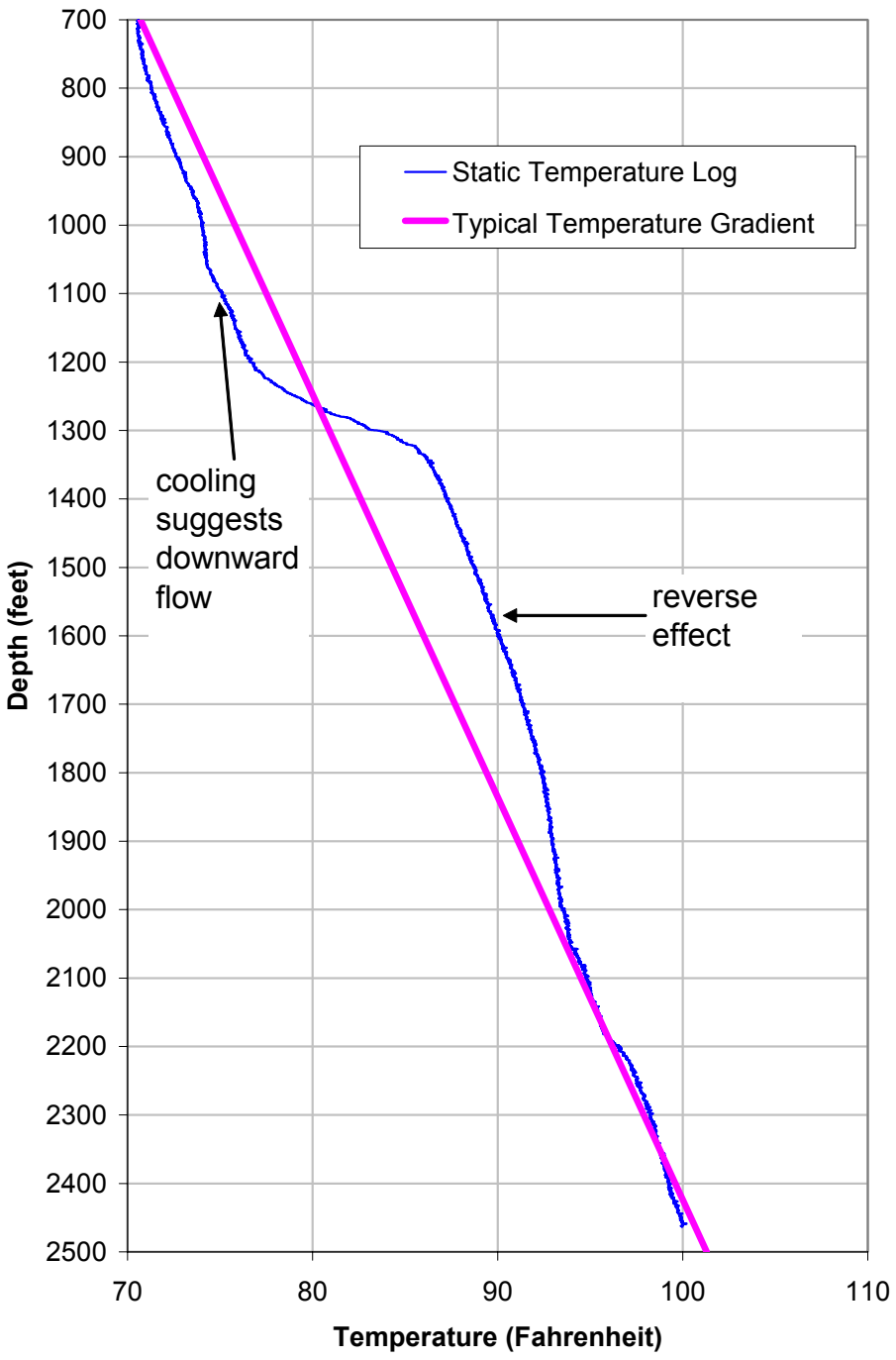

Figure 14. **Comparison of observed water temperature and typical straight-line trend**

