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LANL GW Wells [HWP]

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Subject: "Notes on LANL wells R-4, R-26, and R-34" by Robert H. Gilkeson

The subject report will be a resource for the onference call between CCNS, NMED. and EPA on May 19,2005

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Notes on LANL Characterization Wells R-4, R-26, and R-34
Version May 16, 2005, by
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Executive Summary:
The United States Department of Energy (DOE) has recently published the well completion reports for characterization wells R-4, R-26, and R-34 that are installed in the regional aquifer at Los Alamos National Laboratory (LANL). A review of the reports reveals that none of the three wells are compliant with the regulations of EPA RCRA, New Mexico Environment Department (NMED), or DOE. The groundwater samples collected from the screened intervals are contaminated by drilling additives and by cross-communication of groundwater between perched zones of saturation and the regional aquifer. In addition, the aquifer tests in the screened intervals of the three wells have produced unreliable results for the required knowledge of groundwater flow in the regional aquifer for the environs of the three wells.

The data from the three LANL characterization wells installed by DOE do not meet the RCRA requirement that data be of sufficient known quality to withstand scientific and legal challenges relative to the use for which the data are obtained. In addition, the data do not meet the requirements of DOE Orders for environmental monitoring data to be of high quality. The LANL characterization wells are intended for use as RCRA-compliant monitoring wells.

The Los Alamos Site Office (LASO) of DOE has contracted and directed the installation of many LANL characterization wells including wells R-4, R-26, and R-34. The three wells were installed to satisfy requirements of the LANL Hydrogeologic Workplan. The DOE staff at LASO are responsible for the well installation activities of the LANL Hydrogeologic Workplan. DOE has an interagency agreement with the Sacramento District of the US Army Corps of Engineers (COE) for the installation of many regional and intermediate wells at LANL. The COE awarded the well installation contract to the consulting firm, Kleinfelder. Kleinfelder has subcontracted the drilling services to the drilling company, Water Development Corporation. DOE/LASO manages the Kleinfelder contract directly and has responsibility for Quality Assurance[13]. At the June, 2004 meeting of the Northern New Mexico Citizens Advisory Board (CAB), the DOE staff at LASO defended the drilling methods that were used for the construction of the LANL characterization/monitoring wells. The transcript of the June, 2004 meeting is available from the CAB.

The geochemical data and the aquifer test data for the three characterization wells reveal that the well development procedures have not removed the bentonite clay, biodegradable polymer-based drilling fluid, and biodegradable foam that have invaded the aquifer strata that surround the screened intervals. The drilling additives caused changes to the chemistry of groundwater samples that are collected from the three wells, and

specifically, have chemical properties[5,10,16] for the removal of radionuclide, metal, high explosive, and many chemical contaminants of concern from groundwater. In addition, the drilling additives greatly reduce the in situ permeability of the aquifer strata[5] which cause the aquifer properties determined from the aquifer tests to be invalid.

An important conclusion for the locations of wells R-4 and R-34 is that the boreholes were not drilled to the required depth to address concerns for the presence of contamination in the regional aquifer and concerns for long-term monitoring.

Well R-26 was installed to characterize background water quality and aquifer properties for the regional aquifer at a location that is upgradient of LANL Technical Area (TA)-16, and also upgradient of most of the Laboratory facility. The well does not provide the required knowledge of groundwater quality and aquifer properties because the screened interval was installed in aquifer strata with very low permeability at a depth of greater than 550 feet below the water table of the regional aquifer. In addition, the drilling of an open borehole allowed water in a perched zone of saturation to drain down the borehole to contaminate groundwater in the regional aquifer. The drilling record from the well R-26 borehole is evidence that highly permeable strata are present at a shallow depth in the regional aquifer. The need for knowledge of background water quality[23] requires the installation of a monitoring well in the strata with high permeability. An additional concern is that the elevated level of total organic carbon (TOC) in groundwater samples collected from the two screened intervals in well R-26 is evidence that the well development procedures have not been successful to remove the drilling additives that were used for drilling the borehole.

