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Report of Testing and Sampling of Municipal Supply Well PM-4

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Table of Contents

Abstract 1

1.0 INTRODUCTION 2

1.1 PM-4 Location and Background Information 2

1.2 Project Resources 6

2.0 Field Activity Summary 7

2.1 Phase-I Well Testing 7

2.1.1 Video Log #1 7
2.1.2 Removal of Lubricating Oil from the Well 8
2.1.3 Spinner Log Surveys 8
2.1.3.1 Static Spinner Log Survey 8
2.1.3.2 Dynamic Spinner Log Survey 9
2.1.3.3 Results of Dynamic Spinner Log Survey 12

2.2 Phase-II Zonal Groundwater Sampling 15

2.2.1 Purging of Groundwater 15
2.2.2 Zonal Groundwater Sampling 16
2.2.2.1 Zone #1 22
2.2.2.2 Zone #2 24
2.2.2.3 Zone #3 25
2.2.2.4 Zone #4 26
2.2.2.5 Zone #5 26
2.2.3 Summary of Purging and Sampling Activities 27

2.3 Phase-III Video Log #2 27

3.0 Analytical Results 28

3.1 Results of NPDES Sampling 28

3.2 Results of Zonal Groundwater Sampling 28

4.0 Summary and Conclusions 36

5.0 References 38

6.0 Acknowledgments 40

Figures

Figure 1. Location map of Los Alamos National Laboratory showing locations of selected wells 3
Figure 2. Construction information and stratigraphy of PM-4 5
Figure 3. Drawdown and water quality parameters during pumping of PM-4 on March 17, 1999. 10
Figure 4. Drawdown and water quality parameters during pumping of PM-4 on March 18, 1999. 11
Figure 5. Water level rebound in the well after the pump was turned off on 3/18/99. 12
Figure 6a. Results of the dynamic spinner log survey 13
Figure 6b. Derivative with respect to depth of spinner log survey 13
Figure 7. Water quality parameters during purging from Zone #1. 23
Figure 8. Water quality parameters during purging from Zone #2. 25
Figure 9. Stiff diagrams showing groundwater chemistry 34
Figure 10. Results of analyses for stable isotopes of hydrogen and oxygen 35

Tables

Table 1. Project Personnel 6
Table 2. PM-4 Testing and Sampling Activity Schedule 7
Table 3. Summary of Characteristics of Productive Zones in PM-4. 14
Table 4. Zones Initially Selected for Sampling 15
Table 5. Field Measurement Methods for Groundwater Samples 16
Table 6. Groundwater Sampling Methods 17
Table 7. Summary of Samples Collected from PM-4 17
Table 8. Full Analytical Suite for PM-4 Regional Aquifer Groundwater Samples 19
Table 9. Estimated Detection Limits and Analytical Methods for Inorganic Chemicals in PM-4 Groundwater Samples 20
Table 10. Minimum Detectable Activity and Analytical Methods for Radionuclides in Groundwater Samples 21
Table 11. Analytical Methods for Additional Parameters in PM-4 Groundwater Samples 22
Table 12. Field Measured Water Quality Parameters of Groundwater Samples. 24
Table 13. Results of NPDES Compliance Sampling of PM-4 28
Table 14. Chemical Quality of Groundwater Zones in PM-4 31
Table 15. Trace Metals in Groundwater Zones in PM-4 31
Table 16. Radionuclides in Groundwater Zones in PM-4 32
Table 17. Results of Stable Isotope and Nitrogen Isotope Analyses 33

REPORT OF TESTING AND SAMPLING OF MUNICIPAL SUPPLY WELL PM-4

by

Richard J. Koch, Patrick Longmire, David B. Rogers, and Ken Mullen

Abstract

During drilling of regional aquifer characterization borehole R-25, located in the western part of Los Alamos National Laboratory (LANL) at Technical Area (TA) 16, groundwater samples were collected from perched zones of saturation and the regional aquifer that contained elevated levels of high explosive (HE) compounds. One of the nearest Los Alamos County municipal supply wells potentially located down gradient from borehole R-25 is PM-4, located on Mesita del Buey at the west end of TA-54. During the winter of 1998 and 1999 the pump in PM-4 had been removed from the well for scheduled maintenance by the Los Alamos County Public Utilities Department (PUD). Because the pump was removed from PM-4, the opportunity existed to enter the well to (1) perform tests to determine where within the regional aquifer groundwater entered the well and (2) collect groundwater samples from the producing zones for analyses to determine if HE contaminants were present in discrete zones within the regional aquifer.

The report of the activities that were performed during March 1999 for the testing and sampling of municipal supply well PM-4 is provided. The report provides a description of the field activities associated with the two phases of the project, including (1) the results of the static and dynamic spinner log surveys, and (2) a description of the sampling activities and the field-measured groundwater quality parameters that were obtained during sampling activities. This report also provides the analytical results of the groundwater samples and a brief discussion of the results of the project.

The dynamic spinner log survey was obtained while pumping the well at a rate of 1,000 gpm (historically, the well is pumped at a rate of approximately 1,350 gpm when operating). The result of the dynamic spinner log survey showed that most of the water was produced from the upper 500 ft of the 1,604 ft-long screened interval. The productive zones correlate to the lower part of the Puye Formation, including the Totavi Lentil and the upper part of the Santa Fe Group.

Groundwater samples were collected for analyses from the following depths: 1,340 ft, 1,406 ft, 1,505 ft, 1,635 ft, and 2,085 ft. The groundwater samples were analyzed for inorganic species (major ions and trace elements), HE compounds, stable isotopes of hydrogen, oxygen, and nitrogen, selected radionuclides, and organic compounds including PCBs (in the samples from the upper zone only). Chemical and radiochemical analyses were performed at the Environmental Restoration (ER) Project contract analytical laboratories. The USEPA-SW846 methods and other analytical methods were used for chemical and radiochemical analyses. Tritium analyses were performed using low detection methods at the University of Miami Tritium Laboratory. Alpha spectroscopy analyses were performed on samples from the upper two zones.

High-explosive compounds, including RDX, HMX, TNT, and associated degradation products were not detected in the groundwater samples collected from PM-4. The groundwater from the five zones at PM-4 is characterized by calcium-sodium-bicarbonate compositions. The chemical character of each of the zones sampled is uniform, indicating that the water sampled was homogenous and suggesting that mixing of groundwater may have occurred within the well and along the filter pack material in the annulus of the well before or during sampling the well.

Activities of tritium in the groundwater samples from PM-4 are less than 0.38 pCi/L suggesting that the age of the groundwater is greater than 50 years. Activities of strontium-90, plutonium-238, plutonium-239/240, cesium-137, and uranium-235 in the groundwater samples from PM-4 were below detection

limits. The results of stable isotopes of hydrogen and oxygen, isotopic nitrogen-15/nitrogen-14, and chlorine-36 values are also presented.

The results of the analysis of the zonal groundwater samples from PM-4 indicate that probable mixing of groundwater occurred before or during sampling. The method used to collect the groundwater samples did not ensure collection of water directly from the formation and allows for mixing of water in the annulus of the well, which probably occurs over the 1,604 feet of louvers in PM-4.

1.0 INTRODUCTION

During drilling of regional aquifer characterization borehole R-25, located in the western part of Los Alamos National Laboratory (LANL) at Technical Area (TA) 16, groundwater samples were collected from perched zones of saturation and the regional aquifer that contained elevated levels of high explosive (HE) compounds. HE compounds found in the groundwater at R-25 include RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine), which stands for Royal Demolition Explosive; HMX (octahydro-1,3,5,-tetranitro-1,3,5,7-tetrazoicine), which stands for High-Melting Explosive; TNT (2,4,6-trinitrotouene), and others (LANL 1999). RDX was measured as high as 84 μg/L in groundwater samples collected from a depth of 1,047 ft, which may be within the regional aquifer at R-25; the EPA health advisory guideline for RDX in drinking water is 2 μg/L.

The nearest Los Alamos County municipal supply wells that are potentially located down gradient from borehole R-25 are PM-2, located in Pajarito Canyon at TA-18, PM-4, located on Mesita del Buey at the west end of TA-54, and PM-5, located on a mesa east of TA-52 (Figure 1). Municipal supply wells PM-2 and PM-5 were sampled in late 1998, and the results of the analyses showed that HE compounds were not detected in these municipal supply wells. PM-4 was not sampled because the pump had been removed from the well for scheduled maintenance by the Los Alamos County Public Utilities Department (PUD). However, because the pump was removed from PM-4, the situation afforded a unique opportunity to enter the well to (1) perform tests to determine from where within the regional aquifer groundwater entered the well, and (2) collect samples for analyses from the producing zones to determine if HE contaminants could be present in discrete zones within the regional aquifer.

The Laboratory Water Quality and Hydrology Group ESH-18, in association with the Laboratory Environmental Restoration (ER) Project, undertook the investigation to perform flow testing and zonal sampling of municipal supply well PM-4 in March 1999, before the PUD needed to reinstall the pump in the well in May 1999.

This document provides the report of the activities that were performed during March 1999 for the testing and sampling of municipal supply well PM-4. The document provides a description of the field activities associated with the two phases of the project, including (1) the results of the static and dynamic spinner log surveys, and (2) a description of the sampling activities and the field-measured groundwater quality parameters that were obtained during sampling activities. This document also provides the analytical results of the groundwater samples and a brief discussion of the results of the project. The objective of the report is to document the field activities and to provide the results of the analyses.

1.1 PM-4 Location and Background Information

Municipal supply well PM-4 (structure No. 54-1013) is located on Mesita del Buey in the western part of TA-54 at a ground elevation of 6,920 ft. This well was drilled in 1981 to a depth of 2,920 ft and produces from the regional aquifer.

In 1981, the initial depth to water in PM-4 was 1,060 ft below ground level [elevation 5,860 ft above mean sea level (AMSL)]. Before beginning production in 1982, the water level was 1,050 ft below ground level (5,870 ft AMSL), which indicates that the water level rose 10 ft between the time the regional aquifer was encountered during drilling and the time of the first pumping of the well. In 1997, the nonpumping water level was at a depth of 1,093 ft (elevation 5,827 ft AMSL) and the pumping water level was at a depth of 1,142 ft (elevation 5,778 ft AMSL) (McLin et al. 1998, p. 46).

Figure 2 shows the general construction information for municipal supply well PM-4 and the stratigraphy associated with the well. The geophysical log traces obtained after drilling of the well, including spontaneous potential (SP), natural gamma (NG), density (DEN), and induction log deep (ILD) (resistivity) are also shown on Figure 2. The surface casing is installed to a depth of 41 ft using 42-in.- diameter steel pipe. An intermediate 28-in.-diameter casing string is installed from the surface to a depth of 923 ft.

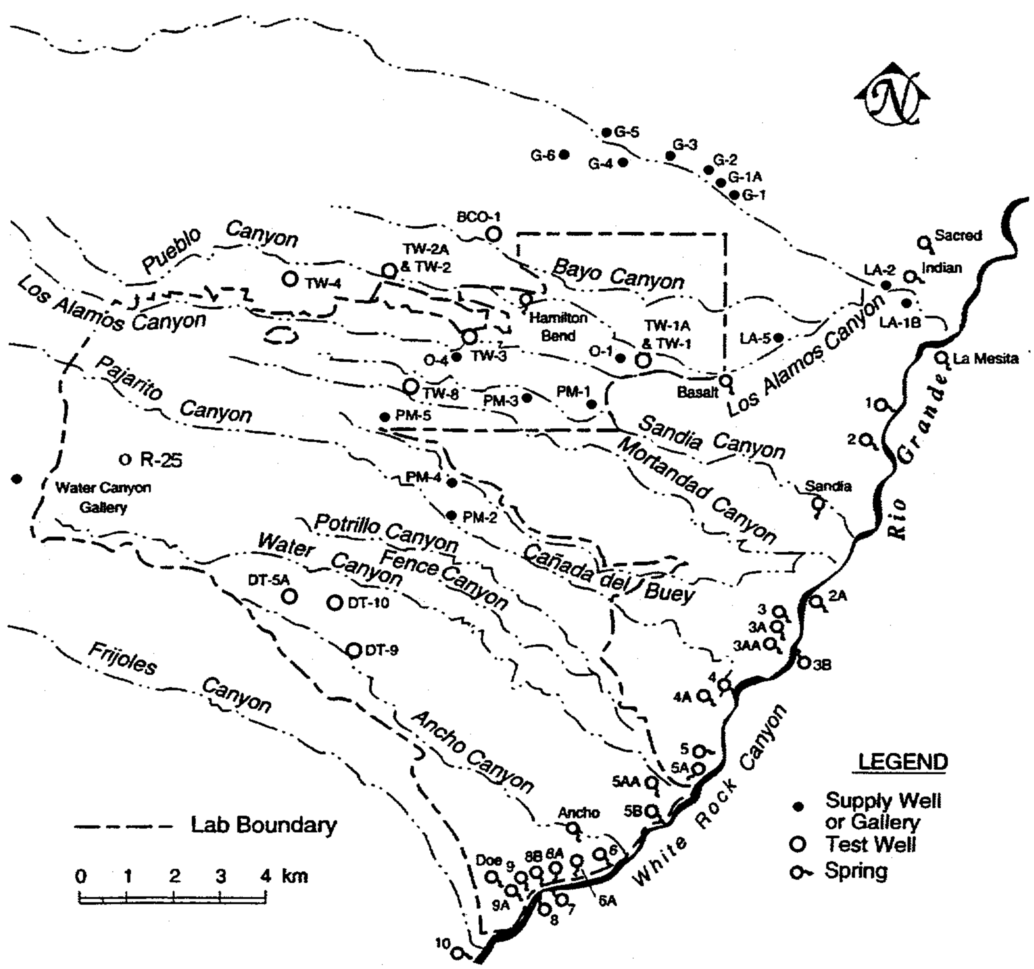

Figure 1. Location map of Los Alamos National Laboratory showing locations of selected wells.

The production casing is installed from the surface to a depth of 2,874 ft using 16-in.- diameter (15 5/8 -in. inside-diameter) steel casing. The screened interval in PM-4 is from a depth of 1,260 to 2,854 ft. A sump is present beneath the slotted casing from a depth of 2,854 to 2,874 ft (Purtymun 1995, 45344, p. 277). The annular space is filled with a gravel pack and a 4-in.-diameter pipe adjacent to the wellhead provides access to the casing annulus.

Two tubes from the surface adjacent to the wellhead provide monitoring access for the well. The tubes connect into the well casing at a depth of 1,255 ft. A transducer for measuring the water level in the well is installed in one of the monitoring access tubes. The transducer water level at the electric panel in the well house at the time of the initial video log survey was 73.5, indicating that the depth of the transducer may be at approximately 1,150 ft.

During operation, the well is equipped with a downhole turbine pump powered from the surface by a steel shaft drive. A Caterpillar engine that runs on natural gas powers the pump. A pumping test of the well was conducted in July 1982 after the well was completed. The specific capacity of the well was approximately 29 gpm per ft of drawdown; after producing the well for about 6 months at 1,400 gpm, the specific capacity increased to 34 gpm/ft. Transmissivity of the aquifer was calculated from drawdown measurements to be approximately 49,000 gpd per ft (ESG 1983, 6418, p. 78; Purtymun et al. 1982, p. 13). Since 1984, the specific capacity of PM-4 has averaged 33 gpm/ft of drawdown at an average pumping rate of 1,310 gpm (McLin et al. 1998, p. 46). PM-4 has the second highest specific capacity of the wells in the Pajarito Mesa well field, second only to PM-3. PM-4 has an average specific capacity about 60% of that at PM-3.

