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memorandum

Environmental Stewardship (ENV)
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SUBJECT: DISTRIBUTION OF REPORT "ANALYSES OF THE PM-4 AQUIFER TEST USING MULTIPLE OBSERVATION WELLS"

Enclosed please find a copy of the report by Stephen McLin entitled "Analyses of the PM-4 Aquifer Test Using Multiple Observation Wells." This report contains work completed under the Pathways Protection Program.

If you have any questions, please contact Stephen McLin at 665-1721 (sgm@lanl.gov) or me at 665-3935 (asimmons@lanl.gov).

Enclosure: "Analyses of the PM-4 Aquifer Test Using Multiple Observation Wells" (LA-14252-MS)

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Analyses of the PM-4 Aquifer Test Using Multiple Observation Wells

Stephen G. McLin

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ANALYSES OF THE PM-4 AQUIFER TEST USING MULTIPLE OBSERVATION WELLS

by

Stephen G. McLin

ABSTRACT

A 21-day aquifer test was conducted at municipal water supply well PM-4 at a constant discharge rate of 1,494 gpm. This pumping interval was immediately followed by a 21-day recovery period. Surrounding observation wells were used to record both drawdown and recovery. These data reveal horizontal propagation of drawdown in the regional aquifer beyond 8,700 ft from PM-4, and a pronounced resistance to vertical drawdown propagation at shallower depths. Hydraulically, the regional aquifer behaves like a leaky-confined aquifer with leaky units located above a highly conductive layer that averages about 850 ft in thickness. Classical distance-drawdown and fully confined aquifer behavior of early-time drawdown data (i.e., less than 4 days) from individual observation wells suggest that the highly conductive layer in the regional aquifer between wells PM-4 and PM-2 has a transmissivity of about 6,451 ft^2/day and a storage coefficient of about 0.00039. The corresponding hydraulic conductivity is about 7.6 ft/day. The aquifer thins between wells PM-4 and PM-5 to an effective thickness of about 490 ft, but the aquifer transmissivity increases to about 6,817 ft^2/day, and the storage coefficient increases to about 0.00046. The corresponding hydraulic conductivity near PM-5 is about 13.9 ft/day. Comparisons of late-time drawdown data (i.e., greater than 4 days) using leaky-confined aquifer models suggest that there is a gradual transition from confined to leaky-confined behavior. These observations provide estimates for aquifer leakage factors.

This test has also demonstrated that regional aquifer materials below the central portions of Pajarito Plateau are strongly heterogeneous, and exhibit pronounced horizontal and vertical anisotropy in hydraulic transmitting properties. An idealized radius of influence about 8,700 to 10,500 ft long extends outward from well PM-4, including portions of the regional aquifer below Mortandad Canyon. Numerous observation wells inside this radius respond to both PM-4 and PM-5 pumping influences. These data also suggest that two competing conceptual models can represent the regional aquifer. First and most likely, aquifer drawdown data suggest a traditional leaky-confined aquifer model is appropriate. Here leaky source beds in the regional aquifer are located above a highly conductive layer of variable thickness that extends between R-20 screen 3, PM-2, PM-4, PM-5, and R-14. A second possibility is that the regional aquifer behaves like a leaky-confined model because it contains interbedded layers of alternating high and low hydraulic conductivities that are sandwiched together into a high-yielding zone. In this second model, the overlying units at the top of the regional aquifer may not be a significant source of water to the municipal supply wells. This second conceptual model requires the low-conductive layers within the alternating sequence to be leaking into the adjacent high-conductive layers. These competing interpretations cannot be resolved without additional, deep, multiple-screened observation wells located near wells PM-4 and PM-5 that characterize vertical leakage between adjacent layers within the regional aquifer. These parameters are important because they provide experimental measurements of aquifer responses to controlled aquifer stresses. They also partially fulfill requirements for aquifer parameter identification that support model verification studies.