It is important to note that perched zones of saturation were present in the boreholes for wells R-4 and R-26 and the drilling of open boreholes allowed cross-flow of groundwater from the perched zones to the regional aquifer. The cross-flow is a violation of regulations of RCRA[23], NMED[20,21], DOE[1,2,3], and the New Mexico State Engineer[22]. For well R-26, the cross-flow prevented the recognition of the water table on the regional aquifer with the result that the screened interval was improperly installed at a depth greater than 550 feet below the top of the regional aquifer in aquifer strata with very low permeability.

The technical literature[5] and the guidance documents of EPA[23] are important knowledge that it was inappropriate to install characterization/monitoring wells in the regional aquifer beneath LANL in aquifer strata that are impacted by biodegradable drilling fluids, biodegradable foam, and bentonite clay drilling muds. In spite of this large body of knowledge, all of the above drilling additives were used for drilling the boreholes for the characterization/monitoring wells that were installed for the LANL Hydrogeologic Workplan. The "not representative" chemistry in groundwater samples collected from the first characterization wells[12,14] installed at LANL demonstrated the importance to avoid the invasion of aquifer strata with the drilling additives. In year 2003, a LANL report[11] predicted that the groundwater samples collected from impacted wells would not be representative of aquifer chemistry for a period as great as ten years. Much of the

contaminant chemistry in the impacted groundwater samples that are collected from the majority of the LANL characterization/monitoring wells are spurious[5,6,10] and do not meet the requirements of RCRA[23], and DOE[1] for early detection of contamination and for data to be scientifically valid and legally defensible. In light of the evidence that it was important to prevent the invasion of the aquifer strata that surround the screened intervals in the LANL characterization wells with the biodegradable drilling fluids, biodegradable foam, and bentonite clay drilling mud, it was a serious mistake for DOE/LASO to continue the installation of the wells in strata that were invaded with the drilling additives.

LANL Characterization Well R-4:

LANL well R-4 is located in Pueblo Canyon where there is a concern for radionuclide and chemical contaminants in perched zones of saturation and in the regional aquifer because of historical releases[7] over decades of liquid waste effluents into Pueblo Canyon from sources including a). the former radioactive wastewater treatment plant that was located at TA-45, and b). the former sewage treatment plant operated by Los Alamos County in upper Pueblo Canyon. The borehole for well R-4 was drilled open hole with fluid-assisted air rotary and mud rotary methods[7].

LANL characterization well R-4 is located approximately 3,800 feet northeast of Los Alamos County supply well Otowi-4. The supply well has a screen length of 1,480 feet that is installed in highly transmissive aquifer strata[19]. Otowi-4 is a high-yield well with a pumping rate of greater than 1,500 gallons per minute[18]. The locations of supply well Otowi-4 and LANL well R-4 are shown on figure 1. The figure is a map from a LANL report[19] that shows the approximate boundary of the region beneath the Laboratory facility where very large supplies of groundwater are available from a thick section of highly transmissive strata in the regional aquifer. The LANL report[19] identified the highly productive strata as the Chaquehui Formation:

> "The Chaquehui Formation is a mappable unit that occurs in the subsurface beneath the plateau. It is a trough filled with coarse sediments as much as 1500 feet thick, 3 to 4 miles wide and extending 7 to 8 miles from the northeast to the southwest. It is an important formation, containing the main aquifer of the Los Alamos area, the only aquifer capable of municipal and industrial supply. The saturated section of the Chaquehui Formation can support the development of high-yield wells. The drilling of test holes and water supply wells which penetrate the main aquifer should be performed so as to prevent contamination of this crucial resource."

It is important to note that the attached figure shows the productive aquifer strata that are important for large production of groundwater to supply wells are located beneath Pueblo Canyon where there is a record of historical releases of waste effluents that contain chemical and radioactive contaminants[7].

A perched water zone was encountered in the well R-4 borehole at a depth of 110 to 125 feet below ground surface and a deeper perched zone was observed at a depth of 226 feet below ground surface[7]. Casing was not installed in the borehole to prevent water in the perched zones from draining down the open bore hole to contaminate the regional

aquifer[7]. The failure to seal off the perched zones is a violation of EPA RCRA[23], DOE Orders[1,2,3], the NMED RCRA/HSWA Permit (Module VIII)[21], the NMED LANL Consent Order[20], and the Rules and Regulations of the New Mexico State Engineer[22].