Turbine lubricating oil was present on the top of the water column inside the casing in PM-4. This oil was found to be 10 ft thick from the result of the initial borehole video log that was obtained. Most of the oil was removed from the well during the PM-4 project by bailing the well. The source of the oil is the lubrication for the pump turbine and shaft; the oil is present as a result of normal pump operation and does not represent a release. The oil used to lubricate the turbine is Texaco R&O-150, a highly paraffinic hydrocarbon-based lubricating oil that is used for turbine pumps in wells because the oil does not easily emulsify with water and easily separates from water. The volume inside the 16-in.-diameter casing is approximately 10 gallons per linear ft; therefore, approximately 100 gallons of oil was present in the well. The used oil was recovered into two 55-gallon barrels and the Los Alamos County PUD disposed of the oil.

Connected to PM-4 is a National Pollution Discharge Elimination System (NPDES) outfall that discharges into Cañada del Buey from an 8-in.-diameter cast iron pipe outfall that is located about 200 ft east of the well. After the pump is shut down for maintenance, and before the well is put back on line, the well must be purged to bleed off the start-up pump pressure and to clean up the water. Before placing the pump back into service each time, the flow is diverted to the NPDES outfall (EPG 1995, 50285, p. VII-26; Purtymun 1995, 45344, p. 114). A recent such discharge from PM-4 occurred November 10, 1998, when 1350 gpm were discharged for 20 minutes to the NPDES outfall, for a total discharge of 27,000 gallons (LANL 1998, 59599, p. 4-61).

Before implementing the PM-4 testing and sampling project, Municipal supply well PM-4 had not been in production since November 1998 because of scheduled repair and maintenance of the pump by the County of Los Alamos PUD. In 1998, Los Alamos County assumed responsibility from the Department of Energy (DOE) for operating the well. The pump was removed from the borehole for refurbishment and was scheduled to be replaced in the borehole in April 1999. The pump being out of the well afforded a rare opportunity to conduct the testing and sampling of the regional aquifer at PM-4.

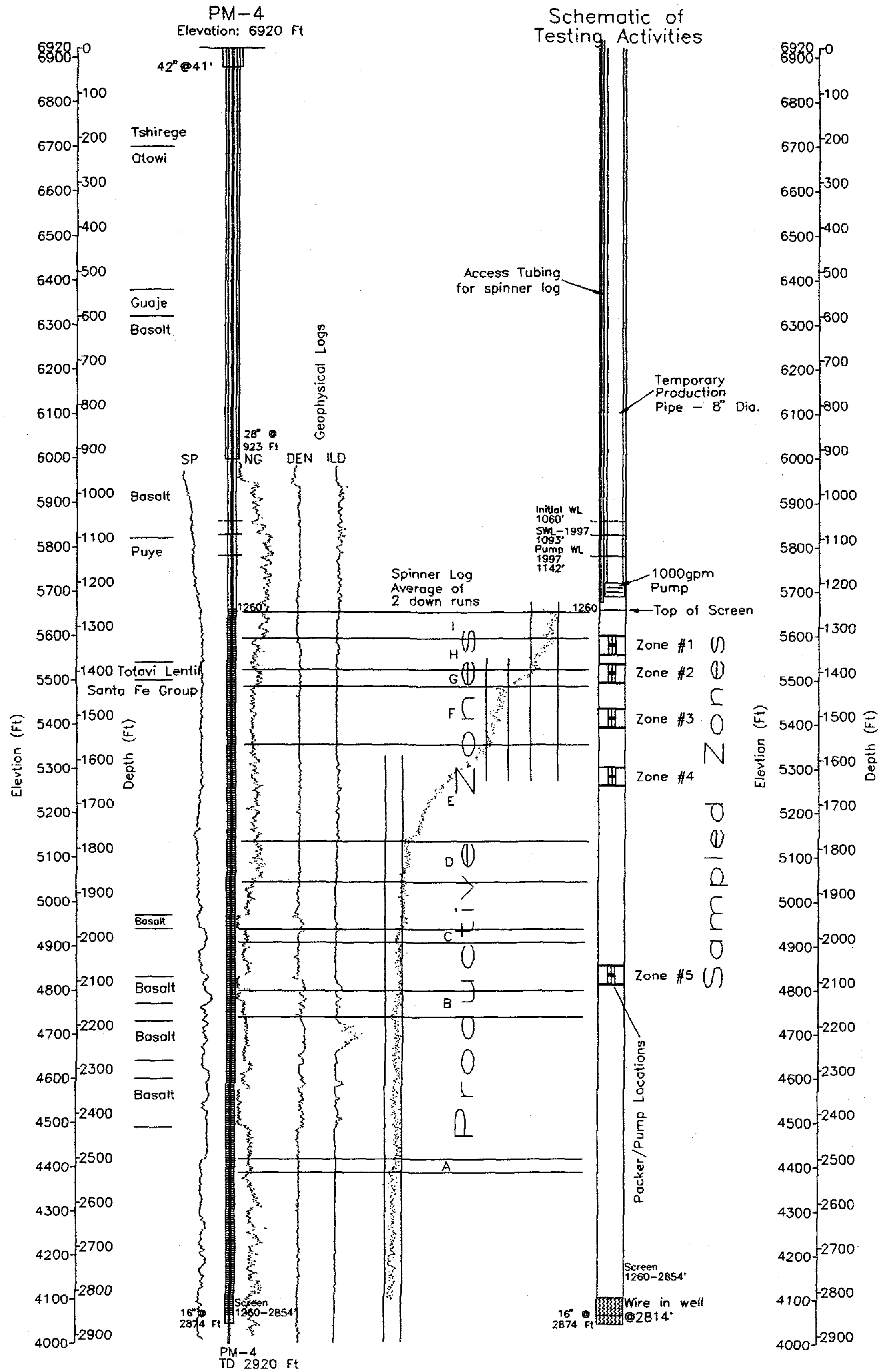

Figure 2. Construction information and stratigraphy of PM-4.

1.2 Project Resources

Laboratory Group ESH-18 subcontracted Science Applications International Corporation (SAIC) personnel through the ER Project Office and the Los Alamos Technical Associates (LATA) ER technical team to perform the PM-4 Testing and Sampling Project. SAIC personnel worked closely with personnel from ESH-18 and from the Los Alamos County PUD during the planning and execution of the PM-4 Testing and Sampling Project. All field activities were approved and coordinated with Laboratory Groups ESH-18, ESH-5, CST-7, FE-8, S-8, the Groundwater Integrating team, and the County of Los Alamos Public Utilities Department. Table 1 shows the roles and responsibilities of personnel involved in the PM-4 testing and sampling project.

Table 1. Project Personnel

Name	Group	Phone No.	Responsibility	Comment
Ken Mullen	ESH-18	667-0818	ESH-18 Team Leader	Project Management POC
Bruce Gallaher	ESH-18	667-3040	Technical Support	Hydrology
Steve McLin	ESH-18	665-1721	Technical Support	Hydrology
David Rogers	ESH-18	667-0313	Technical Support	Hydrology
Dave Broxton	EES-1/ERP	667-2492	Technical Support	ER Coordination
Pat Longmire	CST-7/ERP	665-1264	Technical Support	Geochemistry
David Padilla	F-4	667-2408	Facility Management	Facility Engineering
Charles Trujillo	F-4	667-0491	Facility Management	Facility Engineering
Trung Nguyen	ESH-5	667-7905	Health and Safety Support	Safety Oversight
Bill Purtymun Jr.	S-8	667-6211	Emergency Management and Response Support	Emergency Services Coord.
Richard Koch	SAIC	672-3666	Field team leader	Task Management
Jon Marin	SAIC	672-3666	Alt FTL and site safety officer	
Clint Daymon	SAIC	672-3666	SSO	Site Safety Officer
Joe Sena	SAIC	672-3666	Sampling Technician	
Jennifer Harris	ATS	662-1305	Sample Collection	
Tim Glasco	LA County	662-8148	Utilities Manager	County Coordination
Charles Brown	LA County	662-8157	Utilities Engineering	County Coordination

Proposals were obtained from several well-service companies for the pump installation and removal and for the borehole surveys. The subcontractor selected to perform the pump installation and removal was Beylik Drilling from Rio Rancho, New Mexico. Beylik supplied a well-service rig and a pump capable of producing 1,000 gpm for the spinner log surveys and provided the equipment necessary to insert the packer and submersible pump assembly into the well for purging and sampling the well for the zonal sampling project. The subcontractor selected to provide the borehole video surveys and the spinner log surveys was the COLOG Company, a division of Layne Geosciences Inc., from Golden, Colorado.

Laboratory Group ESH-18 had previously acquired the packers that were used to isolate the zones to be sampled and the submersible pump that was used for the sampling phase of the project. The pump was believed to be capable of 6 gpm at a hydrostatic head of 1,100 ft; however, during the sampling portion of the project, it was discovered that the pump only produced 1.5 gpm at the hydrostatic head present in PM-4. It was necessary to acquire a new higher-capacity pump end for the submersible motor. The pump used was a Grundfos submersible pump model 16S50-39 (5 hp) capable of 20 gpm at a 600-ft pumping head at 3,450 rpm. The new pump end purchased during this project was a Grundfos 10S50-48DS with a rating of 8 gpm at a hydrostatic head of 1,100 ft.

2.0 Field Activity Summary

The activities and the schedule for the testing and sampling of PM-4 are shown in Table 2. The initial activity was to assess the status of the well before conducting testing and sampling activities. The condition of the well and the depth to water was measured using the initial video survey. The amount of turbine lubricating oil on the surface of the water was determined and the depth to the oil/water contact was measured by the video survey. Measurements obtained during the well testing and sampling project were documented according to the appropriate LANL ER standard operating procedures (SOPs). The turbine oil in the well was removed by skimming and bailing. Ten feet of oil was present in the well, which contained a calculated volume of 100 gallons. The oil was removed from the well and placed in 55-gallon barrels that the PUD provided at the well site. The barrels were stored within spill containment barriers provided by the PUD. The PUD provided the appropriate disposal of the used lubricating oil.

2.1 Phase-I Well Testing

The field activities at PM-4 began on March 12, 1999, with the first of two color video surveys of the well. The initial video log was obtained to document the condition of the well before intrusive testing and sampling activities took place and the second video log was obtained to document the condition of the well after the completion of all testing and sampling activities.

2.1.1 Video Log #1

The initial video log of PM-4 was obtained on March 12, 1999. The color video log was obtained from the surface to a depth of 2836 ft. The video log depth was set to zero at the top of the 16-in.-diameter casing, which is flush with a raised cement pad in the well house. The camera was equipped with a down-looking and a side-looking lens that provided close-up views of the inside of the casing and louvers.

Table 2. PM-4 Testing and Sampling Activity Schedule

Activity	**Duration**	**Start**	**Finish**
Readiness review	0.5 day	3/11/99	3/11/99
Field operations	15 day	3/12/99	3/31/99
Borehole Video #1	0.5 day	3/12/99	3/12/99
Move in rig and equipment	1 day	3/13/99	3/13/99
Bail oil from well	0.5 day	3/13/99	3/13/99
Install 3-in. diameter access tube	0.5 day	3/14/99	3/14/99
Install 1000 gpm pump	2.5 day	3/14/99	3/16/99
Run static spinner log	0.5 day	3/16/99	3/16/99
Run dynamic spinner log	2 day	3/17/99	3/18/99
Pull 1000 gpm pump	1.5 day	3/18/99	3/19/99
Bail oil from well	0.5 day	3/22/99	3/22/99
Setup packer/pump assembly	0.5 day	3/22/99	3/22/99
Purge/collect groundwater samples	3 day	3/26/99	3/30/99
Run video log #2	0.5 day	3/31/99	3/31/99
Rig down/move equipment out	1 day	4/1/99	4/1/99

The depth to oil was measured during the initial video log to be 1,077 ft. The depth to the oil/water contact was measured to be 1,087 ft. The video log showed that the two auxiliary access ports enter the casing at approximately 1,255 ft depth. The depth to the top of the louvers was measured to be 1,259 ft. The transducer reading in the well house at the time of the video log survey was 73.5, indicating that the approximate depth of the transducer may be at 1,150 ft.

A twisted wire was encountered in the well at a depth of 2,814 ft. The wire is balled up in the bottom of the well. The video survey tool was run to a depth of 2,836 ft where the visibility was reduced to zero by sediment that was stirred up by the video logging tool disturbing the wire in the hole.

The initial video log shows a small amount of water entering the well at the top of the louvers at a depth of about 1,260 ft, where a small telltale movement of algae was observed. No other movement of water was observed in the well. The inside of the louvers and casing contain variable amounts of encrustation and cementation, which appear to increase downward in the well, to a degree where in the lower 700 ft of the well, the louvers do not appear to be open.

2.1.2 Removal of Lubricating Oil from the Well

Beylik Drilling personnel set up the well-service rig and associated equipment on March 13, 1999. When the service rig was in place, a bailer was used to retrieve the used turbine lubricating oil from the well. The bailer was a 12-ft-long section of 12-in.-diameter steel pipe with wire line connections at the top and metal plate with a spigot on the bottom to drain off the fluid from the bailer.

The bailer was run into the hole five times. The last run of the bailer recovered less than 1 gallon of oil. A total of approximately 90 gallons of oil were recovered from the well. The recovered oil was placed in two 55-gallon barrels. The barrels were secured and stored in a containment device.

After the oil was removed from the well, Beylik personnel conducted a survey of the well to determine how straight the well is. The survey of the well was performed to determine if the well is straight enough to run the 3–in.-diameter access tubing and the 1,000-gpm pump in the hole at the same time. A 30-ft-long rigid wiper assembly with a diameter of 15 3/8 in. was used to determine the straightness of the well. The results of the survey indicated that the casing is straight enough to run the equipment for the dynamic spinner log survey.

After the dynamic spinner log survey was completed and the 1,000 gpm pump and the 3-in.-diameter access tubing were removed from the well, the well was again bailed on March 22, 1999, to remove any oil remaining from the lubrication of the 1,000-gpm pump and shaft drive. A total of six runs in the hole were made with the bailer. The first run recovered about 2 to 3 gallons of oil, but the next four runs did not recover any fluid because the bailer was floating on the water in the well. Additional weights were added to the bailer for run number six, which recovered only water from the bailer.

2.1.3 Spinner Log Surveys

In preparation for the dynamic spinner log survey, a submersible pump capable of producing 1,000 gpm at a hydrostatic head of 1,150 ft was temporarily installed in the well. The submersible pump was installed at a depth of approximately 1,200 ft in the well. To provide access for the spinner log survey tool below the pump, a temporary 3-in.-diameter access tube was installed in the well before inserting the pump. The access tubing was installed from the surface to below the bottom of the pump, or to a depth of about 1,250 ft on March 14, 1999.

The 1,000-gpm submersible pump was installed from March 14 to March 16, 1999. A 1,085-hp diesel motor was connected to the pump through a shaft drive to the wellhead gearbox to power the submersible pump. The static spinner log survey was run after the 1,000 gpm pump was installed and during final installation of the protective cowling for the shaft drive and the discharge piping.