I. INTRODUCTION

Purpose and Scope

A long-term aquifer test was conducted at municipal water supply well PM-4 during February and March of 2005. This test consisted of a 21-day pumping interval followed by a 21-day recovery period. Both drawdown and recovery data were collected at PM-4 and numerous observation wells. The purpose of this aquifer test was the experimental determination of regional aquifer parameters that characterize the saturated porous media below Pajarito Plateau. This test consisted of pumping PM-4 at a constant discharge rate and observing water level changes in both the pumping and surrounding observation wells. Charles Theis (1935) first introduced the theoretical response of an ideal, confined aquifer to pumping while he was with the US Geological Survey's district office in Albuquerque, New Mexico. Using an analogy between two-dimensional (2-D) heat and water flow, he developed an analytical solution to the governing partial differential equation that related drawdown to aquifer transmissivity (T) and storage coefficient (S). Here T represents the rate of flow to a pumping well in gallons per minute through an imaginary, vertical cross-section of aquifer material one foot wide and extending the full saturated thickness of the aquifer that is subjected to a hydraulic gradient of one. Today T is commonly expressed in equivalent units of length squared per unit time (L^2/T). Hydraulic conductivity (K) is determined by dividing T by the aquifer thickness (b). Values for T and K are important because they define how the aquifer will respond to stress (e.g., pumping, natural discharge, or recharge). In addition, S is defined as the volume of water yielded to a pumping well per unit area of saturated aquifer material per unit decline in water level. As such, S is dimensionless. Specific storage (S_s) is determined after dividing S by b, and has units of inverse length. Aquifer parameters like T and S were originally developed for confined aquifer conditions assuming radial, 2-D, horizontal flow. However, in complex three-dimensional (3-D) groundwater representations, it is often best to use the parameters K and S_s because the influence of b has been removed. The primary objective of this report is to determine values for the aquifer parameters T, K, b, S, and S_s using test data obtained from both the pumping well and numerous observation wells.

A secondary objective of this aquifer test was to characterize aquifer heterogeneity and anisotropy in the regional aquifer. Heterogeneity is demonstrated when aquifer parameters change from well to well. Anisotropy simply means that parameter values may be directionally dependent. For example, hydraulic conductivity at one location may have different horizontal (K_h) and vertical (K_v) values, and the ratio (K_h/K_v) between the two may vary from point to point. Typically, $K_h \geq K_v$ for most aquifer materials. Directional variations in K_h would be revealed by an elliptically shaped cone of depression rather than a circular one. This cone expands laterally outward from the production well in response to pumping and requires at least two observation wells at different locations to verify the elliptical shape. Horizontal anisotropy is important because it reveals preferential water movement toward the well more easily in one horizontal flow direction than in another. Similarly, variations in K_v would be revealed by different drawdown values recorded in adjacent observation wells (or nested piezometers) completed at different vertical depths in the aquifer. Vertical anisotropy is important because it says that water generally moves more easily in the horizontal direction than in the vertical direction (i.e., parallel to sedimentary bedding planes rather than perpendicular to them). In addition, understanding vertical hydraulic communication (i.e., leakage) between adjacent units depends on knowing something about K_v for individual geologic units.

A third and final objective was to run the aquifer test long enough so that the cone of depression could expand radially outward to intersect any potential recharge or barrier boundaries that might be present. These boundary effects would typically be revealed by the differences between measured drawdown in an observation well and idealized drawdown predicted at the same time and location using an appropriate analytical aquifer model (e.g., the Theis confined aquifer model represented by the Theis type curve).

These aquifer parameters are important because they provide experimental measurements of aquifer responses (i.e., drawdown and recovery) to controlled aquifer stresses (i.e., pumping). These aquifer parameters can then be used in numerical models to simulate aquifer behavior and test the validity of alternative conceptual models. Once verified, these models can be used to simulate complex aquifer behavior (i.e., anisotropy, leakage, or potential contaminant transport) with confidence or to test alternative geometric configurations in the model or physical-chemical processes affecting potential contaminant transport. They can also be used to identify data gaps where additional aquifer tests might be helpful or to evaluate alternative aquifer monitoring configurations. Ultimately, this aquifer test partially fulfills requirements for aquifer parameter identification that can be used for model verification studies.

Hydrogeologic Setting

Municipal water supply well PM-4 was completed on Mesita del Buey in 1981 (Purtymun 1995), at a depth of 2,874 ft below ground surface (ft bgs). This well is located on the north side of Pajarito Road, approximately 3.25 miles northwest of White Rock (see Figure 1) and near the Technical Area 54 (TA-54) entrance. A number of monitoring wells (or R-wells) have also been installed over the past seven years as part of the Hydrogeologic Workplan (LANL 1998) in support of the Groundwater Protection Management Program (LANL 1996). Most of these wells are located in the central portions of Pajarito Plateau and also penetrate into the regional aquifer. This regional aquifer is the only source of potable drinking water for Los Alamos County, Los Alamos National Laboratory, and Bandelier National Monument. Historically, the highest yielding water supply wells have penetrated into relatively thick sequences of the Puye fanglomerate (Griggs 1964; Purtymun and Stoker 1988) where axial deposits of ancestral Rio Grande gravels (i.e., the Totavi Lentil of Griggs) are commonly encountered. Locations of these and older high-yielding formations are generally defined according to the location of a Miocene trough as seen in Figure 1. Although the areal extent of this trough has not been completely defined along the northern, western, and southern portions of the plateau, it has been clearly identified in numerous R-wells in the central plateau region where PM-4 is located. This trough has been described by numerous authors (e.g., Broxton and Vaniman 2005; Broxton and Reneau 1996; and Purtymun and Stoker 1988).