The borehole for well R-4 was only drilled to a depth of 111 feet into the regional aquifer with a total depth in very permeable strata as shown by lost circulation and no sample recovery in the depth interval of 835 to 843 feet below ground surface[7]. The lost circulation in the strata at the bottom of the borehole was because the bentonite clay drilling mud, the borehole stabilization materials, and the drill cuttings flowed outward away from the borehole into the highly permeable strata. The lost circulation is direct evidence of strata with high permeability. The use of the mud rotary drilling method for characterization well R-4 (and many of the LANL characterization/monitoring wells) was a serious mistake. The regulations of EPA RCRA[23], NMED[20], and DOE[1,2,3] require drilling a borehole with an appropriate drilling method to determine the nature and total thickness of the highly permeable aquifer strata beneath Pueblo Canyon, and for installation of a monitoring well that will provide groundwater samples that are representative of the regional aquifer. There is consensus in the technical literature[5] that the mud rotary drilling method is inappropriate in general for monitoring wells, and specifically for drilling in aquifer strata where there is a concern for monitoring for the presence of radionuclide and metal contaminants.

An appropriate drilling method for the location of well R-4 in Pueblo Canyon is air rotary under-reamer casing advance with use of retractable drill casings[5]. A careful study of the highly permeable aquifer strata beneath Pueblo Canyon is necessary to identify the appropriate intervals for the installation of the well screens for a). contaminant monitoring, and b). the performance of pumping tests to determine aquifer properties. A single monitoring well with a screened interval that is contaminated by drilling additives does not meet the characterization and monitoring requirements for the regional aquifer in the environs of LANL characterization well R-4.

LANL characterization well R-4 is constructed with a single screen 23 feet long installed with the top of the screen located 60 feet below the water table of the regional aquifer[7]. The mud rotary drilling method invaded the aquifer strata[7] that surround the screen with large quantities of the bentonite clay drilling mud, the biodegradable polymer-based drilling fluid, the drill cuttings, and the borehole stabilization materials including soda ash and PAC-L*. The extreme difficulty to remove the invaded materials from the aquifer strata that surround the LANL characterization/monitoring wells is described in the report by Gilkeson[5]. The proof that the drilling additives were not removed from the aquifer strata that surround the well screen in well R-4 is a). the high level of TOC (4.02 ppm) that was measured in a groundwater sample[7] collected <u>after</u> termination of the well development procedures, and b). the aquifer test data[7] that show the pumping tests improved the hydraulic conductivity of the strata that surround the screened interval (i.e., the pumping tests continued the development of the well).

The high levels of TOC (total organic carbon) in the groundwater sample collected after the termination of the well development procedures are evidence that an organic fuel is available that will cause "biofouling plugging" of the screened interval. The serious chemical and physical damage that results from the "biofouling plugging" of screened intervals in monitoring wells and the enhanced properties of bentonite clay to remove radionuclide contaminants from groundwater are described in the report by Gilkeson[5]. The presence of residual drilling additives in the aquifer strata will prevent contaminant analyses on groundwater samples collected from LANL well R-4 from meeting RCRA requirements[23] for contaminant data to be scientifically valid and legally defensible.

Three pumping tests[7] were performed in well R-4 over the period of Dec.15, 2003 to Jan. 6, 2004. The data from the first two tests were invalid because of mechanical problems[7]. The mechanical problems were resolved for the third test. However, the data collected in the third test are compromised because a). the puny pumping rate of 13.9 gallons per minute did not stress the aquifer strata that have a very high transmissivity of approximately 100,000 gallons/day/foot[7], b). the data from the pumping test are invalid as the data reveal that the permeability of the aquifer strata surrounding the screened interval are partially plugged by the presence of residual drilling additives[7], and c). the early data from the pumping test are compromised by the water that was present in the well casing[7]. The collection of accurate early data is very important. The problem of the water in storage inside the well casing could have been reduced by the use of a packer to seal the well casing above the screen. However, this was not done. An additional basic problem that prevents accurate interpretation of the pumping test data is that the thickness and changes in permeability of the "package" of aquifer strata that are in open hydraulic communication for the pumping test are not known. The calculated aquifer properties[7] were based on an assumed thickness of the aquifer strata of 200 feet and an assumed unconfined storage coefficient of 0.1. The DOE well R-4 completion report[7] defends the assumed values with the statement - "<u>These values were as good as any</u>"- (Page D-11, DOE well R-4 Report). The conclusion of the aquifer testing is that the hydraulic conductivity of the strata surrounding well R-4 that are partially plugged by the drilling additives ranges from 10.1 feet/day to 250 feet/day[7].