2.1.3.1 Static Spinner Log Survey

The static spinner log survey was obtained to determine the possible vertical movement of water in the static casing. The static spinner log survey was obtained on March 16, 1999, after the 1,000-gpm pump was set in place for the dynamic spinner log survey and immediately before performing the dynamic spinner log survey. The static spinner log survey was run from the top of the screened interval to a depth of 2,811 ft, where an obstruction in the well was encountered. The zero depth for the static spinner log survey was adjusted to the top of a temporary steel platform that was installed by Beylik personnel and which was 1 ft above the top of the well casing. The water level was encountered at a depth of 1,078 ft (1,077 ft from top of well casing), consistent with the water level measured during the video log survey.

Three complete two-way passes of the spinner log tool were made as part of the static spinner log survey. Two passes were made at 90 ft per minute and the third pass was made at 60 ft per minute. The static spinner log survey was obtained from the depths of 1,255 to 2,811 ft. The static spinner log survey did not indicate any movement of water in the well. The results of the multiple passes of the tool through the well appeared to be repeatable and conformable, indicating that the tool was functioning properly. After the survey was finished, the tool was positioned stationary at the top of the louvers at a depth of 1,260 ft where some slight movement of water was noted in the initial video log of the well. The spinner log survey tool at this position did not measure movement of water. (It was later determined that the spinner log tool would not record vertical movement of water in the well less than 15 to 20 ft/min). The spinner log tool was raised above the water level in the 3-in.-diameter access tubing for overnight storage in preparation for running the dynamic spinner log survey the next day.

2.1.3.2 Dynamic Spinner Log Survey

The dynamic spinner log survey was obtained to determine the locations of groundwater flow within the regional aquifer into the well during pumping. The 1,000-gpm pump, access port tubing, and discharge lines were in place and ready for the dynamic spinner log survey on the morning of March 17, 1999, the day after the static spinner log survey was obtained. The water level measured by the spinner log tool before pumping on March 17 was at a depth of 1,072 ft (1,071 ft from the top of the casing), indicating that the water level had risen about 5 ft since March 12. The transducer reading before the pump was turned on was 76.5 ft, indicating that the water level was 3 ft higher than on March 12.

The 1,000-gpm pump was started at 07:19 on March 17 for the dynamic spinner log survey. The water reached the surface in about 5 minutes, and the initial pumping rate was 800 gpm. The valve at the wellhead was opened, and the well was pumped at 1,000 gpm beginning at 07:34. The pump was capable of pumping higher volumes, but the valve at the well head was used to maintain a flow rate of 1,000 gpm.

The discharge from the well was diverted through collapsible tubing to the NPDES outfall, which discharges to Cañada del Buey. On the morning of March 17, 1999, ESH-18 NPDES personnel collected samples of the discharged water for compliance with the Laboratory NPDES permit. These samples were analyzed for pH, chloride, selected metals, tritium, radon-226, and radon-228. The results of the analyses are presented in Section 3.

The spinner log tool was lowered from the 3-in.-diameter access tubing into the well, and the dynamic spinner log survey was started. However, the spinner log tool did not consistently return data. After working the tool up and down through the well for several hours, it was determined that the survey tool was not functioning properly, and the tool had to be removed from the well for repairs. The pump was turned off at 10:45, and the tool was removed from the well. To remove the logging tool, the shaft drive from the motor to the gear box at the well had to be dismantled, and the gear box was lifted from the top of the well. The tool was repaired and in working condition by late afternoon on March 17, but rather than begin the dynamic spinner log survey at dusk, the decision was made to wait until morning on March 18, 1999, to begin pumping and running the spinner log survey.

While attempting to run the dynamic spinner log survey on March 17, the well was pumped for 3.5 hours at 1,000 gpm, during which 190,000 gallons of water were produced. Water levels measured by the transducer were recorded at 30-second intervals during the first 15 minutes of the pumping and at one-minute intervals thereafter for two hours. After the first two hours, the water level was recorded at 5-minute intervals. Figure 3 shows the time-drawdown curve of the water level at 10-minute intervals during the pumping and the field-measured water quality parameters on March 17, 1999. The water level was measured relative to the depth of the transducer, which was at approximately 1,150-ft depth.

The field-measured water quality parameters were obtained using a Hydrolab® MiniSonde probe that was positioned in the outfall channel area beneath the discharge line. The water quality parameters measured included conductance, pH, temperature, and dissolved oxygen, each of which was recorded at 10-minute intervals. Figure 3 shows the time-series chart of the water quality parameters. The conductance of the produced water was 115 µS/cm. The figure shows variations in the conductance and the dissolved oxygen values that result from the measurement in an open channel under turbulent flow, where the probe was only partially immersed in the water at times because of the velocity of the water moving the probe in the discharge channel. The sharp decline in the conductance values combined with the increase in water level and the decrease in temperature represents the time of pump shutdown and the end of the flow of water.

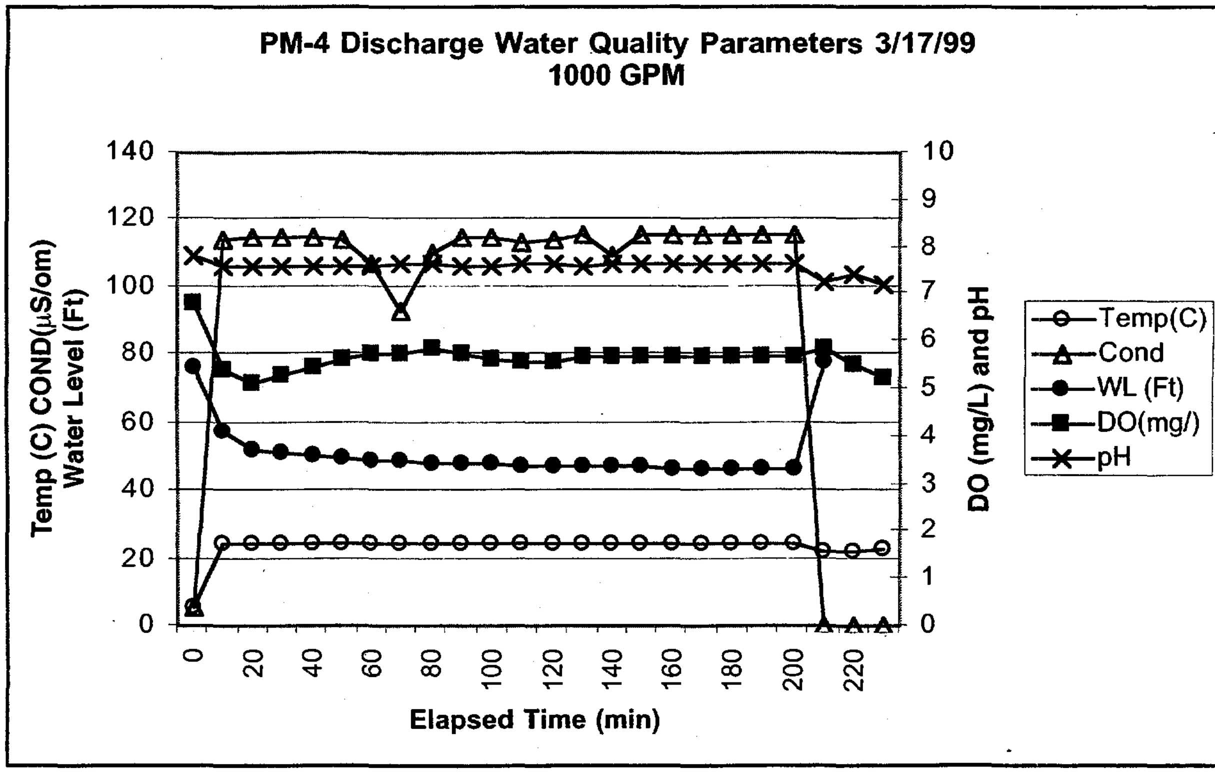

Figure 3. Drawdown and water quality parameters during pumping of PM-4 on March 17, 1999.

During the pumping, the water level declined about 20 ft during the first 10 minutes of pumping and slowly but continuously declined thereafter. By the end of pumping, the water level declined a total of 30.3 ft and was continuing to slowly decline. After the pump was turned off, the water level rebounded rapidly and rose in the well because of the back flow of 1,200 ft of water from the production pipe into the well.

The spinner log tool was repaired and reinserted into the well the afternoon of March 17. To test the operation of the tool, an auxiliary static spinner log survey was run that encompassed a complete pass through the entire well. The spinner log tool was determined to be working properly but because of the lateness in the day, it was decided to run the dynamic spinner log survey on the morning of March 18, 1999. The spinner log tool was stored in the well overnight near the top of the louvers so that no possible damage to the tool could occur while raising it into the 3-in.-diameter access tubing.

On March 18, 1999, the 1,000-gpm pump was turned on at 07:45 and the well was pumped for 3.5 hours while the dynamic spinner log survey was obtained. A total of 219,000 gallons of water were produced during the running of the dynamic spinner log survey. The spinner log survey included two complete passes of the tool (down and up) through the well at 60 ft per minute and one complete pass at 110 ft per minute. The results of the survey appeared to be reproducible, and the log curves were conformable; the dynamic spinner log survey appeared to provide sufficient information about the source of formation water into the well. The results of the dynamic spinner log survey are discussed below.

During pumping of the well on March 18, water levels measured by the transducer were recorded at 1-minute intervals during the first 25 minutes of the pumping, at two-minute intervals until 75 minutes had elapsed, and at 5-minute intervals until the pump was shut down after 3.5 hours elapsed time. After the pump was shut down, the water levels were recorded about every 15 seconds for 5 minutes while the water backflowed into the well and while the water level in the well equilibrated. Figure 4 shows the time-drawdown curve of the water level at 10-minute intervals during the pumping and the field-measured water quality parameters obtained on March 18, 1999.

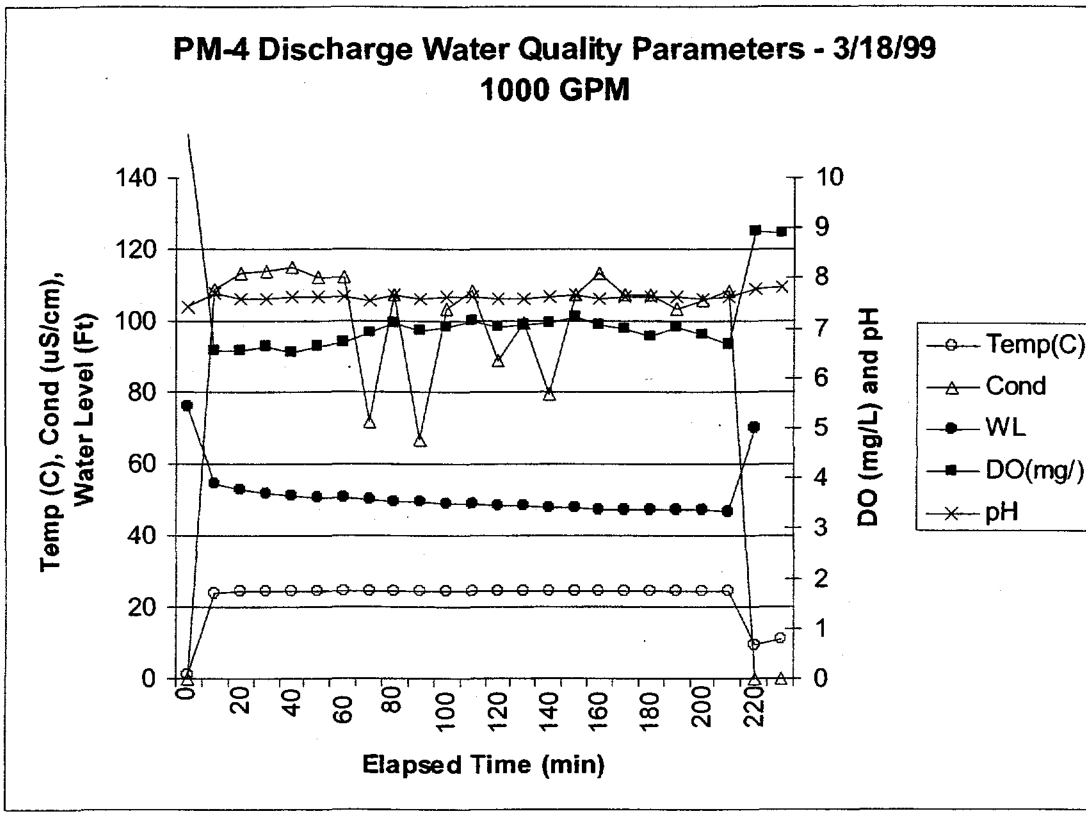

Figure 4. Drawdown and water quality parameters during pumping of PM-4 on March 18, 1999.

On March 18, the field-measured water quality parameters were again obtained using a Hydrolab® MiniSonde probe that was positioned in the outfall channel area beneath the discharge line. Water quality parameters measured included conductance, pH, temperature, and dissolved oxygen, each of which was recorded at 10-minute intervals. Figure 4 shows the time-series chart of the water quality parameters obtained on March 18. The conductance of the produced water was around 100 to 115 μS/cm. The chart shows variations in the conductance and the dissolved oxygen values that resulted from the probe being only partially immersed in the water for a significant portion of the pumping time. The sharp decline in the conductance values combined with the increase in water level and the decrease in temperature represents the time of pump shutdown and the end of the flow of water.

During the pumping on March 18, the water level declined about 20 ft during the first 10 minutes of pumping and slowly but continuously declined thereafter. By the end of pumping, the water level declined a total of 29.3 ft (from 76.1 to 46.8 ft) and was continuing to slowly decline. After the pump was turned off, the water level rebounded rapidly and rose in the well because of the backflow of 1,200 ft of water from the production pipe into the well. Figure 5 shows the rebound of the water level in the well after the pump was turned off. The water rose to a maximum transducer reading of 84.2 ft, and lowered to 70.1 ft, which was 6 ft lower than the static water level before pumping.

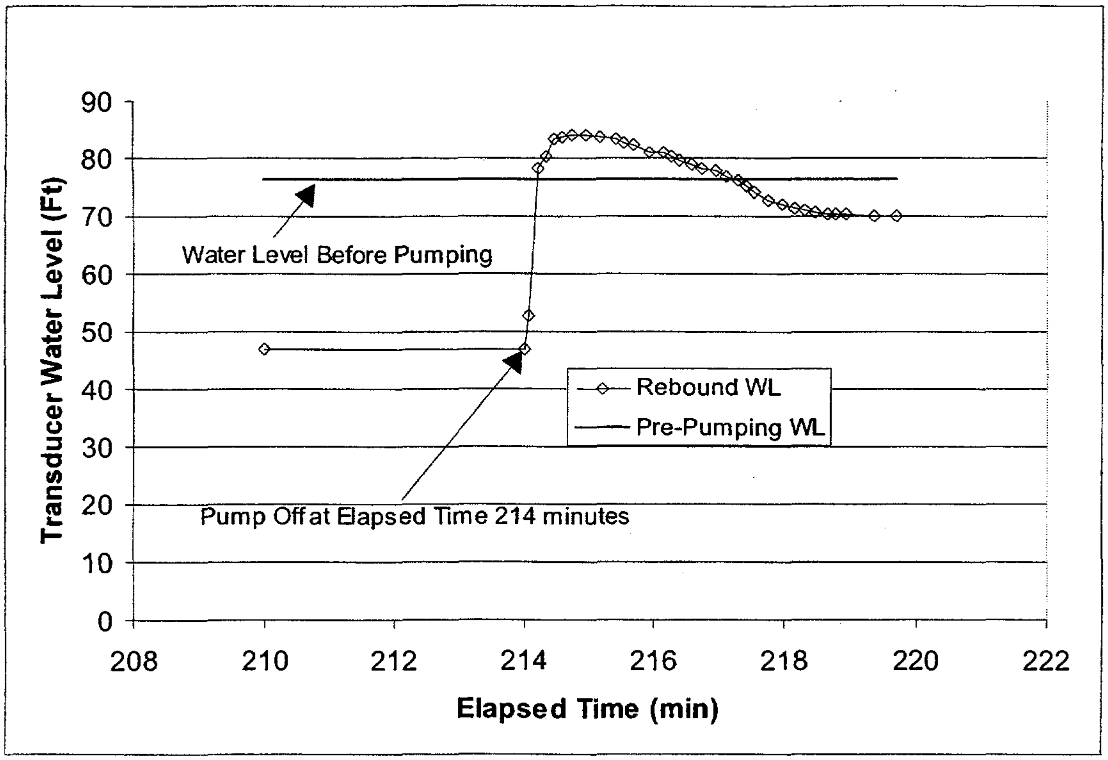

Figure 5. Water level rebound in the well after the pump was turned off on 3/18/99.