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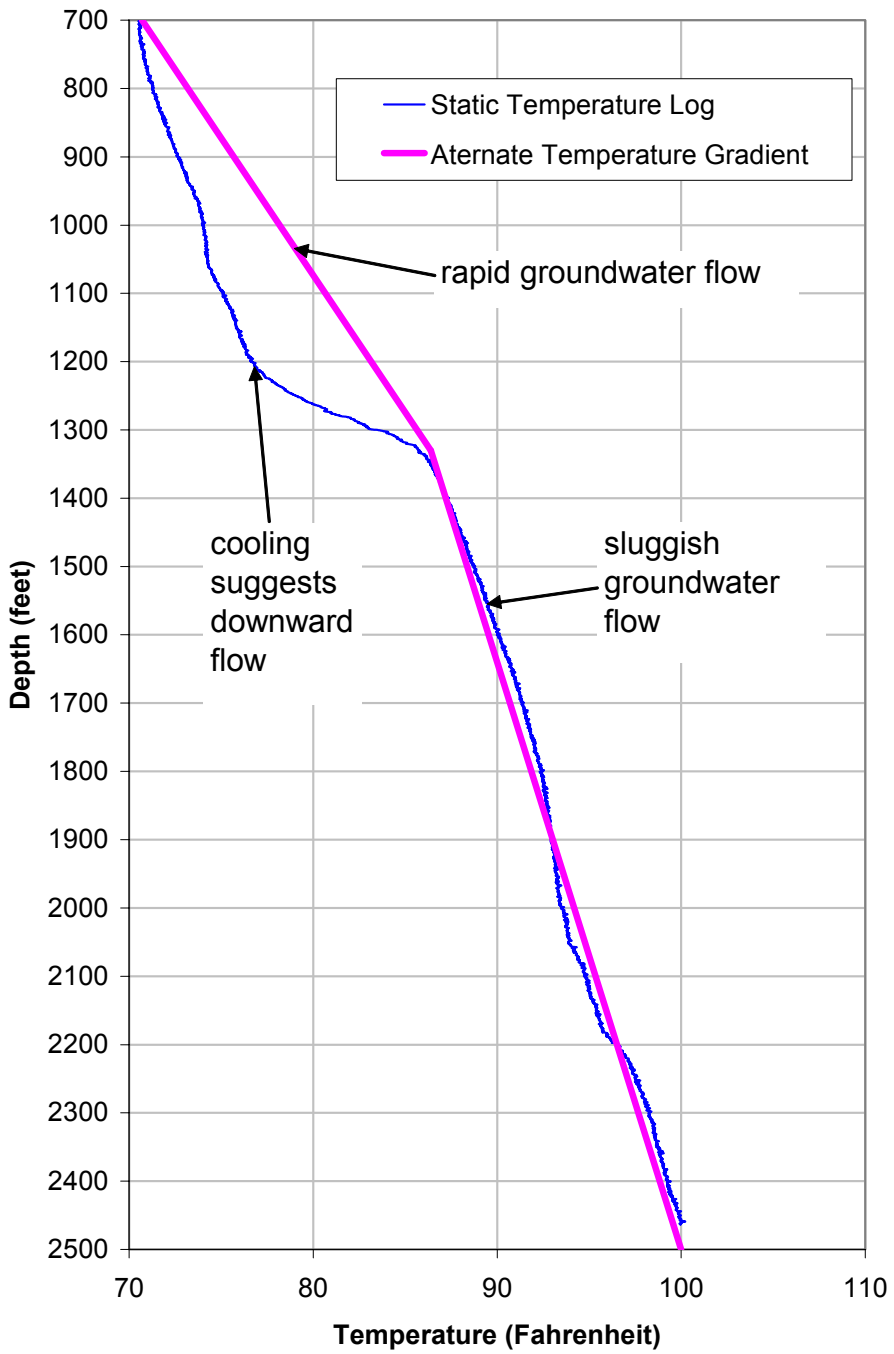

Figure 15. **Comparison of observed water temperature and segmented straight-line trend**

groundwater flux from the nearby Miocene trough through the sediments above 1330 ft results in more rapid cooling than occurs below that depth. The idea of a segmented background temperature gradient is reasonable and is consistent with the idea of a strictly downward groundwater gradient at Otowi 1.

The temperature log recorded during pumping (Figure 13) showed a distinct shift to higher temperatures caused by warm, deeper water moving up the borehole. As the rising warm water encountered and mixed with cooler water entering the screen, the temperature of the mixture declined. The flatter segments of the curve (greater rate of temperature drop) show the areas of greater groundwater inflow.