The conclusion in this report is that the aquifer testing in characterization well R-4 does not provide valid knowledge of the thickness and permeability of the "fast pathway" strata in the regional aquifer beneath Pueblo Canyon. However, the aquifer testing reveals that the strata have a high transmissivity, and are an important groundwater resource. The lithologic description of the aquifer strata in the DOE well R-4 completion report[7] warrant an estimated hydraulic conductivity[4] greater than 100 feet/day for the strata in the depth interval of the well screen, and an even greater hydraulic conductivity for the highly permeable aquifer strata in the interval of "lost circulation" at the bottom of the R-4 borehole.

The serious mistakes by DOE concerning the installation and aquifer testing of LANL well R-4 require that this well be replaced. In addition, for the location of well R-4,

RCRA regulations[23] require that DOE investigate the presence of contamination in the regional aquifer to a minimum depth of possibly greater than 500 feet. The required depth for characterization of contamination in groundwater beneath Pueblo Canyon and for characterization of aquifer properties is not known at this time and can only be determined by drilling a deep borehole with the proper methods. The characterization to a great depth in the regional aquifer is essential because of a). the large and deep groundwater resource that is available beneath Pueblo Canyon at a location of historical release of liquid effluent wastes to environs along the floor of the canyon, and b). the great length and depth in the regional aquifer of the well screen in supply well Otowi-4.

LANL Characterization Well R-26:
The purpose[8] of LANL well R-26 is a). to further characterize intermediate-depth perched groundwater that is present at existing LANL wells R-25 and SHB-3, and b). to provide background water chemistry for perched and regional groundwater upgradient of LANL activities in the vicinity of Technical Area (TA) -16. The perched groundwater at well R-25 is contaminated with high explosives[8].

The R-26 borehole was drilled open hole using fluid-assisted air rotary and mud rotary methods[8]. A thick perched zone of saturation was present in the open borehole with the water table on the zone measured at a depth of 604.2 feet below ground surface[8]. When the borehole was advanced to a depth of 900 feet, the water table of the perched zone was measured at a deeper elevation of 611.7 feet below ground surface[8]. The deeper measurement is evidence that the confining layer beneath the perched zone was breached and the perched water was draining down the open borehole. The failure to install casing to seal the perched zone from contaminating the regional aquifer is a violation of the regulations of EPA RCRA[23], the NMED RCRA/HSWA Permit (Module VIII)[21], the NMED LANL Consent Order[20], the Rules and Regultion of the New Mexico State Enginer[22], and the DOE Orders[1,2,3].

The R-26 borehole was drilled to a depth of 1000 feet below ground surface with fluid-assisted air rotary methods. However, an unstable borehole at this depth required changing the drilling method to mud rotary[8]. The attempt to start drilling with the mud rotary method in the open borehole was not possible because the bentonite clay drilling mud and borehole stabilization materials were flowing out into the highly permeable aquifer strata. To prevent the lost circulation, retractable drill casing was installed in the open borehole to a depth of 1005 feet[8]. Mud rotary open borehole methods were then used to drill from 1005 feet to the total depth of 1,490.5 feet below ground surface. The borehole was drilled to this depth because the top of the regional aquifer was predicted to be at a depth of 1,314 feet below ground surface[8]. In reality, the top of the regional aquifer is at a much shallower depth of 865 feet below ground surface. The top of the regional aquifer was not identified during drilling activities because the open borehole was flooded with water from the perched zone of saturation. The static water level of 865 feet below ground surface[8] was measured after the well screen was installed in the regional aquifer over the depth interval of 1,421.8 feet to 1,445 feet below ground

surface. The top of the screen was installed at a depth of 557 feet below the water table on the regional aquifer.