At the conclusion of the dynamic spinner log survey, the spinner log tool was removed from the well and Beylik personnel removed the 1,000-gpm pump and the access tubing from the well. During this time the technical team reviewed the preliminary results of the spinner log surveys and selected zones for specific sampling in the well.

2.1.3.3 Results of Dynamic Spinner Log Survey

The results of the static and dynamic spinner log surveys were provided by COLOG in paper log format and digital file format. Copies of the spinner log surveys are maintained in the Water Quality and Hydrology Group (ESH-18) geophysical log library at TA-59, building 117. The summary of the results of the dynamic spinner log survey is shown graphically in Figures 6a and 6b and is also shown in Figure 2, which shows the correlation of the dynamic spinner log with the stratigraphy and the zones that were sampled.

The dynamic spinner log data were acquired for each 0.1-ft interval from the depth range of 1,261.7 to 2,818.1 ft. The data obtained for the spinner log survey are in counts per second (cps); one revolution of the impeller on the tool represents 2 counts; thus, 30 cps represents 15 revolutions per second of the impeller. The data shown on Figure 6a are the average of two downward passes of the tool at 60 ft per minute and show the spinner survey data for each whole foot interval as a thin line, which represents the average of the ten data points from each 0.1-foot interval. The 1-ft averaged spinner log data show a variation of 2 to 3 cps within any given zone, possibly because of turbulence within the well caused by the movement of the tool and/or flow in the well, debris in the well interfering with the impeller or the sensor,

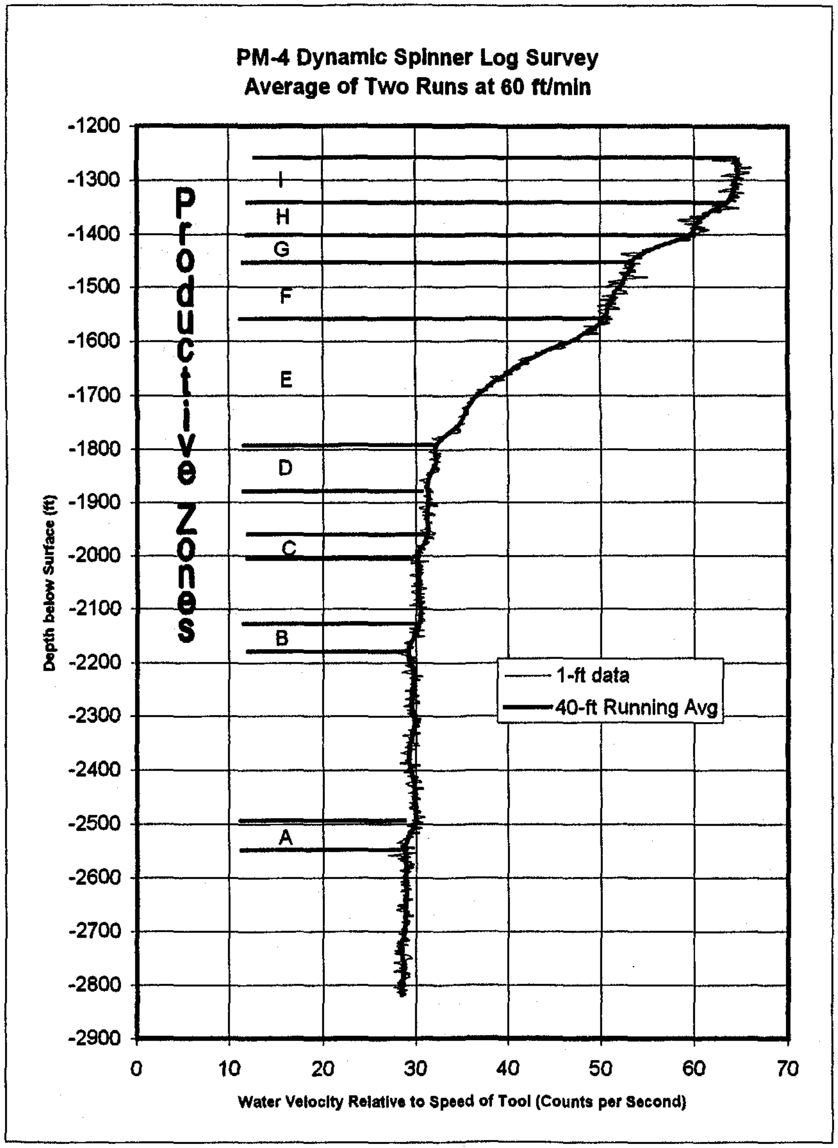

Figure 6a. Results of the dynamic spinner log survey.

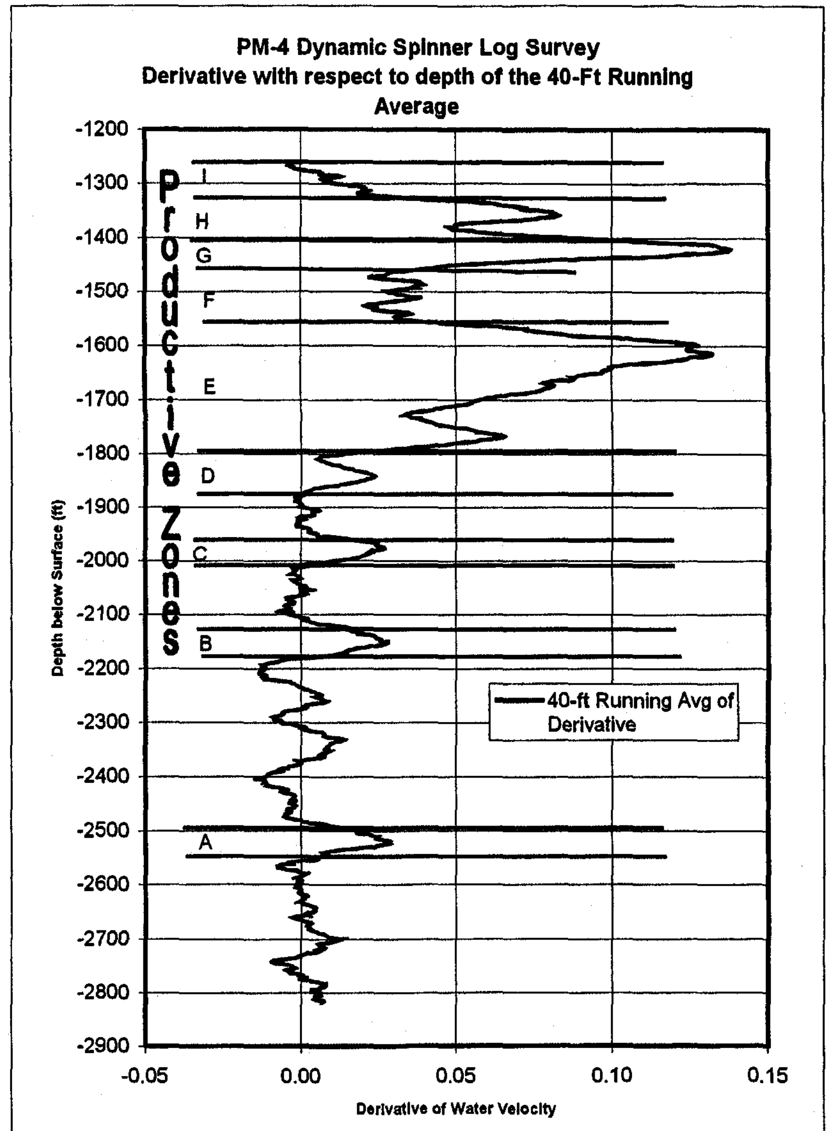

Figure 6b. Derivative with respect to depth of spinner log.

and/or to inefficiency of the measuring tool. To provide a smoothing of the spinner log data, a 40-ft running average was calculated for each 1-ft interval, which is shown on Figure 6a as a thicker line. Zones within the well that indicate a vertical spinner log trace have a uniform vertical water velocity relative to the speed of the tool; these are zones where water is not entering the well and are interpreted to be nonproductive zones.

The velocity of the water in the well is greatest at the top of the screened interval because all produced water is moving upward in the casing at this location. The spinner log survey shows that the fastest water movement (about 65 cps at a 1,000-gpm pump rate and a tool velocity of 60 ft/min) is near the top of the screened interval (1,260 ft depth). As the spinner log tool passes deeper through the screened interval and through succeeding productive zones, the water velocity relative to the speed of the tool decreases to a point near about 1,800-ft depth where little additional water appears to be entering the well from there downward. The shallower portions of the well evidently met the 1,000-gpm pumping demand placed on the well during the survey; it is not known if increasing the pumping demand would have increased production from deeper zones.

The productive zones are shown on the spinner log trace as having a positive-slope relative to vertical. The larger the slope variation from vertical, the more water enters the well within any given interval. Because the slope of the spinner log trace indicates zones of water production, the first derivative with respect to depth of the spinner log data, or the rate of change of inflow into the well with depth, was calculated and plotted on Figure 6b to more effectively depict the productive zones. The derivative with respect to depth was calculated from the 40-ft running average data that are shown on Figure 6a (thick line). The derivative values incorporated a significant amount of variability and were averaged over 40 ft for each value to smooth the derivative curve shown in Figure 6b. The productive zones are shown on Figure 6b as positive deflections from vertical. In nonproductive zones, the derivative values fluctuate up to about ±0.01, which is interpreted to be the result of imprecision of the spinner log-measuring tool. For evaluation and comparison purposes, the letters A through I have been assigned to nine different zones of production based on obvious changes in slope of the spinner log trace (see Figures 6a, 6b, and 2).

The characteristics of each productive zone are summarized in Table 3. The top and bottom depth value of each distinct zone that has a nonvertical log trace on the spinner log is listed in Table 3 with the thickness of each zone and the spinner log value of the top and bottom of each zone. The difference in the spinner log value across each zone was divided into the total range of spinner log values to calculate the approximate percentage of total production that is apparently coming from each zone. The 40-foot running average value was used because of the variation in the 1-ft data (see Figure 6a). Zone E is the thickest zone (240 ft thick) and provides 50% of the total production in the well. This zone correlates to probable coarse-grained sediments within the upper part of the Santa Fe Group (Figure 2). Zone G is about 50 ft thick and provides 18% of the total productive volume. Zone G correlates to the Totavi Lentil at the base of the Puye Formation (Figure 2).

Table 3. Summary of Characteristics of Productive Zones in PM-4.

	Producing Zones (Ft)			Spinner Log Data Value (cps)			% of Total Production	
Zone	Top Depth	Bottom Depth	Thickness	Bottom	Top	Difference		Stratigraphic Unit
A	2500	2550	50	28.5	29.4	0.9	2%	Santa Fe Group
B	2120	2180	60	29.4	30	0.6	2%	Santa Fe Group
C	1970	2000	30	30	31	1	3%	Santa Fe Group
D	1800	1890	90	31	32.1	1.1	3%	Santa Fe Group
E	1560	1800	240	32.1	50	17.9	50%	Santa Fe Group
F	1450	1560	110	50	53.5	3.5	10%	Santa Fe Group
G	1400	1450	50	53.5	60	6.5	18%	Totavi Lentil
H	1340	1380	40	60	63.4	3.4	9%	Puye Formation
I	1260	1340	80	63.4	64.6	1.2	3%	Puye Formation

The apparent production capacity of each zone can be interpreted from the derivative curve shown in Figure 6b. The greater the slope of the spinner log trace (Figure 6a) or the derivative value (Figure 6b), the better the apparent production capacity of a zone. The zone with the highest apparent production capacity is Zone G, which correlates to the Totavi Lentil at the base of the Puye Formation. Because of the relative thinness of Zone G (Table 3), only 18% of the production is derived from this high-capacity zone. The zone with the second highest apparent production capacity is the upper portion of zone E, which produces 50% of the total volume of water (Table 3). The third best apparent production capacity is zone H in the lower Puye Formation (see Figure 6b).

After completion of the dynamic spinner log survey, the ESH-18 technical team met to review the results of the spinner log data on March 19, 1999. Based on the preliminary results of the dynamic spinner log survey, five zones were initially selected to be sampled in the well. The five zones planned for sampling are shown in Table 4 and include the following approximate depths in the well: 1,350, 1,420, 1,515, 1,640, and 2,090 ft.

Table 4. Zones Initially Selected for Sampling

Sample Zone Number	Planned Depth (ft)	Comment
1	1,350	Correlates to Zone "H", Lower Puye Formation
2	1,420	Correlates to Zone "G", highest apparent production capacity, Totavi Lentil
3	1,515	Correlates to Zone "F", upper Santa Fe Group Sediments
4	1,640	Correlates to Zone "E", zone of greatest amount of production, Santa Fe Group
5	2,090	Deepest Zone, no apparent production, Santa Fe Group basalt

2.2 Phase-II Zonal Groundwater Sampling

2.2.1 Purging of Groundwater

At the conclusion of the dynamic spinner log survey, the 1,000-gpm pump and the associated production piping and access port tubing were removed from the well in preparation for the second phase of the project. The second phase of the PM-4 testing and sampling project is the groundwater sampling of discrete zones within the regional aquifer. For this task, downhole sampling equipment provided by the Water Quality and Hydrology Group (ESH-18) and the Field Support Facility (FSF) was used to isolate portions of the screened casing in an attempt to collect groundwater samples from discrete zones.

The Laboratory's equipment included two 16-in.-diameter K-packers and a submersible pump that was supposedly capable of approximately 6 gpm at a head of 1,100 ft and associated connection piping with the packer assembly. The K-packers and the pump were assembled so that the packers were connected using two 20-ft lengths of 4-in.-diameter galvanized pipe with the pump positioned near the top packer assembly. The K-packers are similar to wiper plugs and have several bands of rubber blades around a metal cylinder that has the same outside diameter as the inside of the casing, but the packers do not necessarily form a perfect seal with the casing. The slots were located in the center portion of the galvanized pipe between the two packers. The sampling assembly was designed to collect groundwater samples from a discrete 40-ft-long zone within the screened casing. The method used to collect the zonal groundwater samples could not prevent the movement of water around the packers and in the annulus outside of the casing. The sampling assembly was a best effort to collect discrete samples from individual zones; the analytical results, however, indicated that groundwater was likely drawn from the annulus of the well and/or from around the packers and not necessarily from the formation adjacent to the sampled zones. Additional discussion of the analytical results is given in Sections 3.2 and 4.0.