Figure 16 shows areas of low, moderate, and high groundwater contribution inferred from the dynamic temperature log. The corresponding depth intervals and thicknesses are listed in Table 7. The relative contributions suggested by the temperature log agree well with the conclusions drawn from the dynamic spinner log (Figure 12 and Table 6).

Table 7
Otowi 1 Temperature Log Results

Top Depth (ft)	Bottom Depth (ft)	Thickness (ft)	Production Per Foot
1019	1050	31	High
1050	1100	50	Moderate
1100	1130	30	High
1130	1260	130	Low
1260	1330	70	Moderate
1330	1950	620	Low
1950	2463	513	Moderate

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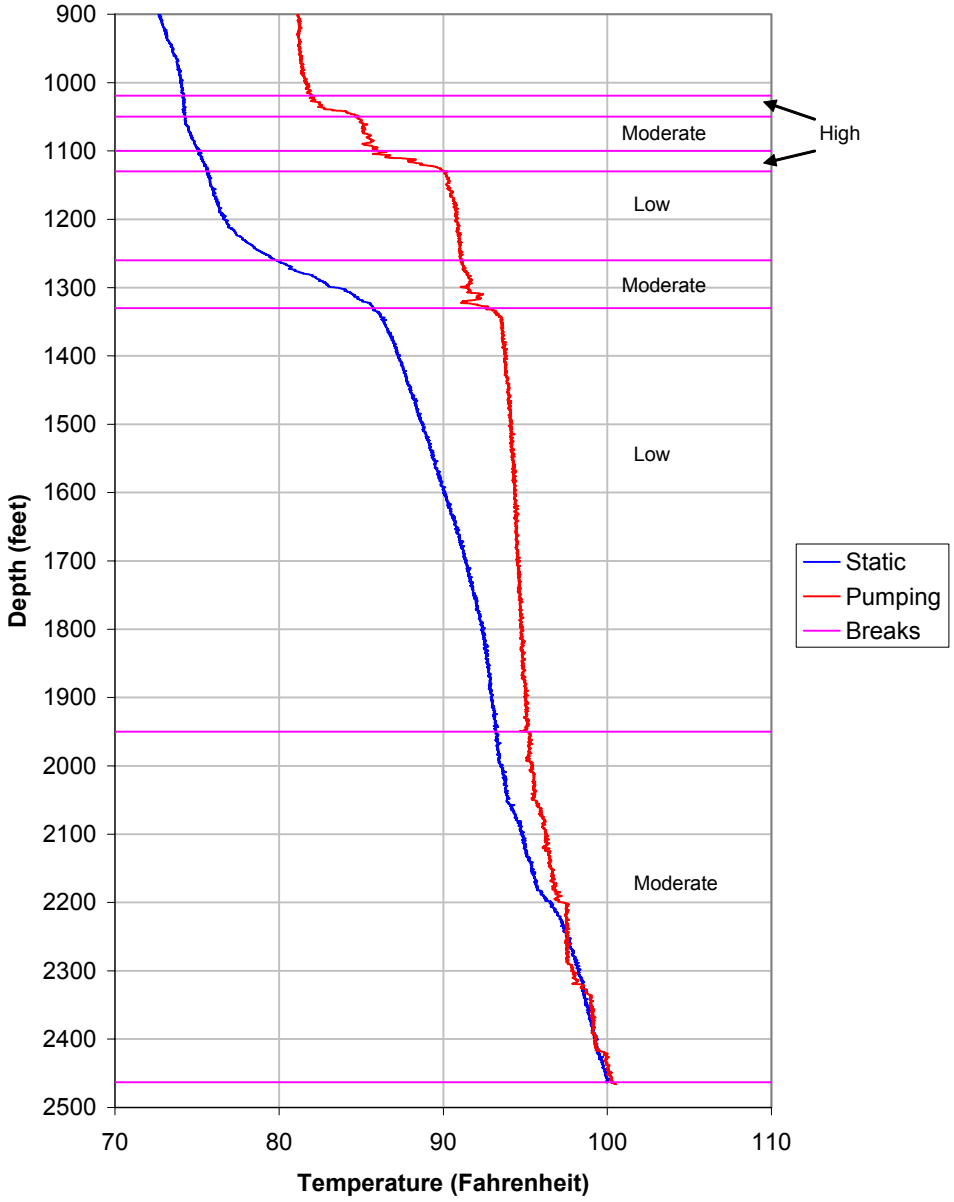