An aquifer test in the screened interval in LANL well R-26 that was installed deep in the regional aquifer determined a very low permeability of 0.0022 feet per day[8]. The borehole log describes the strata in the regional aquifer at the depth of the well screen as silty, poorly sorted fine sand. Strata with this description have a low permeability[4], and at well R-26 an even lower permeability because they were invaded with the drilling additives.

It is important to realize that the great loss of bentonite clay mud and borehole stabilization materials into the aquifer strata at the depth of 1,000 feet below ground surface (a depth of 135 feet below the water table) is evidence that the strata at this depth in the regional aquifer have a high permeability. The R-26 borehole log[8] describes the strata in the depth interval of 1000 feet to 1025 feet below ground surface as well-sorted coarse sand (SP). The sediments warrant an estimated hydraulic conductivity[4] greater than 100 feet/day. The permeable layer of coarse sand overlay a 50-foot thick confining layer of sediments with very low permeability that are described as silty, clayey sand[8]. The presence of the confining layer is supported by the Schlumberger* geophysics performed in the open borehole[8]. The confining layer will prevent downward flow of groundwater that has recharged the regional aquifer. For the location of well R-26, there is a need to install a monitoring well in appropriate strata above the confining layer.

LANL well R-26 is a multiple-screen well with two screened intervals. The discrete screened intervals are installed in both the thick, perched zone of saturation and deep in the regional aquifer. The open borehole and the multiple-screen well allowed downward flow of water from the perched zone to invade deep into the regional aquifer. The essentially identical geochemical data for water samples collected from the perched zone and the regional aquifer is evidence of contamination of the regional aquifer by water from the perched zone[8]. Unfortunately, the DOE report for well R-26[8] does not recognize that the analytical data for the groundwater sample collected from the regional aquifer are spurious because of cross-contamination. A Westbay* sampling system is installed in the multiple-screen well[8]. With the Westbay* sampling system, groundwater is not purged from a screened interval before samples are collected for the analytical suite. The concerns with the methods used by LANL to collect water samples from the multiple-screen wells are described in the report by Gilkeson[5].

The TOC concentrations in the groundwater samples collected from the two screened intervals in LANL well R-26 are elevated above background which indicates the presence of residual biodegradable drilling additives in the strata surrounding the screens. Over time, there is potential for the process known as "biofouling plugging" to damage the geochemical and physical properties of the screened intervals. The biofouling plugging process has caused damage to many of the LANL characterization wells[5,6,10]. In addition, the screened interval installed in the regional aquifer at well R-26 is surrounded by strata that are invaded with bentonite clay drilling mud.

LANL well R-26 does not provide the necessary background data for the regional aquifer. The unexpectedly high water table on the regional aquifer at the location of well R-26 indicates local recharge to the regional aquifer and is evidence of the need to install monitoring wells to characterize the groundwater at a). the top of the regional aquifer, and also b). in the strata with high permeability located at a depth of 135 feet below the water table on the regional aquifer. A requirement of monitoring wells that are installed for characterization of background water quality[23] is that the wells are installed in the permeable aquifer strata that comprise the active groundwater flow system and not in strata with very low hydraulic conductivity such as the strata located deep in the regional aquifer where screen no. 2 is installed in LANL well R-26[8]. The need for one or two monitoring wells installed in the regional aquifer at the location of well R-26 will not be understood until proper methods are used for drilling a borehole into the regional aquifer.

LANL Characterization Well R-34:
LANL well R-34 is located on property of San Ildefonso Pueblo as a monitoring point for the regional aquifer[9] approximately midway between LANL wells R-13 and R-22. Well R-22 is located immediately east of Area G, the active disposal facility at LANL for landfill disposal of low-level radioactive wastes. Contaminants detected in screened intervals that are installed deep in the regional aquifer at well R-22[14] include tritium, technetium-99, SVOC's, and VOC's. Problems with the installation of well R-22 that prevent accurate characterization of the nature and extent of contamination in the regional aquifer beneath Area G are described in the two reports by Gilkeson[5,6].