The total volume of water inside the casing between the K-packers was about 500 gallons. The following calculations show how this volume was determined:

16-in.-diameter casing = 1.333 ft diam = a radius of 0.667 ft
the volume between the packers is calculated using $\pi r^2 h$, or $\pi(0.667)^2 \times 40 = 56\ ft^3$
$56\ ft^3 \times 7.48\ gal./ft^3 = 420$ gal., rounded to 500 gal..

The pump that was used to collect the groundwater samples was a 5-hp Grundfos electric submersible pump (model 16S50-39) capable of 20 gpm (6 gpm at 1,100-ft head) at 3,450 rpm. The pump and packer assembly were installed March 23 and were ready to pump on the morning of March 24, 1999. Each section of production tubing was measured before being put into the well so that the exact depth of the pump and packer assembly was known. For the first zone sampled, the pump was at a depth of 1,316 ft and the sampling port (slots in the galvanized pipe between the K-packers) was at a depth of 1,340 ft.

On March 24, 1999, the pump was turned on at 07:10 to begin sampling zone #1. The pump was operated for 170 minutes at an average flow of 1.5 gpm, for an estimated volume of 255 gallons, which is about 50% of one volume of water between the packers. The Grundfos 16S50-39 pump did not perform to specifications and only pumped 1.5 gpm from a head of 1,077 ft. The amount of time involved to obtain the samples and the charges for standby for the crew would have been infeasible. Therefore, a larger pump for the existing submersible motor was ordered, and the pump/packer assembly was pulled from the hole in preparation for equipping the motor with the larger pump. The new pump end that was installed was a Grundfos 10S50-48DS, which is rated at 8 gpm at 1,100 ft of head.

The new pump was assembled and was installed in the well on the afternoon of March 25, 1999. The pump was tested for about one hour, and the flow was determined to be about 8.5 gpm. At this flow rate, the time to purge 1,500 gallons (3 volumes of water between the packers) was about 3 hours.

2.2.2 Zonal Groundwater Sampling

The collection of zonal groundwater samples occurred over three days from March 26 to March 30, 1999. At the time of the sample collection, the groundwater was measured for the parameters listed in Table 5.

Table 5. Field Measurement Methods for Groundwater Samples

Measurement	Precision[a]	Method
pH	±0.02	LANL-ER-SOP-06.02
Specific conductance	±1 mmho/cm (µS/cm)	LANL-ER-SOP-06.02
Temperature	±1 °C	LANL-ER-SOP-06.02
Dissolved oxygen	±0.1 mg/L	LANL-ER-SOP-06.02[b]
Turbidity (nephelometric)	±1 NTU[c]	EPA Method 180.1

a. Precision with which measurement was recorded.
b. ER Project SOPs.
c. NTU = Nephelometric Turbidity Units.

For each groundwater sample, the following activities were performed:

- Recorded the depth range of the zone isolated by the packers before sampling;
- Prevented groundwater samples from freezing;
- Immediately recorded field-measured parameters for groundwater samples;
- Added preservatives to appropriate sample containers;
- Filled appropriate sample containers with unfiltered and filtered water, where appropriate;
- Placed custody seals on each sample container;

- Stored sample portions in appropriate transport containers; and
- Transported the samples to the sample management office (SMO) at the FSF.

Table 6 lists the field methods used for the collection of the groundwater samples and Table 7 is a summary of the samples that were collected.

The purge water was discharged to the NPDES outfall associated with well PM-4 for this purpose. These discharges were coordinated with personnel from the ESH-18 NPDES program. Containment of the purge water was not necessary, but a water containment tank with a capacity of 10,000 gallons was available at the site for this purpose if needed.

Table 6. Groundwater Sampling Methods

Activity	LANL-ER-SOP/QP No.*
Notebook Documentation for Environmental Restoration Technical Activities	QP-5.7
General Instructions for Field Investigations	SOP-01.01
Sample Containers and Preservation	SOP-01.02
Handling, Packaging, and Shipping of Samples	SOP-01.03
Sample Control and Field Documentation	SOP-01.04
Management of Environmental Restoration Project Wastes	SOP-01.06
Purging of Wells for Representative Sampling	SOP-06.01
Field Analytical Measurements of Groundwater Samples	SOP-06.02
Sampling of Commercial/Municipal/Domestic Wells	SOP-06.04
Fluid Level Measurements	SOP-07.02
Transportation, Receipt, and Admittance of Borehole Samples	SOP-12.02

* SOP = Standard Operating Procedure, QP = Quality Procedure

Table 7. Summary of Samples Collected from PM-4

Zone	Depth	Date	Time	F/UF*	Sample ID	Request Numbers
1	1340	3/26/1999	10:30	UF	CAPM-99-4001	5368R, 5369R, 5370R, 5374R, 5375R, 5377R
1	1340	3/26/1999	10:30	F	CAPM-99-4002	5384R
2	1406	3/26/1999	15:30	UF	CAPM-99-4003	5378R, 5379R, 5380R, 5384R, 5385R, 5387R
2	1406	3/26/1999	15:30	F	CAPM-99-4004	5384R
3	1505	3/29/1999	10:30	UF	CAPM-99-4005	5398R, 5399R, 5402R, 5403R, 5404R, 5405R
3	1505	3/29/1999	10:30	F	CAPM-99-4006	5384R
4	1635	3/29/1999	15:45	UF	CAPM-99-4007	5411R, 5410R, 5414R, 5415R, 5416R, 5418R
4	1635	3/29/1999	15:45	F	CAPM-99-4008	5403R
5	2085	3/30/1999	9:45	UF	CAPM-99-4009	5410R, 5414R, 5415R, 5416R, 5418R
5	2085	3/30/1999	9:45	F	CAPM-99-4010	5403R
Field Blank		3/26/1999	10:10	UF	CAPM-99-4011	5378R, 5379R

* F = Filtered, UF = Unfiltered

Groundwater samples were collected from specific zones for three different analytical suites; the analytical suite for each sample depended on the depth of the zone that was sampled. The uppermost zone sampled was analyzed for the full suite of analytes that are listed in Table 8. The lower four zones were analyzed for a selected suite of analytes; the second zone was analyzed for a selected suite of analytes but for a full suite of radionuclides. The analytical methods used for the analyses are listed in Tables 9, 10, and 11.

The following bullets summarize the analytical suites that were applied to the samples from different zones in the well.

- Groundwater samples collected from the uppermost zone at 1,340 ft depth were analyzed for a full suite of analytes, which are listed in Table 8 and include the following categories of constituents:
    - General inorganics—major cations and anions
    - Full suite radionuclides including low-detection-limit tritium
    - HE compounds (low detection limit)
    - Humic Acid/DOC Fractionation
    - Stable isotopes including hydrogen, oxygen, and nitrogen isotopes
    - Trace elements/trace metals
    - VOCs
    - SVOCs
    - Pesticides/PCBs
- Groundwater samples collected from the second zone from the top, at 1,406 ft depth, were analyzed for the following constituents:
    - General inorganics—major cations and anions
    - Full suite of radionuclides including low-detection-limit tritium
    - HE Compounds (low detection limit)
    - Humic Acid/DOC Fractionation
    - Stable isotopes of hydrogen and oxygen
    - Carbon-14
    - Nitrogen Isotopes (Samples were collected and archived. They were to be analyzed if nitrate as nitrogen is greater than 1 mg/L.)
- Groundwater samples collected from the lower three zones sampled in the well were analyzed for the following constituents:
    - General inorganics_major cations and anions
    - Low-level Tritium
    - Strontium-90
    - HE Compounds (low detection limit)
    - Humic Acid/DOC Fractionation
    - Stable isotopes
    - Carbon-14
    - Nitrogen Isotopes (Samples were collected and archived. They were to be analyzed if nitrate as nitrogen is greater than 1 mg/L)

All water samples were analyzed for general inorganic chemicals to characterize the geochemistry of discrete zones of the regional aquifer. Measurements for inorganic chemicals included analyses for 26 trace metals, major anions (bromide, chloride, fluoride, nitrate, sulfate, and field alkalinity), minor anions (chlorate, nitrite, and orthophosphate), dissolved silica, and total cyanide.

Table 8. Full Analytical Suite for PM-4 Regional Aquifer Groundwater Samples

Field-Measured Parameters		
pH	Specific conductance	Turbidity
Dissolved oxygen	Temperature	
Major and Minor Ions		
Aluminum	Fluoride	Phosphate
Ammonium	Iron	Potassium
Bromide	Magnesium	Sodium
Calcium	Manganese	Sulfate
Chlorate	Nitrate	
Chloride	Nitrite	
Trace Elements		
Aluminum	Chromium	Silver
Antimony	Cobalt	Thallium
Arsenic	Copper	Titanium
Barium	Lead	Uranium
Beryllium	Mercury	Vanadium
Boron	Nickel	Zinc
Cadmium	Selenium	
Organic Chemicals		
VOCs	Pesticides/PCBs	
SVOCs / subset PAHs		
HE (low detection limit)		
Dissolved Organic Carbon (fractionation analysis) (to Huffman Laboratory)		
Total Suspended Solids		
Total Dissolved Solids		
Neutral Species (SiO_2)		
Hardness		
Cyanide		
Stable and Radiogenic Isotopes		
Carbon-14	Chlorine-36	Oxygen-18/oxygen-16
Carbon-13	Deuterium/hydrogen	Nitrogen-15/nitrogen-14 (Coastal)

Radionuclides			
Americium-241	Plutonium-239, 240		Gamma spectroscopy
Cesium-137	Strontium-90		Gross-alpha, -beta, and -gamma
Plutonium-238			Tritium (low-detection-limit)

Table 9. Estimated Detection Limits and Analytical Methods for Inorganic Chemicals in PM-4 Groundwater Samples

Analyte [a]	EDL (µg/L)	Analytical Method	Analytical Protocol [b]
Metals			
Aluminum	10	ICPES	SW-6010B
Ammonium	20	IC	SW-9056
Antimony	0.1	ICPMS	SW-6020
Arsenic	1	ETVAA	SW-7060A
Barium	2	ICPES	SW-6010B
Beryllium	5	ICPES	SW-6010B
Boron	10	ICPES	SW-6010B
Cadmium	1	ICPMS	SW-6020
Calcium	10	ICPES	SW-6010B
Chromium	2	ICPES	SW-6010B
Cobalt	2	ICPES	SW-6010B
Copper	2	ICPES	SW-6010B
Iron	10	ICPES	SW-6010B
Lead	3	ETVAA or ICPMS	SW-7421 or SW-6020
Magnesium	10	ICPES	SW-6010B
Manganese	2	ICPES	SW-6010B
Mercury	0.2	CVAA	SW-7470A
Nickel	2	ICPES	SW-6010B
Potassium	10	ICPES	SW-6010B
Selenium	0.2	ETVAA	SW-7740
Silver	0.2	ICPES	SW-6010B
Sodium	50	ICPES	SW-6010B
Thallium	2	ICPMS	SW-6020
Titanium	2	ICPES	SW-6010B
Uranium	0.1	KPA[c]	Not Applicable
Vanadium	2	ICPES	SW-6010B
Zinc	10	ICPES	SW-6010B
Anions (dissolved)			
Bromide	20	IC	SW-9056
Chlorate	20	IC	SW-9056
Chloride	20	IC	SW-9056
Fluoride	20	IC	SW-9056
Nitrate	40	IC	SW-9056
Nitrite	40	IC	SW-9056
Orthophosphate	20	IC	SW-9056
Sulfate	100	IC	SW-9056
Other Inorganic Chemicals (dissolved)			
Silica	200	Colorimetry	EPA Method 370.1
Total cyanide	50	Colorimetry	SW-9012A

a. Unfiltered water samples were collected for total concentrations of constituents. If the turbidity was greater than 5 NTUs, unfiltered and filtered water samples were to be collected. An Aliquot of each sample was filtered at the time of collection to remove particles larger than 0.45 µm for certain analyses.

b. EPA SW-846 Method (EPA 1987, 57589) or equivalent

c. Kinetic Phosphorometric Analyses

Table 10. Minimum Detectable Activity and Analytical Methods for Radionuclides in Groundwater Samples

Analyte [a]	Half-Life (yr)	Detected Emission	Minimum Detectable Activity (pCi/L)	Analytical Method
Americium-241	432.2	α	0.05	α-Spectrometry
Plutonium-238	87.7	α	0.05	α-Spectrometry
Plutonium-239,240[b]	2.411×10^4	α	0.05	α-Spectrometry
Strontium-90	28.7	β	1.0	GPC
Tritium	12.4	β	250	LSC
Tritium (low level)	12.4	β	1	Electrolytic enrichment/GPC
Gamma spectroscopy	N/A[c]	γ	10[d]	γ-Spectroscopy
Gross-alpha	N/A	α	1.0	GPC or LSC
Gross-beta	N/A	β	1.0	GPC or LSC
Gross-gamma	N/A	γ	20	NaI(Tl) or HPGe detection

a. Water samples were not filtered at the time of collection because turbidity was less than 5 NTUs.

b. The plutonium-239 and plutonium-240 isotopes cannot be distinguished by alpha spectrometry. The half-life of plutonium-239 is given.

c. N/A = not applicable

d. The minimum detectable activity for cesium-137 using gamma spectroscopy is 1.0 pCi/L; the minimum detectable activities for other analytes obtained using gamma spectroscopy varies.

To better understand the nature of recharge to the regional aquifer, analysis for carbon-14, chlorine-36, and stable isotopic ratios of deuterium/hydrogen and oxygen-18/oxygen-16 were performed on some samples to estimate the age of water and to help identify specific sources of recharge. Analyses for carbon-13 and dissolved organic carbon (humic acids by fractionation analysis) were performed to provide a better understanding of the organic geochemistry of the groundwater.

In addition to measurements of gross-alpha, -beta, and -gamma radioactivity, the radionuclide analytes include americium-241; plutonium-238; plutonium-239,240; strontium-90; and tritium (low detection limit). Total uranium was analyzed using kinetic phosphorometric analysis (KPA) because concentrations of uranium in PM-4 were expected to be relatively low and within the range of LANL background levels.

All analyses for inorganic and organic chemicals were performed in accordance with EPA SW-846 protocols (EPA 1987, 57589), EPA standard methods (EPA 1983, 56406), or standard methods for chemical analysis of water (Franson 1995, 56405). The detailed analyte lists, estimated quantitation limits (EQLs), minimum detectable activities, required quality control (QC) procedures, and the acceptance criteria are found in the 1995 ER Project analytical services statement of work (LANL 1995, 49738) or the version that was current when the samples were analyzed. Laboratory analyses for the analytes were performed on unfiltered samples because the water sample were relatively nonturbid at the time of sampling, that is, the samples were all less than 5 NTUs.