Figure 16. **Production contribution inferred from dynamic water-temperature log**

As a further check on the conclusions drawn from the dynamic spinner log regarding relative yield contributions, depth-discrete temperature and relative-yield contribution data were combined to reconstruct and predict the expected water temperature of the bulk flow exiting the well screen. For each of the depth intervals shown in Table 6, the average temperature over that interval was computed from the static temperature log data. By summing all contributing zones, a predicted weighted average water temperature was calculated as shown in Table 8.

Table 8
Otowi 1 Water Temperature Calculations

Top Depth (ft)	Bottom Depth (ft)	Production (%)	Average Temperature (degrees F)
1019	1060	41.6	74.22
1060	1100	2.2	74.69
1100	1130	21.3	75.37
1130	1260	1.7	76.96
1260	1330	5.1	82.96
1330	1890	3.4	90.02
1890	2100	5.6	93.62
2100	2463	19.1	97.65
Computed Weighted Average Temperature			81.07
Pumped Water Temperature at Top of Screen			81.94

The predicted weighted average temperature of pumped water exiting the top of the well screen was 81.07 degrees Fahrenheit versus a measured value at the top of the perforations during pumping of 81.94 degrees. The good agreement between these values supports the dynamic spinner log interpretation. Furthermore, the slight underestimate of the calculation is likely attributable to the biased (cooler) measured static groundwater temperatures in the upper portion of the well screen caused by the downward flux of cooler water described previously.

The static and dynamic temperatures shown in the logs in Figure 13 play a role in determining the measured static water level in the well. Because warmer water is slightly less dense than cooler water, a warm water column in equilibrium with down-hole aquifer pressures will be “taller” than a cool water column and thus will result in a higher measured water level.

If the temperatures shown on the dynamic temperature log in Figure 13 could be maintained following pump shutoff, the recovering water level would approach a new level higher than the original because of the lower average density of the warmed water column. Based on the magnitude of the temperature differences in the two curves in Figure 13 and the corresponding relative water densities, the water level would be expected to rise a little more than a foot above the initially measured level.

Curiously, in a setting in which the initial head difference between the top and bottom portions of the aquifer was small, say less than a foot, warming of the water column caused by brief pumping could actually cause a reversal of ambient flow in the well following pump shutoff. If the initial flow had been downward, warming of the water column could raise its level above the pressure of the upper portion of the aquifer, causing flow from the borehole into the upper zone. Water would be replenished by flow into the well from the deep portion of the aquifer. Such an unusual occurrence would only be observed where a sufficiently large temperature gradient and a sufficiently small vertically downward component of the hydraulic gradient existed.

In Otowi 1, however, the residual drawdown following pump shutoff was substantially greater than the small potential water-level difference associated with the warmer water column. Also, it is likely that the static head in the upper portion of the regional aquifer is several feet or tens of feet greater than that of the deeper sediments at the Otowi 1 location, based on the vertical head data shown in Table 1. Consequently, as soon as pumping was discontinued, downward flow was reestablished and the prepumping temperature distribution within the well was restored.

Another consideration is the possibility of thermal convection currents within the well resulting from warmer, lighter water at depth rising up the borehole and cooler water descending. Unfortunately, there was no way to determine whether such a phenomenon existed in Otowi 1 or, if so, what the magnitude of its effect might have been.

Fluid Resistivity Logs

Fluid resistivity logs were conducted in Otowi 1 for both static and pumping conditions. The log results are plotted in Figure 17. The resistivity logs did not provide new or different information. Note that they are essentially mirror images of the temperature logs (Figure 13) because higher temperature implies greater ionic activity and conductance and therefore lower resistivity.