The potential contaminants[9] being investigated in the regional aquifer at the location of characterization/monitoring well R-34 include radionuclides, metals, nitrate, perchlorate, chloride, sulfate, fluoride and excessive Total Dissolved Solids (TDS). The drilling of the open borehole for well R-34 was with the fluid-assisted air rotary drilling method[9]. The borehole was stabilized with biodegradable polymer-based drilling fluid (Baroid EZ-MUD*) and biodegradable foam (Baroid QUIK FOAM*). The properties of the drilling additives to mask the detection of contaminants in groundwater are well understood in the monitoring well industry[5] and confirmed by LANL reports[10,16]. The use of the drilling additives was inappropriate for the contaminants of concern at the location of well R-34.

The open borehole for well R-34 was drilled to a total depth of 1,065 feet below ground surface. A single-screen well was installed in the regional aquifer with a screen length of 22.9 feet in the depth interval of 883.7 feet to 906.6 feet below ground surface[9]. The water table at the top of the regional aquifer is at a depth of 796 feet below ground surface. The lithologic record for the strata in the regional aquifer is poor because of the poor recovery of drill cuttings[9]. However, the Totavi Lentil river gravel sediments are interpreted[9] to be present in the depth interval of 1,050 feet to 1,065 feet, the total depth of the borehole. It is unfortunate that the borehole did not characterize the thickness and properties of the Totavi Lentil River gravel sediments as these highly permeable sediments are known to be present in the regional aquifer beneath Area G[6,15]. The highly

permeable river gravel strata are strata where contamination is likely to be present and a "fast pathway" for travel of contaminated groundwater.

A pumping test was performed in LANL well R-34. However, the large fluctuations in the production of water by the pump[9] is direct evidence of the presence of a very large volume of drill air, and biodegradable drilling foam entrained into the aquifer strata. It is important to note that there was lost circulation[9] of the drill air, biodegradable drilling fluid, and biodegradable foam during drilling through the depth interval of 845 feet to 1065 feet below ground surface, the total depth of the borehole. The presence of drill air and drilling additives in the aquifer strata blocks the effective porosity of the strata and artificially causes a large reduction in the permeability of the strata. The erratic and interrupted flow of water during the pumping test[9] is direct evidence of blockage of aquifer permeability by the entrained drilling air and drilling foam. The anomalously low hydraulic conductivity value determined by the pumping test of 3.6 to 6.0 feet per day[9] is spurious and should not have been published. The lost circulation of the drill air and drilling additives over a great reach in the regional aquifer is direct evidence that the regional aquifer in the region of well R-34 has a high permeability, a high transmissivity, and is an important groundwater resource. The total thickness of the productive strata in the regional aquifer is not known.

The groundwater sample that was collected from well R-34 contains an elevated concentration of TOC[9]. The invasion of a large volume of drill air and the biodegradable drilling additives deep into the regional aquifer are a recipe for great damage to the geochemistry and physical properties of the aquifer strata by the process known as "biofouling plugging". This process is described in the Gilkeson report[5]. The chemical changes caused by the biofouling plugging process may prevent the detection of many contaminants of concern in groundwater for the location of well R-34.

The RCRA regulations[23] require that the aquifer strata in the region of LANL well R-34 are characterized to a minimum depth that includes the strata beneath the Totavi Lentil River gravels. The groundwater resources beneath San Ildefonso Pueblo are the property of the Pueblo and DOE is required to accurately investigate the presence of contamination in the valuable groundwater resource from waste disposal practices at LANL. LANL well R-34 does not satisfy the requirement of DOE to assure San Ildefonso Pueblo that waste disposal practices at LANL have not damaged the Pueblo's groundwater resources. There is a need to replace LANL well R-34 with a minimum of two monitoring wells installed in the regional aquifer. One well shall be installed in the permeable strata near the top of the regional aquifer. The second well shall be installed at an appropriate depth in the Totavi Lentil river gravel strata. A third well may be required if strata with high permeability are present beneath the Totavi Lentil river gravels. The boreholes for the wells shall be drilled with methods that do not invade the regional aquifer with biodegradable polymer-based drilling fluids, biodegradable foam, or bentonite clay drilling mud. DOE has a requirement to install monitoring wells for San Ildefonso Pueblo to a). accurately investigate the nature and extent of contamination in

the regional aquifer beneath Pueblo land, and b). accurately monitor for contamination in the future.