Table 11. Analytical Methods for Additional Parameters in PM-4 Groundwater Samples

Analyte	Analytical Method
Stable and Radiogenic Isotopes[a]	
Carbon-14, Carbon-13	Accelerator MS
Nitrogen-15/Nitrogen-14[e]	Isotopic Ratio Mass Spectrometry (Coastal Sciences)
Deuterium/hydrogen	Isotopic Ratio Mass Spectrometry (Coastal Sciences)
Oxygen-18/oxygen-16	Isotopic Ratio Mass Spectrometry (Coastal Sciences)
Chloride-36	MS
Organic Chemicals	
VOCs	SW-8260[b]
SVOCs	SW-8270
HE[d]	SW-8330
Other Analytes	
Total organic carbon (TOC)	SW-415.1[c]
Dissolved organic carbon (DOC) (humic substances)	USGS/WRI 79-4
Hardness (as calcium carbonate)	EPA Method 130

a. Stable isotopes will be measured in all groundwater samples.
b. EPA SW-846 Methods (EPA 1987, 57589)
c. EPA 1983, 56406
d. All groundwater samples were analyzed for low-detection-limit HE compounds.
e. Samples from the lower four zones were archived and nitrogen isotopes were to be analyzed in deeper samples if NO_3 as N was >1.0 mg/L.

2.2.2.1 Zone #1

The purging of Zone #1 began the morning of March 26, 1999. The packers for Zone #1 were located at 1,320 and 1,360 ft depth, the slotted casing was located at the depth interval from 1,338 to 1,340 ft, and the pump was at a depth of 1,320 ft. The three casing volumes were purged in 3 hours and 16 minutes after which the samples were collected from Zone #1.

The general water quality parameters of the purge water were measured using a Hydrolab® MiniSonde probe that was positioned in a stainless-steel bucket that was continuously fed water from the wellhead through 1/2-in.-diameter vinyl tubing. Water quality parameters measured included conductance, pH, temperature, dissolved oxygen, and turbidity, each of which was recorded at 1-minute intervals. Figure 7 shows the time-series chart of the water quality parameters during the purge of Zone #1. The conductance of the produced water was around 110 μS/cm. The chart shows the higher turbidity of the first casing volume of water and the reduced turbidity of the water that was produced later during the purge. Variations in the turbidity values are partially attributable to the position of the tool in the stainless-steel bucket. Depending on how the turbidity meter was positioned in the bucket, different readings were obtained, possibly from reflection of the walls of the bucket to the meter. In general, the field-measured water quality parameters of the purged water, especially the dissolved oxygen and the turbidity appeared to stabilize after about 2 hours, or two casing volumes.

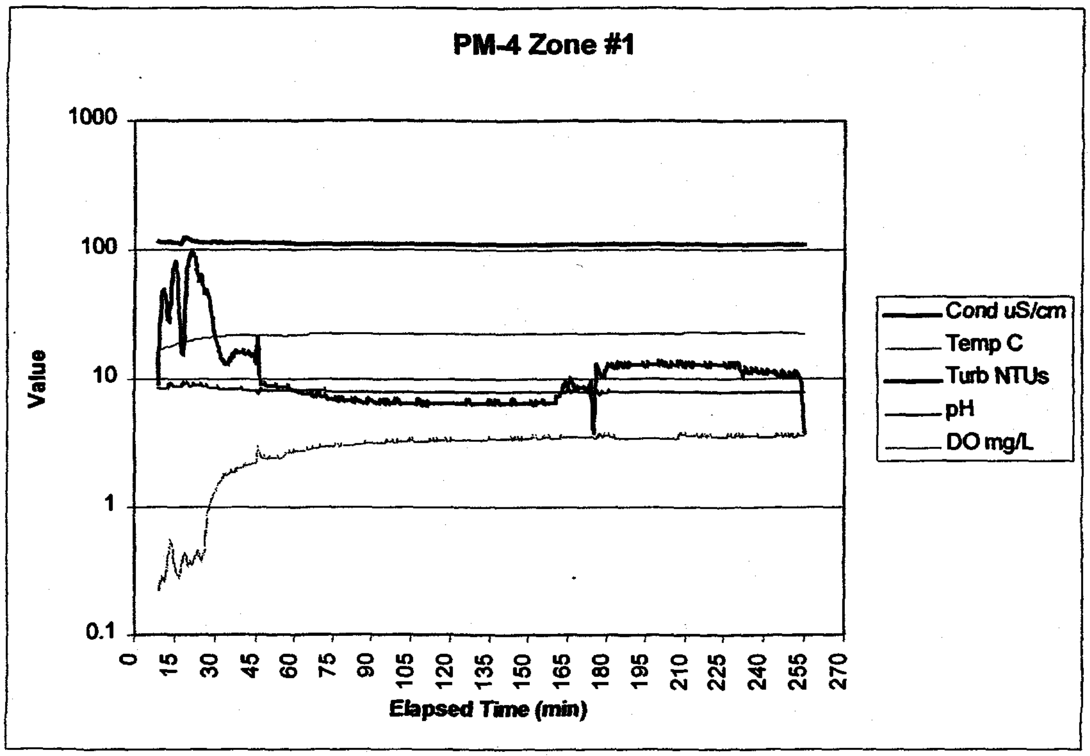

Figure 7. Water quality parameters during purging from zone #1.

Before collection of the water samples, the field-measured water quality parameters were measured using a Horiba Water Parameter Meter. The results of the field-measured water quality parameters are shown in Table 12. Because the turbidity of the groundwater was less than 5 NTUs, filtered samples were not collected for all analytes.

Samples were collected from Zone #1 on March 26. These samples were analyzed for a full suite of analytes, which included the following categories of constituents:

- General inorganics — major cations and anions
- *Full suite radionuclides including low-detection-limit tritium*
- HE compounds (low detection limit)
- Humic Acid/DOC Fractionation
- Stable isotopes including hydrogen, oxygen, and nitrogen isotopes
- Trace elements/trace metals
- VOCs
- SVOCs
- Pesticides/PCBs

Table 12. Field Measured Water Quality Parameters of Groundwater Samples.

Zone	Depth	Date	Conductance (μS/cm)	DO (mg/L)	pH (SU)	T (C)	Turbidity (NTU*)
1	1340	3/26/1999	100	4.8	7.4	22	3.3
2	1406	3/26/1999	110	3.4	7.9	22	2.45
3	1505	3/29/1999	100	4.3	7.9	22	0
4	1635	3/29/1999	100	4.6	7.8	22	0.02
5	2085	3/30/1999	100	3.2	8.0	22	0

*NTU = Nephelometric Turbidity Units

2.2.2.2 *Zone #2*

After collection of the groundwater samples from Zone #1, the pump and packer assembly were lowered in the well on March 26, 1999, in preparation for purging and sampling Zone #2. The packers were relocated to the depths 1386 and 1426 ft, and the slotted casing was relocated to the depth interval 1,404 to 1,406 ft. Zone #2 collected groundwater samples from the Totavi Lentil, which contained the highest apparent production capacity. On the afternoon of March 26, a total of 1500 gallons were purged from Zone #2 in 3 hours and 20 minutes.

The general water quality parameters of the purge water were measured using a Hydrolab® MiniSonde probe that was positioned in a stainless-steel bucket that was continuously fed water from the well head through 1/2-in.-diameter vinyl tubing. Water quality parameters measured included conductance, pH, temperature, dissolved oxygen, and turbidity, each of which was recorded at 1-minute intervals. Figure 8 shows the time-series chart of the water quality parameters during the purge of Zone #2. The conductance of the produced water was around 110 μS/cm. The chart shows the increased turbidity of the disturbed water in the well from moving the pump/packer assembly beginning at about 27 minutes into the purge time, which is the amount of time needed to displace the volume of water in the column of production pipe. The relatively turbid water was displaced within 2 hours of purging the well. Variations in the turbidity values are partially attributable to the position of the tool in the stainless-steel bucket, depending on how the turbidity meter was positioned in the bucket, different readings were obtained, possibly from reflection of the walls of the bucket to the meter. In general, the field-measured water quality parameters of the purged water (especially the dissolved oxygen and the turbidity) appear to stabilize after about 2 hours, or two casing volumes.

Before collection of the water samples from Zone #2, the field-measured water quality parameters were measured using a Horiba Water Parameter Meter. The results of the field-measured water quality parameters are shown in Table 12. Because the turbidity of the groundwater was less than 5 NTUs, filtered samples were not collected for all analytes.

Samples were collected from Zone #2 on March 26. These samples were analyzed for a limited suite of analytes, which included the following categories of constituents:

- General inorganics—major cations and anions
- Full suite radionuclides including low-detection-limit tritium
- HE Compounds (low detection limit)
- Humic Acid/DOC Fractionation
- Stable isotopes of hydrogen and oxygen
- Carbon-14

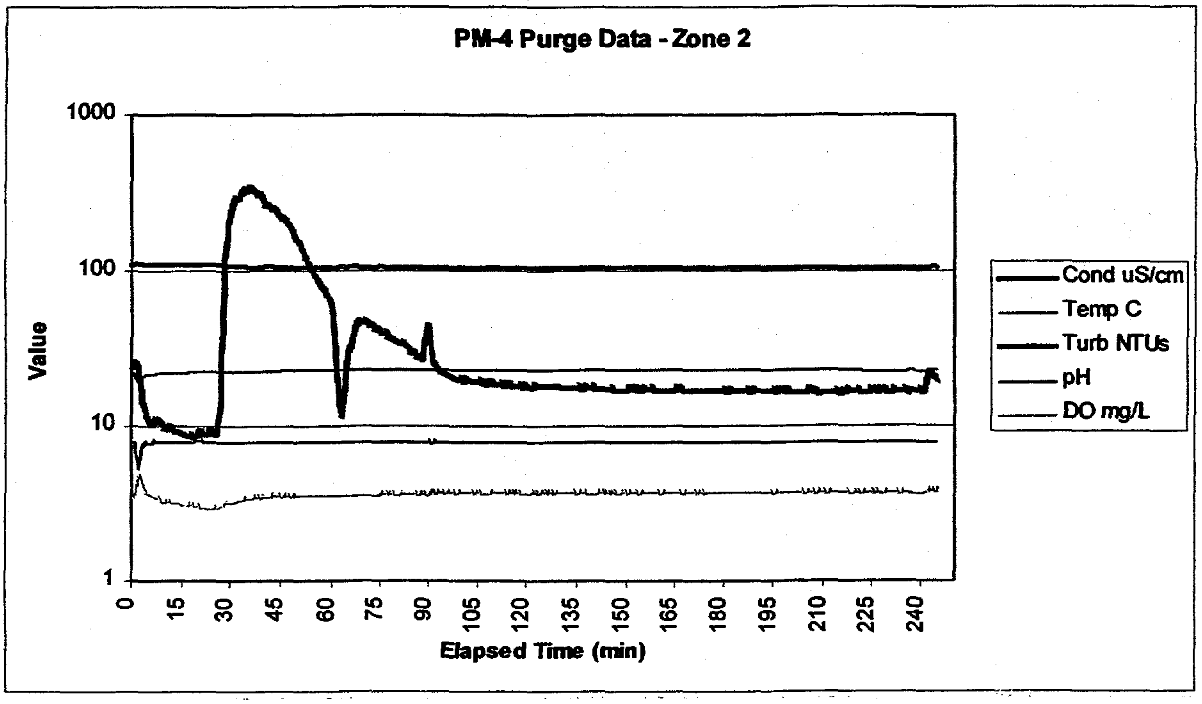

Figure 8. Water quality parameters during purging from Zone #2.

Samples were collected from Zone #2 and archived for the potential analyses for nitrogen isotopes if nitrate as nitrogen was greater than 1 mg/L. The results from the nitrate as nitrogen were less than 1 mg/L so the samples from Zone #2 were not analyzed for nitrogen isotopes.

<u>2.2.2.3 Zone #3</u>

After collection of the groundwater samples from Zone #2, the pump and packer assembly were lowered in the well on March 29, 1999, in preparation for purging and sampling Zone #3. The packers were relocated to the depths of 1,485 and 1,525 ft, and the slotted casing was relocated to the depth interval of 1,503 to 1,505 ft. A total of 1,500 gallons were purged from Zone #3. Because the field-measured water quality parameters measured during the purging of Zone #1 and Zone #2 showed that the purging of three casing volumes or 1,500 gallons were sufficient to stabilize the water quality parameters, continuous monitoring of the water quality parameters was not performed. The field-measured water quality parameters measured after purging 1,500 gallons from Zone #3 are shown in Table 12. The conductance of the groundwater from Zone #3 was 100 µS/cm.

Samples were collected from Zone #3 on the morning of March 29. These samples were analyzed for a limited suite of analytes, which included the following categories of constituents:

- General inorganics—major cations and anions
- Low-level Tritium
- Strontium-90
- HE Compounds (low detection limit)
- Humic Acid/DOC Fractionation
- Stable isotopes
- Carbon-14

Samples were collected from Zone #3 and archived for the potential analyses for nitrogen isotopes if nitrate as nitrogen was greater than 1 mg/L. The results from the nitrate as nitrogen were less than 1 mg/L so the samples from Zone #3 were not analyzed for nitrogen isotopes.

2.2.2.4 *Zone #4*

After collection of the groundwater samples from Zone #3, the pump and packer assembly was lowered in the well on March 29, 1999 in preparation for purging and sampling Zone #4. The packers were relocated to the depths 1615 and 1655 ft, and the slotted casing was relocated to the depth interval of 1,633 to 1,635 ft. A total of 1,500 gallons were purged from Zone #4 in 3 h and 15 minutes. Because the field-measured water quality parameters measured during the purging of Zone #1 and Zone #2 showed that the purging of three casing volumes or 1,500 gallons were sufficient to stabilize the water quality parameters, continuous monitoring of the water quality parameters was not performed. The field-measured water quality parameters measured after purging 1,500 gallons from Zone #4 are shown in Table 12. The conductance of the groundwater from Zone #4 was 100 μS/cm.

Samples were collected from Zone #4 on the afternoon of March 29. These samples were analyzed for a limited suite of analytes, which included the following categories of constituents:

- General inorganics—major cations and anions
- Low-level Tritium
- Strontium-90
- HE Compounds (low detection limit)
- Humic Acid/DOC Fractionation
- Stable isotopes
- Carbon-14

Samples were collected from Zone #4 and archived for the potential analyses for nitrogen isotopes if nitrate as nitrogen was greater than 1 mg/L. The results from the nitrate as nitrogen were less than 1 mg/L, so the samples from Zone #4 were not analyzed for nitrogen isotopes.

2.2.2.5 *Zone #5*

After collection of the groundwater samples from Zone #4, the pump and packer assembly was lowered in the well on March 29, 1999, in preparation for purging and sampling Zone #5. The packers were relocated to the depths 2,065 and 2,105 ft, and the slotted casing was relocated to the depth interval 2,083 to 2,085 ft. At this depth, the groundwater samples could be obtained from basalt within the Santa Fe Group sediments (see Figure 2). On the morning of March 30, a total of 1,500 gallons were purged from Zone #5 in 3 hrs and 20 minutes. Because the field-measured water quality parameters measured during the purging of Zone #1 and Zone #2 showed that the purging of 3 casing volumes or 1,500 gallons were sufficient to stabilize the water quality parameters, continuous monitoring of the water quality parameters was not performed. The field-measured water quality parameters measured after purging 1,500 gallons from Zone #5 are shown in Table 12. The conductance of the groundwater from Zone #5 was 100 μS/cm.