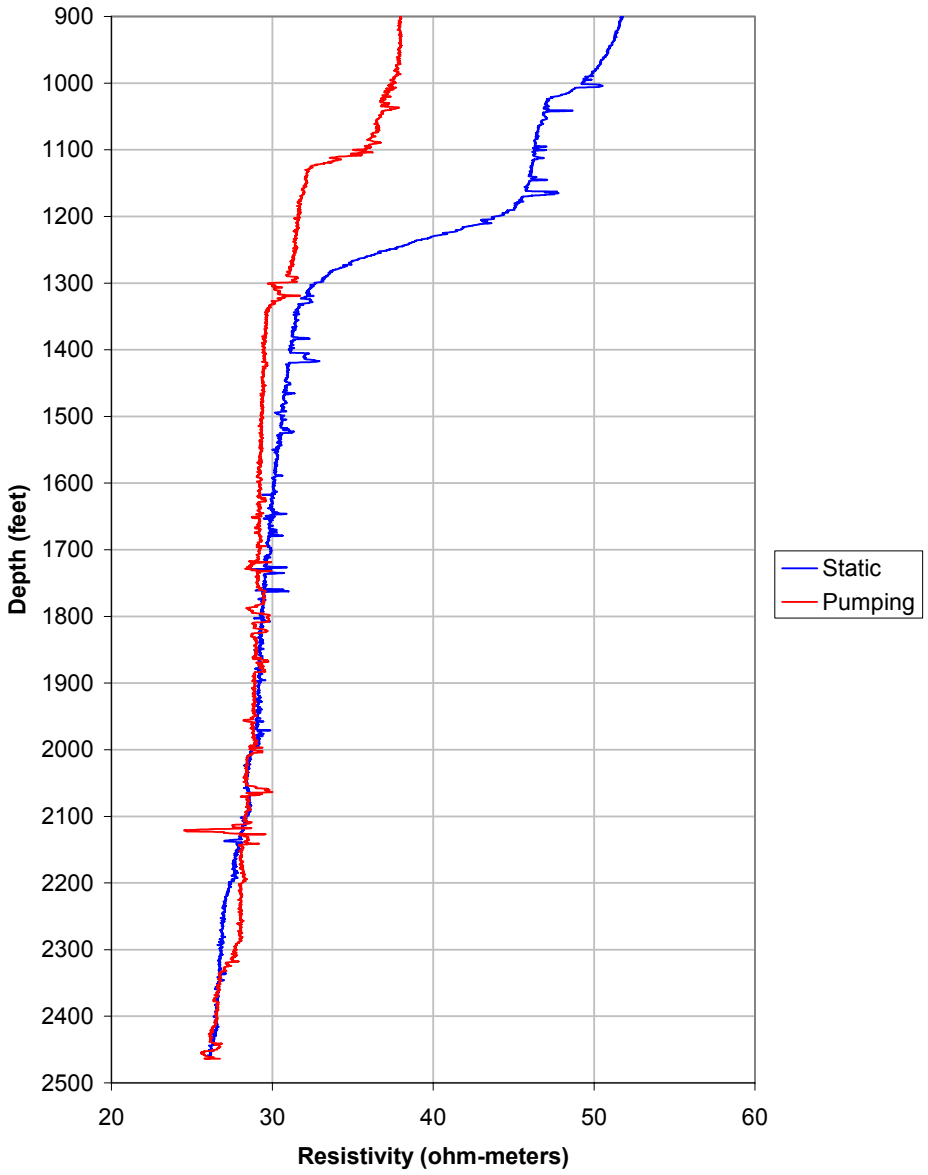

Figure 17. Static and dynamic fluid resistivity logs

Field measurements of conductance produced very different results, as shown in Figure 18. Most of the field measurements were made at about the same temperature (the samples had cooled somewhat before analysis) and, with the temperature variable removed, yielded nearly identical conductivities of about 245 microsiemens per centimeter (µS/cm). This corresponds to a resistivity of about 41 ohm-meters. While the fluid resistivity log data were consistent with the temperature data, they did not provide independent information.