San Ildefonso Pueblo owns property immediately east of Area G at a location that is downgradient of Area G for flow of groundwater in the regional aquifer. On the map in Figure 2, Area G is displayed as MDA G, and San Ildefonso Pueblo is located north and east of the LANL TA-54 Boundary. The detection of radionuclide and chemical contamination in well R-22[14] at a location immediately east and downgradient of Area G requires the installation of monitoring wells on San Ildefonso Pueblo a). for a careful investigation for the presence of chemical and radioactive contaminants in the regional aquifer, and b). to monitor for contamination in the future.

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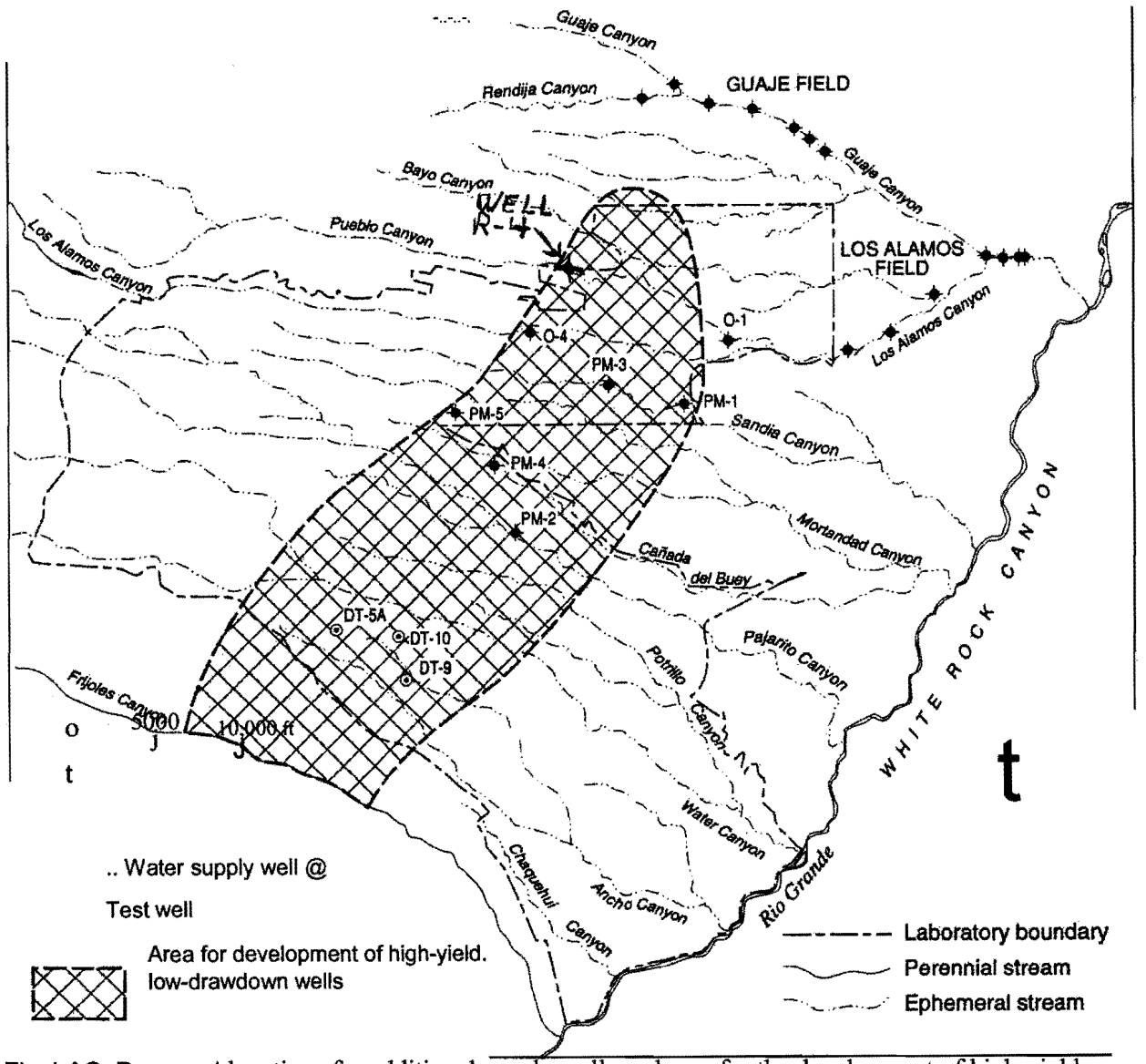

Fig. I-AG. Proposed locations for additional supply wells and area for the development of high-yield, low-drawdown wells (Purtymun 1984).