Figure 1 also shows the location of geologic cross-section A-A′ that runs west-to-east across Pajarito Plateau and just south of well PM-4. This geologic section is shown in Figure 2 and is based on recent work by Broxton and Vaniman (2005). This cross-section is important because it shows a complex regional aquifer that includes westward thickening, coarse-grained, alluvial fans derived from the Jemez Volcanic field that accumulated in the western part of the Española Basin. These volcanogenic alluvial fans overlie thick, finer-grained, piedmont-slope deposits derived from distal sources on the east side of the Española Basin. Historical information for the regional aquifer below Pajarito Plateau was previously described (Cushman 1965; Griggs 1964; Theis and Conover 1962).

Figure 3 shows an enlarged area surrounding well PM-4 where numerous observation wells are located. Figure 3 also shows an idealized radius of influence, or maximum extent of measured drawdown, that was observed in the 21-day aquifer test at PM-4. This radius is idealized because one must assume homogeneous and isotropic aquifer properties that generate concentric circles of equal drawdown in response to pumping at a constant rate.

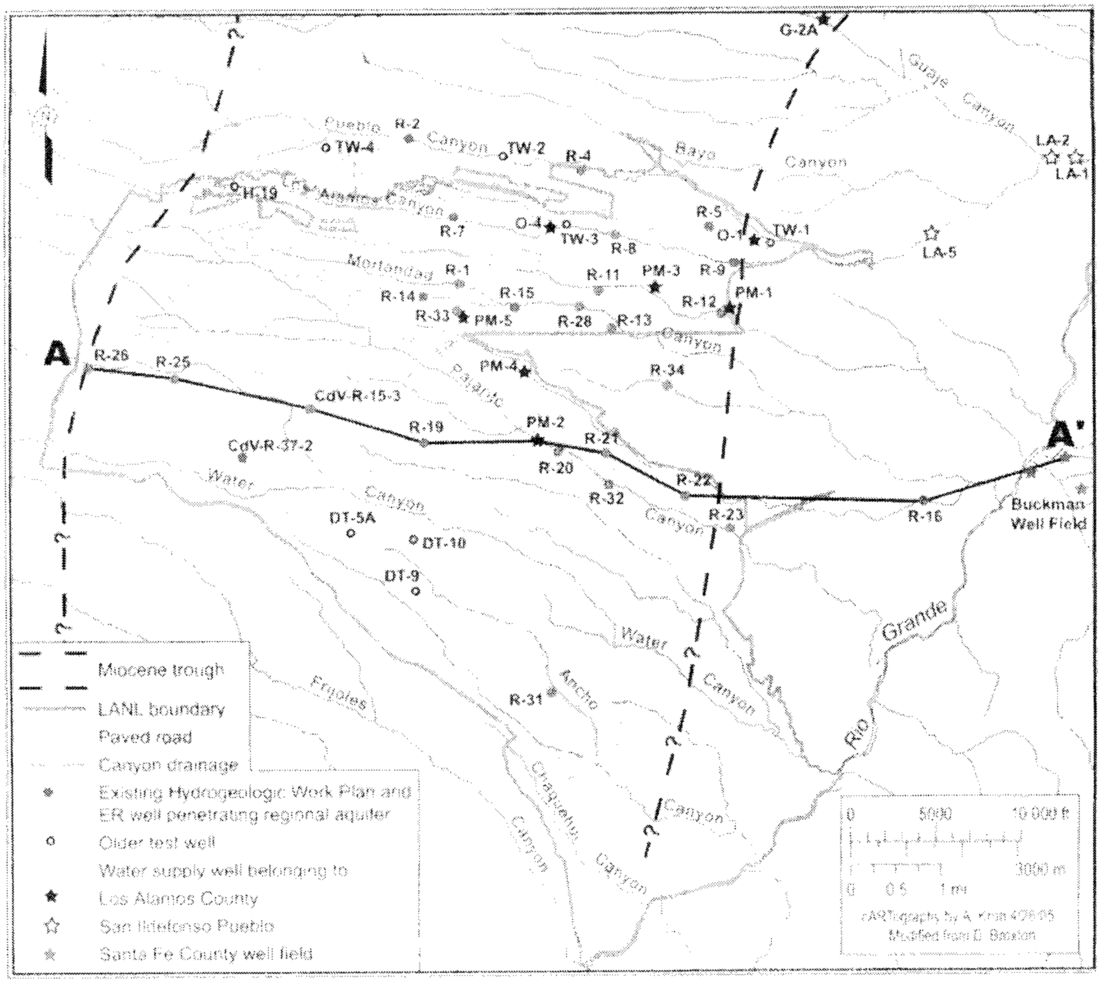

Figure 1. Location of wells on Pajarito Plateau. Note the location of geologic cross-section A-A′.