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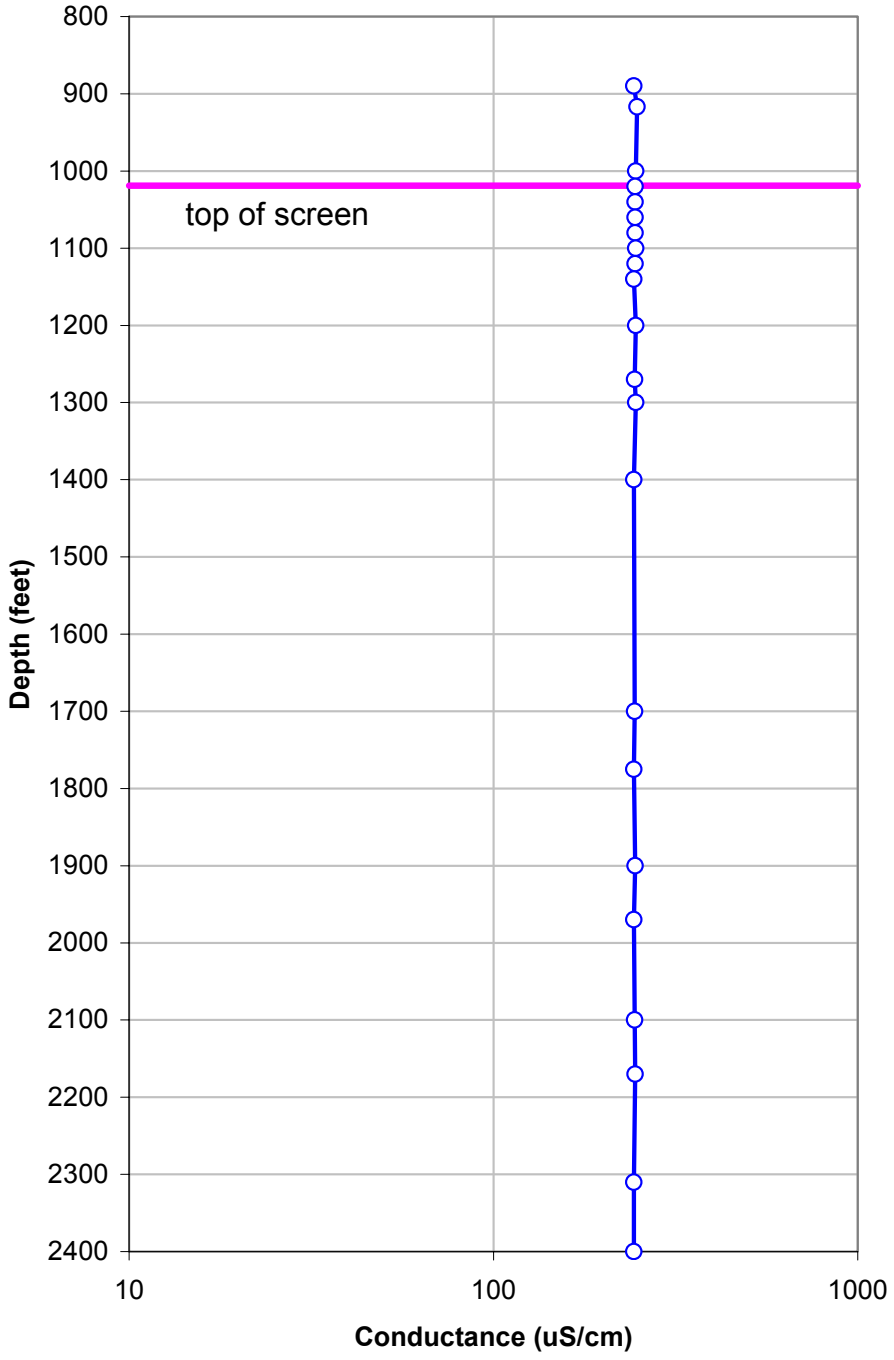

Figure 18. Field measurements of conductance

IMPLICATIONS FOR R-3 DESIGN

Regional aquifer well R-3 will be used to help identify the vertical location of the contaminant plume that is affecting Otowi 1. A key element in designing R-3 is selecting the screen intervals.

Observations and conclusions from the Otowi 1 assessment suggest that the source of contamination entering the well is at a horizon shallower than 1019 ft (above elevation 5377 ft). At the same time, detection of some of these constituents in regional aquifer wells R-4 and R-5 confirm that they have moved beyond the perched zone and into the regional aquifer up gradient of Otowi 1. Thus, although the presence of contamination in the perched zone at the proposed R-3 location has been demonstrated by samples taken from vadose zone well R-3a, it seems that the regional aquifer should be the primary focus of the investigation and the target location for screens in R-3. The potential target zone thus extends from the static water level at 691 ft to the top of the perforations in Otowi 1 at 1019 ft—a span of 328 ft.