Samples were collected from Zone #5 on the morning of March 30. These samples were analyzed for a limited suite of analytes, which included the following categories of constituents:

- General inorganics—major cations and anions
- Low-level Tritium
- Strontium-90
- HE Compounds (low detection limit)
- Humic Acid/DOC Fractionation
- Stable isotopes
- Carbon-14

Samples were collected from Zone #5 and archived for the potential analyses for nitrogen isotopes if nitrate as nitrogen was greater than 1 mg/L. The results from the nitrate as nitrogen were less than 1 mg/L so the samples from Zone #4 were not analyzed for nitrogen isotopes.

2.2.3 Summary of Purging and Sampling Activities

During the purging and pumping of the well for the collection of groundwater samples, a total of 8800 gallons of water were produced from the five zones over the 2.5 days of sampling. The average rate of production of the submersible pump during the sampling was 7.5 gpm. The produced water was discharged to the NPDES outfall attached to the well. Groundwater samples were collected from each of the 5 zones that were selected for sampling.

2.3 Phase-III Video Log #2

After completion of the zonal groundwater sampling and the removal of the pump/packer assembly from the well, the second video log survey of the well was obtained on March 31, 1999. The survey log was measured from the top of the temporary casing, which was about 1 ft above the top of the permanent well casing. The first video log was obtained from the top of the permanent casing, so the measurements for the second video log survey were therefore about 1 ft higher relative to the first video log.

The static oil level was encountered at a depth of 1,074 ft, and the oil/water contact was at a depth of 1,075 ft. The sounder tubes were present at a depth of 1,256 ft, and the tops of the louvers were at a depth of 1,259 ft. The wire in the bottom of the hole was encountered at a depth of 2,814 ft, and the survey was stopped at a depth of 2,836 ft where the water becomes too cloudy from sediment associated with the wire to see the casing. The survey was also stopped at this depth to prevent potentially entangling the video camera and associated equipment with the wire in the well.

The second video log survey did not indicate the movement of water inside the well. Additionally, the second video log survey did not show that the well casing was damaged or otherwise impacted by the installation and removal of the 1,000-gpm pump that was used for the dynamic spinner log survey or the pump/packer assembly that was used for groundwater sampling.

3.0 Analytical Results

3.1 Results of NPDES Sampling

On March 17, 1999, while pumping the well at 1,000 gpm for the dynamic spinner log survey, ESH-18 NPDES personnel collected samples of the discharged water for compliance with the Laboratory NPDES permit. The samples were analyzed for pH, total residual chloride, selected metals, tritium, radium-226, and radium-228. The samples represent a composite of all producing zones from well PM-4, and effectively represent the groundwater that is produced for municipal supply use. The results of the analyses are shown in Table 13. The pH of the water was 7.9, and no chlorine gas was detected because the water from the well was not chlorinated during the test. Tritium, using the higher detection limit liquid scintillation counting method, was 105 ±640 pCi/L. Metals detected in the groundwater include arsenic, boron, chromium, copper, and lead.

Table 13. Results of NPDES Compliance Sampling of PM-4

Analyte	F/UF	Analytic Result	Uncertainty	Reporting Units	Analytical Method	Comment
pH	UF	7.9	NR	SU	150.1	
Chlorine	UF	0	NR	mg/L	4500	Amperometric titration method
Metals						
Aluminum	UF	<0.2	NR	mg/L	200.7	
Arsenic	UF	1	1	µg/L	206.2	
Boron	UF	0.017	0.007	mg/L	200.7	
Cadmium	UF	<3	NR	µg/L	200.8	
Chromium	UF	0.006	0.003	mg/L	200.7	
Cobalt	UF	<0.02	NR	mg/L	200.7	
Copper	UF	0.14	0.014	mg/L	200.7	
Lead	UF	10	3	µg/L	200.8	
Mercury	UF	<0.10	NR	µg/L	200.7	
Selenium	UF	<2	NR	µg/L	270.2	
Vanadium	UF	<0.02	NR	mg/L	200.7	
Zinc	UF	<0.04	NR	mg/L	200.7	
Radionuclides						
Tritium	UF	150	640	pCi/L	LS	Liquid scintillation counting
Radium-226	UF	-0.02	NR	pCi/L	903.1	
Radium-228	UF	-4.2	NR	pCi/L	903.1	

F/UF = Filtered/Unfiltered
N/A = Not Applicable
NR = Not Reported
EPA Serial Number EPA04A118, Sampling Date: March 17, 1999

3.2 Results of Zonal Groundwater Sampling

Zonal groundwater samples were collected from supply well PM-4 from March 26 through March 30, 1999, as described in Section 2.2.2. Groundwater samples were collected from five depth zones in the regional aquifer, which are listed in Table 7. All the groundwater samples had low turbidity values that were less than 3.3 NTU values (see Table 12).

The groundwater samples were analyzed for inorganic species (major ions and trace elements), HE compounds, stable isotopes of hydrogen, oxygen, and nitrogen, selected radionuclides, and organic compounds including PCBs (in the samples from the upper zone only). Chemical and radiochemical analyses were performed at ER Project contract analytical laboratories. The USEPA-SW846 methods and other analytical methods were used for chemical and radiochemical analyses. Tritium analyses were performed using low-detection methods at the University of Miami Tritium Laboratory. Alpha spectroscopy analyses were performed only on samples from the upper two zones.

The results of the analyses of the samples are shown in Tables 14 through 17. Table 14 contains the results of analyses for cations and anions and general inorganic constituents, Table 15 contains the results of analyses for metals and trace elements, Table 16 contains the results of analyses for radionuclide constituents, and Table 17 contains the results of stable isotope and nitrogen isotope analyses.

High-explosive compounds, including RDX, HMX, TNT, and associated degradation products were not detected in groundwater samples collected from PM-4. This suggests that the high-explosive contamination at R-25 has not reached and/or significantly impacted groundwater from PM-4. No other anthropogenic volatile and semivolatile organic compounds including PCBs were detected in the groundwater samples collected from PM-4. The TOC in the sample from Zone #1 was 3.2 mg/L.

Groundwater samples collected from the five zones at PM-4 are characterized by calcium-sodium-bicarbonate compositions. Stiff diagrams showing the chemical character of each of the zones sampled are shown in Figure 9. The ionic composition of the groundwater samples is uniform, indicating that the water is homogenous and suggesting that mixing of groundwater may have occurred within the well and along the filter pack material during sampling of the well. The total dissolved solids (TDS) content of all five zones of groundwater samples ranges from 207 mg/L to 216 mg/L.

Activities of tritium in the groundwater samples from PM-4 are less than 0.12 tritium units (TUs) or less than 0.38 pCi/L (Table 16), indicating that tritium was not detected in the groundwater. These results suggest that the groundwater has not received recent recharge from precipitation or surface water and that the age of the groundwater is greater than 50 years (prebomb atmospheric fallout). Activities of americium-241, neptunium-237, strontium-90, plutonium-238, and plutonium-239 were below detection limits. The results of gamma spectrometry (including cesium-137, cobalt-60, etc.) performed on samples from the upper two zones were at or below detection limits for all constituents, indicating that the gamma-emitting radionuclides were not detected. The concentrations of uranium ranged from 0.51 to 0.71 μg/L, which is within the usual range for total uranium concentrations encountered in the regional aquifer (e.g. ESP 1998, 59904, p. 183).

Results of stable isotopes of hydrogen and oxygen are listed in Table 17 and are shown in Figure 10. The data suggest that PM-4 groundwater was ultimately derived from a meteoric water source(s). The stable isotopic composition of the groundwater samples from different zones is similar, suggesting that mixing of groundwater may have occurred within PM-4 during sampling.

The analytical results for nitrogen-15/nitrogen-14 ratios from nitrate are shown in Table 17. Isotopic nitrogen-15/nitrogen-14 compositions of the groundwater samples are slightly depleted in nitrogen-15 characterized by negative values ranging from -2.7 to -0.9 per mil. These values are typical of other LANL background groundwater and surface water samples. These PM-4 data fit very well with the LANL background 15N/14N data (Longmire et al. 1999).

Corrected chlorine-36 values, in units of chlorine-36 units (CLU), are also shown in Table 17. Corrected chlorine-36 values range from 765 to 911 CLU. The results of chlorine-36 analyses suggest that bomb-pulse chloride generally is not present in groundwater samples collected from PM-4. Prebomb meteoric recharge at Los Alamos has an estimated chlorine-36/chlorine ratio on the order of 600-800 CLU

(Longmire et al. 1999). Bomb pulse chlorine-36 is not present in the samples collected from PM-4. The results of nitrogen and chlorine isotopic analyses are consistent with the results of the low-level tritium analyses. Preliminary calculations, with several major assumptions, suggest that the age of the groundwater from PM-4 ranges from 243,407 to 330,216 years before present, based on the chlorine-36 results. These calculated ages, however, are one to two orders of magnitude greater than age estimates of groundwater from nearby wells (PM-1, PM-3, and PM-5) using carbon-14 age dating techniques (Rogers et al., 1996).

Table 14. Chemical Quality of Groundwater Zones in PM-4

Sample No.	Depth	Sample Date	F/UF	Br *	Ca	Cl^-	ClO_3	Cn	F	I	K	Mg	Na	NH_3 as N	NO_2/NO_3 as N	PO_4	SO_4	TOC
CAPM-99-4001	1340	03/26/99	UF	< 0.2	9.09	1.8	< 0.1	< 0.01	0.18	< 0.1	2.06	3.03	9.44	< 0.54	0.28	< 0.05	1.8	3.2
CAPM-99-4003	1406	03/26/99	UF	< 0.2	8.66	1.8	< 0.1	< 0.01	0.21	< 0.1	2.1	2.78	9.68	< 0.65	0.28	< 0.05	1.7	2.3
CAPM-99-4005	1505	03/29/99	UF	< 0.2	8.94	1.9	< 0.1	< 0.01	0.21	< 0.1	2.11	2.79	9.74	< 0.62	0.29	< 0.05	1.8	NA
CAPM-99-4007	1635	03/29/99	UF	< 0.2	9.00	1.9	< 0.1	< 0.01	0.21	< 0.1	2.13	2.88	9.7	< 0.69	0.29	< 0.05	1.9	NA
CAPM-99-4009	2085	03/30/99	UF	< 0.2	9.23	1.9	< 0.1	< 0.01	0.21	< 0.1	2.13	2.8	9.71	< 0.64	0.26	< 0.05	2.0	NA

* = all units in mg/L; NA = Not Analyzed; data from Paragon Analytics, Inc.

< = Result less than detection limit; the associated numerical value is the detection limit.

Table 14 (Continued). Chemical Quality of Groundwater Zones in PM-4

Sample No.	Depth	Sample Date	F/UF	Alkalinity* ($CaCO_3$)	CO_3	Hardness ($CaCO_3$)	pH (SU)	SiO_2	TDS	TSS
CAPM-99-4001	1340	03/26/99	UF	57.3	0	35.9	7.45	80.13	210.7	<0.2
CAPM-99-4003	1406	03/26/99	UF	55.7	0	34.1	7.50	82.93	210.9	<0.1
CAPM-99-4005	1505	03/29/99	UF	56.5	0	33.9	7.69	82.80	207.9	<0.1
CAPM-99-4007	1635	03/29/99	UF	57.0	0	35.3	7.60	82.53	212.0	<0.1
CAPM-99-4009	2085	03/30/99	UF	57.4	0	37.1	7.80	82.26	217.4	<0.1

* = all units in mg/L; NA = Not Analyzed; data from Laboratory group CST-7.

< = Result less than detection limit; the associated numerical value is the detection limit.

Table 15. Trace Metals in Groundwater Zones in PM-4

Well Name	Depth	Sample Date	F/UF	Ag *	Al	As	Ba	Be	Cd	Co	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Sb	Se	Tl	V	Zn
PM-4	1340	03/26/99	UF	< 1	< 4.8	< 1.9	16.6	0.84	< 0.2	< 0.5	4.3	< 0.6	719	< 0.03	50.4	< 3	4.4	< 0.8	< 2.3	< 2.9	< 3.40	5.8	29.3
PM-4	1406	03/26/99	UF	< 1	< 4.8	< 1.9	19.3	0.84	< 0.2	< 0.5	4.5	< 0.6	836	< 0.03	54.8	4.5	3.9	< 0.8	< 2.3	< 2.9	7.40	5.9	23.8
PM-4	1505	03/29/99	UF	< 1	< 4.8	< 1.9	17.2	0.84	< 0.2	< 0.5	3.9	< 0.6	561	< 0.03	56.7	< 3	3.4	< 0.8	< 2.3	< 2.9	< 3.40	6.0	18.0
PM-4	1635	03/29/99	UF	< 1	< 4.8	< 1.9	16.7	0.88	< 0.2	< 0.5	4.1	< 0.6	708	< 0.03	58.4	< 3	3.6	< 0.8	3.0	3.9	5.30	5.8	18.6
PM-4	2085	03/30/99	UF	< 1	< 4.8	< 1.9	15.0	0.85	< 0.2	< 0.5	4.2	< 0.6	944	< 0.03	74.8	4	3.1	< 0.8	< 2.3	< 2.9	< 3.40	5.1	25.2

* all units in μg/L

< = Result less than detection limit; the associated numerical value is the detection limit.