Figure from *"Geologic and Hydrologic Records of Observation Wells, Test Holes, Test Wells, Supply Wells, Springs, and Surface Water Stations in the Los Alamos Area" by W. D. Purtymun,* Report LA-12883-MS, January, 1995. Los Alamos National Laboratory, Los Alamos, New Mexico

Figure 1. The approximate boundary of the region beneath the Laboratory facility where very large supplies of groundwater are available from a thick section of highly transmissive strata in the regional aquifer. The strata are the Chaqquehui Formation. The figure shows the location of LANL characterization well R-4.

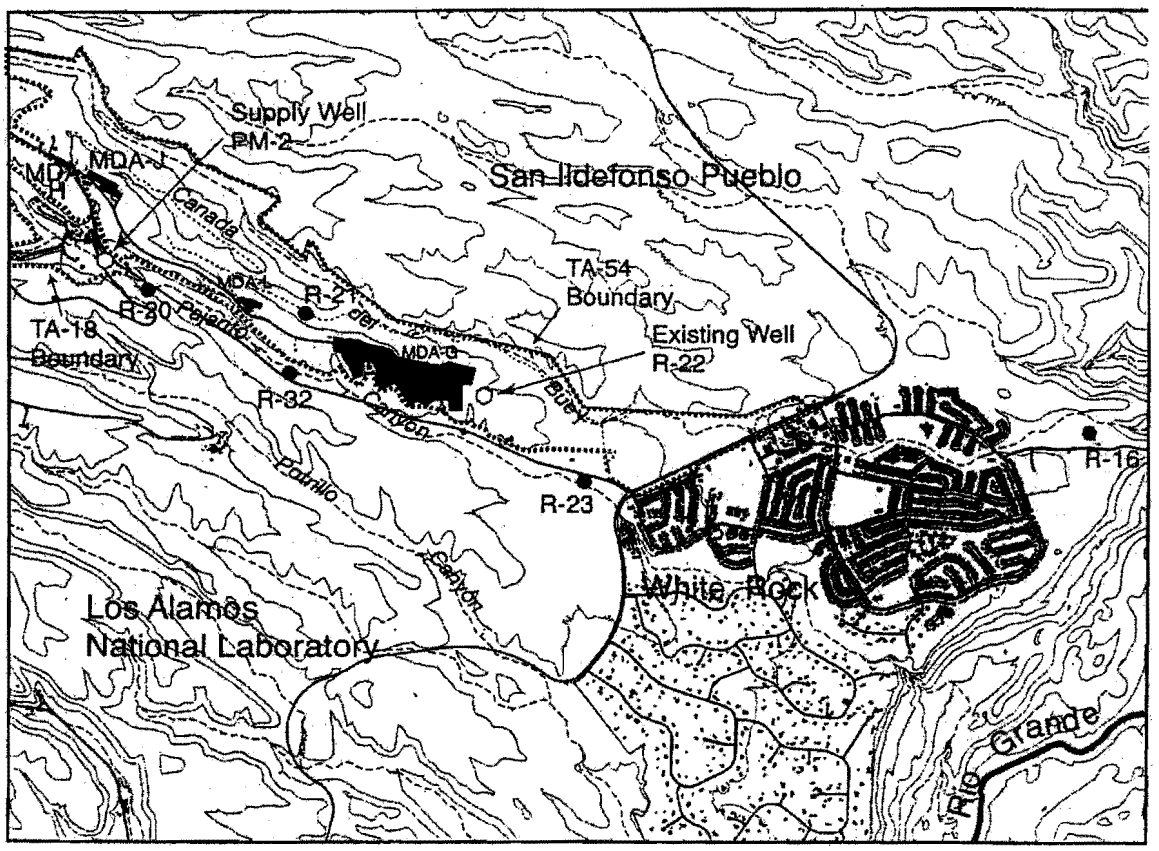

Figure 2. LANL characterization wells in the vicinity of MDA G. The wells include R-16, R-20, R-21, R-22, R-23, and R-32.