Originally, R-3 was planned to incorporate up to three screened intervals. However, going beyond two screens in a single well would likely rule out implementation of a valved submersible pump sampling system such as that installed successfully at R-10. Therefore, to simplify well development, hydraulic testing, and permanent sampling system design, it would be advantageous to limit the number of screened intervals to two and consider an additional well if more sampling horizons are required.

With a broad target zone—328 ft thick—the chances of “hitting the target,” that is, finding the plume, can be increased by using long well screens and by preferentially targeting the most permeable horizons. Also, because nitrate and perchlorate contaminants in nearby well R-5 were observed at the water table, targeting the upper portion of the 328-ft thick interval initially would make sense. A second well, if needed, could tap deeper sediments.

Also, tritium in R-5 was observed only in the perched zone. This may imply that tritium hasn’t yet reached the regional aquifer at the proposed R-3 location but may exist only in the vadose zone there.

SUMMARY

Los Alamos County Well Otowi 1 was investigated to evaluate the condition of the well and to determine the source location of perchlorate, nitrate, and tritium observed in water pumped from the well. The Otowi 1 investigation included video, spinner, temperature, and fluid resistivity logging during both static (nonpumping) and dynamic (pumping) conditions. It also included purging the well for several days and obtaining depth-discrete groundwater samples while simultaneously pumping the well. Following are the key findings of the investigation:

1. An inventory of 15 multiscreen wells in the central and northern portions of the laboratory shows significant and consistent downward hydraulic gradients in all wells. (The only known well showing an upward gradient is

R-31 in the southern portion of the laboratory.) This implies that downward gradients likely exist at Otowi 1 as well.

2. The construction of Otowi 1, with a filter pack from above the water table to 2497 ft and screened continuously from 1019 to 2477 ft, allows it to serve as a conduit from the top of the regional aquifer to the total depth of the well.
3. Comparison of new pumping data to old records showed that Otowi 1 has lost little production capacity over the past 16 yr.
4. Thief sampling showed highest concentrations of perchlorate, nitrate, and tritium at the top of the perforated interval, implying that the plume or plumes lie somewhere above 1019 ft and suggesting a downward hydraulic gradient.
5. Detection of perchlorate and nitrate in the regional aquifer in R-4 and R-5 confirms that these contaminants have breached the perched zone. Thus, the plume within the regional aquifer is bracketed between the depths of 691 ft (static-water level) and 1019 ft (top of perforations in Otowi 1)—an interval that is 328 ft thick.
6. Very low levels of perchlorate, nitrate, and tritium were observed at all tested depths in Otowi 1, down to 2400 ft below land surface, consistent with contaminants being spread throughout the well through a downward vertical gradient.
7. Ryznar Stability Index calculations suggest that the water in Otowi 1 is more likely to corrode steel rather than to deposit calcium carbonate scale.
8. Silicon compounds dissolved in the Otowi 1 water samples average 49 ppm as silica—higher than observed in most groundwaters.
9. Video logging showed the well to be structurally sound but coated extensively with massive amounts of light-colored scale and nodules, probably a combination of silica encrustation and redeposited corrosion products from the casing and screen. Greatest accumulation of encrustation was in the bottom half of the well where water temperatures are highest.
10. Spinner and temperature logs helped define the production zones in Otowi 1. Results showed about 65% of the production coming from above 1130 ft and another 19% entering the well below 2100 ft.
11. Warming of the water column caused by pumping offers the potential of altering the measured water level following shutdown. In Otowi 1, however, once the pump is turned off, downward flow is reestablished, and the original temperature profile is restored.
12. Rough estimates of downward flux of water within the filter pack and plausible conjecture of plume height vis-à-vis the height of the saturated zone contributing to the downward flux in the filter pack suggest that the plume concentrations of perchlorate, nitrate, and tritium may be a couple of orders of magnitude greater than the concentrations measured in groundwater samples taken from the casing above the perforated zone in Otowi 1.
13. In its current configuration, Otowi 1 will continue to serve as a conduit for vertical movement of groundwater contamination.

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Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau; the U.S. Department of Energy–Los Alamos Site Office; the U.S. Environmental Protection Agency, Region 6; and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

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