Table 16. Radionuclides in Groundwater Zones in PM-4

Sample ID	Well Name	Sample Date	Depth	Matrix	Suite	Analyte	F/UF	Sample Value	Uncertainty [a]	Units	Detection Limit	Detected [b]
Zone #1												
CAPM-99-4001	PM-4	03/26/99	1340	GW	Rad	Gross Alpha	UF	0.63	0.35	pCi/L	1.2	No
CAPM-99-4001	PM-4	03/26/99	1340	GW	Rad	Am-241	UF	0.008	0.011	pCi/L	0.052	No
CAPM-99-4001	PM-4	03/26/99	1340	GW	Rad	Gross Beta	UF	1.09	0.475	pCi/L	1.6	No
CAPM-99-4001	PM-4	03/26/99	1340	GW	Rad	Np-237	UF	0.004	0.011	pCi/L	0.042	No
CAPM-99-4001	PM-4	03/26/99	1340	GW	Rad	Pu-238	UF	0.001	0.012	pCi/L	0.056	No
CAPM-99-4001	PM-4	03/26/99	1340	GW	Rad	Pu-239	UF	0.0156	0.0084	pCi/L	0.029	No
CAPM-99-4001	PM-4	03/26/99	1340	GW	Rad	Sr-90	UF	0.24	0.115	pCi/L	0.36	No
CAPM-99-4001	PM-4	03/26/99	1340	GW	H-3	Tritium [c]	UF	-0.13	0.32	pCi/L	0.1	No
CAPM-99-4001	PM-4	03/26/99	1340	GW	Rad	U	UF	0.71	0.08	μg/L	0.2	Yes
Zone #2												
CAPM-99-4003	PM-4	03/26/99	1406	GW	Rad	Gross Alpha	UF	0.07	0.305	pCi/L	1.1	No
CAPM-99-4003	PM-4	03/26/99	1406	GW	Rad	Am-241	UF	0.0139	0.0089	pCi/L	0.032	No
CAPM-99-4003	PM-4	03/26/99	1406	GW	Rad	Gross Beta	UF	1.9	0.5	pCi/L	1.6	No
CAPM-99-4003	PM-4	03/26/99	1406	GW	Rad	Np-237	UF	-0.018	0.019	pCi/L	0.071	No
CAPM-99-4003	PM-4	03/26/99	1406	GW	Rad	Pu-238	UF	-0.0059	0.0052	pCi/L	0.034	No
CAPM-99-4003	PM-4	03/26/99	1406	GW	Rad	Pu-239	UF	0.003	0.0052	pCi/L	0.01	No
CAPM-99-4003	PM-4	03/26/99	1406	GW	Rad	Sr-90	UF	0.26	0.115	pCi/L	0.36	No
CAPM-99-4003	PM-4	03/26/99	1406	GW	H-3	Tritium [c]	UF	0	0.32	pCi/L	0.1	No
CAPM-99-4003	PM-4	03/26/99	1406	GW	Rad	U	UF	0.61	0.7	μg/L	0.1	Yes
Zone #3												
CAPM-99-4005	PM-4	03/29/99	1505	GW	Rad	Sr-90	UF	-0.05	0.095	pCi/L	0.32	No
CAPM-99-4005	PM-4	03/29/99	1505	GW	H-3	Tritium [c]	UF	0.26	0.32	pCi/L	0.1	No
CAPM-99-4005	PM-4	03/29/99	1505	GW	Rad	U	UF	0.57	0.065	μg/L	0.1	Yes
Zone #4												
CAPM-99-4007	PM-4	03/29/99	1635	GW	Rad	Sr-90	UF	0.06	0.10	pCi/L	0.34	No
CAPM-99-4007	PM-4	03/29/99	1635	GW	H-3	Tritium [c]	UF	-0.22	0.32	pCi/L	0.1	No
CAPM-99-4007	PM-4	03/29/99	1635	GW	Rad	U	UF	0.51	0.06	μg/L	0.1	Yes
Zone #5												
CAPM-99-4009	PM-4	03/30/99	2085	GW	Rad	Sr-90	UF	0.14	0.105	pCi/L	0.34	No
CAPM-99-4009	PM-4	03/30/99	2085	GW	H-3	Tritium [c]	UF	0.38	0.32	pCi/L	0.1	No
CAPM-99-4009	PM-4	03/30/99	2085	GW	Rad	U	UF	0.52	0.06	μg/L	0.1	Yes

a. Uncertainty is the radioactive counting uncertainty (1 standard deviation). Radioactivity counting uncertainties may be less than analytical method uncertainties.
b. Detect assessments are based on the validation flag "U" meaning that the analyte was analyzed for but was not detected.
c. Tritium analysis by low-detection methods at the University of Miami Tritium Laboratory.

Table 17. Results of Stable Isotope and Nitrogen Isotope Analyses

Sample Zone	Depth (Ft)	Sample ID	Request Numbers	Corrected Chlorine-36 (CLU)[a]	CLU Uncertainty (CLU)	δNitrogen-15 – NO_3 (permil)	δD[b] (permil)	δOxygen-18[c] (permil)
1	1340	CAPM-99-4001	5373R, 5374R	827	39	-2.7	-78	-10.8
2	1406	CAPM-99-4003	5383R, 5384R	821	43	-2.3	-76	-10.7
3	1505	CAPM-99-4005	5402R, 5403R	765	39	-1.0	-75	-11
4	1635	CAPM-99-4007	5414R, 5415R	881	47	-0.9	-77	-11
5	2085	CAPM-99-4009	5414R, 5415R	911	47	-1.0	-76	-11.1

a. CLU = chlorine-36 Units
b. δD = Deuterium versus standard mean ocean-water ratio
c. $\delta^{18}O$ = oxygen-18/oxygen-16 ratio

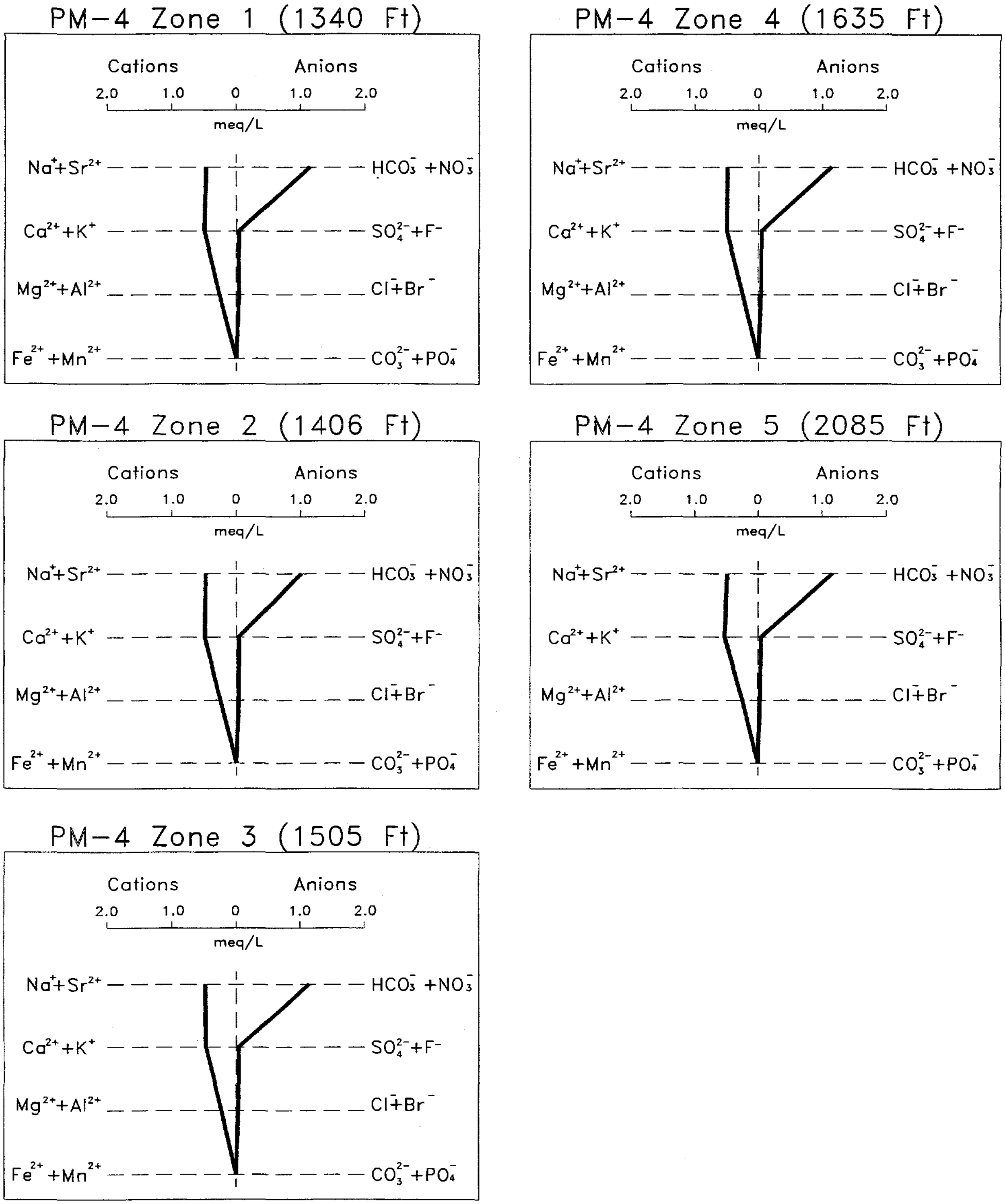

Figure 9. Stiff diagrams showing groundwater chemistry.

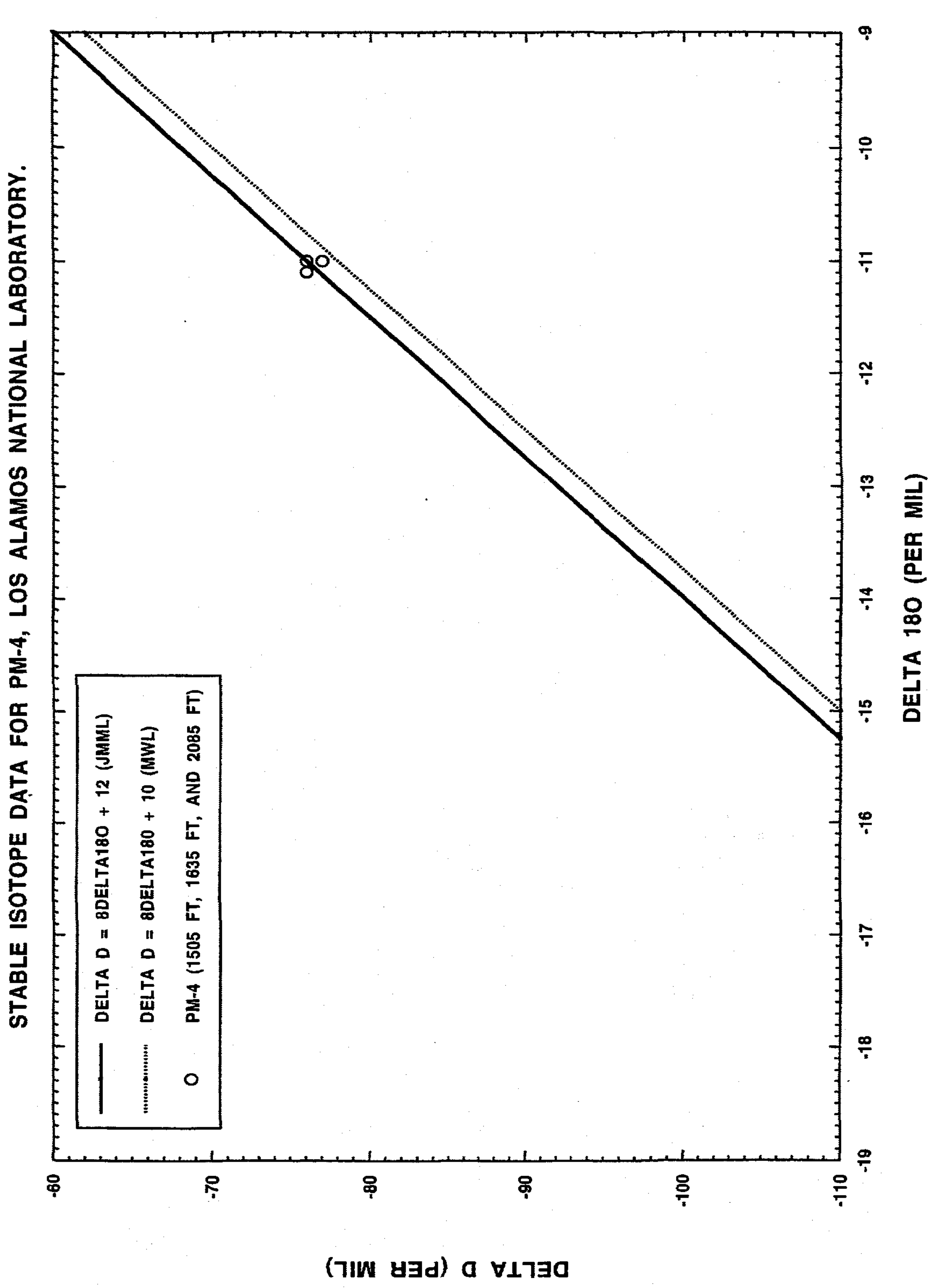

Figure 10. Results of analyses for stable isotopes of hydrogen and oxygen.

4.0 Summary and Conclusions

The testing and sampling of municipal supply well PM-4 was conducted in March 1999. Static and dynamic spinner log surveys were obtained from the well. The static spinner log survey did not measure natural vertical flow of groundwater in the well, which was also confirmed by the results of the video log surveys that did not show significant amounts of movement of water in the well.

The dynamic spinner log survey was obtained while pumping the well at a rate of 1,000 gpm (historically the well is pumped at a rate of approximately 1,350 gpm when operating). The result of the dynamic spinner log survey showed that most of the water is produced from the upper 500 ft of the 1,604-ft-long screened interval. The productive zone is from about 1,300 to 1,800 ft depth in the well. The shallower portions of the well evidently met the 1,000-gpm pumping demand placed on the well during the survey; it is not known if increasing the pumping demand would have increased production from deeper zones. The productive zones correlate to the lower part of the Puye Formation including the Totavi Lentil, and the upper part of the Santa Fe Group.

Based on the results of the dynamic spinner log survey, five zones in the well were selected for groundwater sampling. The upper four zones corresponded with the best water-producing intervals and the fifth and deepest zone was in basalt within the Santa Fe Group. A pump/packer assembly was lowered into the well to collect the groundwater samples. The K-packers are similar to wiper plugs and have several bands of rubber blades around a metal cylinder that have the same outside diameter as the inside of the casing, but the packers do not necessarily form a perfect seal with the casing. At least three volumes of water were purged from each packer zone and water-quality parameters of the purged water were monitored before the collection of the groundwater samples. The method used to collect the zonal groundwater samples could not prevent the movement of water around the packers and in the annulus outside of the casing.

Groundwater samples were collected for analyses from the following depths: 1,340 ft, 1,406 ft, 1,505 ft, 1,635 ft, and 2,085 ft. All the groundwater samples had low turbidity values that were less than 3.3 NTU values. The groundwater samples were analyzed for inorganic species (major ions and trace elements), HE compounds, stable isotopes of hydrogen, oxygen, and nitrogen, selected radionuclides, and organic compounds including PCBs (in the samples from the upper zone only). Chemical and radiochemical analyses were performed at ER Project contract analytical laboratories. The USEPA-SW846 methods and other analytical methods were used for chemical and radiochemical analyses. Tritium analyses were performed using low-detection methods at the University of Miami Tritium Laboratory. Alpha spectroscopy analyses were performed only on samples from the upper two zones.

High explosive compounds, including RDX, HMX, TNT, and associated degradation products were not detected in the groundwater samples collected from PM-4. This suggests that the high explosive contamination at R-25 has not reached and/or significantly impacted groundwater from PM-4.

The groundwater from the five zones at PM-4 is characterized by calcium-sodium-bicarbonate compositions. The chemical character of each of the zones sampled is uniform, indicating that the water sampled is homogenous and suggesting that mixing of groundwater may have occurred within the well and along the filter pack material in the annulus of the well before or during sampling the well.

Activities of tritium in the groundwater samples from PM-4 are less than 0.12 TUs or less than 0.38 pCi/L. The results of a low-level detection limit analysis for tritium suggests that the groundwater has not received recent recharge from precipitation or surface water and that the age of the groundwater is greater than 50 years (prebomb atmospheric fallout). Activities of strontium-90, plutonium-238, plutonium-239/240, cesium-137, and uranium-235 in the groundwater samples from PM-4 were below detection limits.

Results of stable isotopes of hydrogen and oxygen suggest that PM-4 groundwater was ultimately derived from a meteoric water source(s) that was similar to current precipitation in the area. The stable isotopic composition of the groundwater samples from different zones is similar, suggesting that mixing of groundwater may have occurred within PM-4 before or during sampling.

Isotopic nitrogen-15/nitrogen-14 compositions of the groundwater samples are slightly depleted in nitrogen-15 characterized by negative values ranging from -2.7 ‰ to -0.9 ‰. Corrected chlorine-36 values, in units of chlorine-36 units (CLU), range from 765 to 911 CLU. These results suggest that bomb-pulse chloride generally is not present in groundwater samples collected from PM-4 indicating that the water is older than 50 years before present. Results of preliminary calculations, with several major assumptions, suggest that the age of the groundwater in PM-4 ranges from 243,407 and 330,216 years before present, based on the chlorine-36 results.

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