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SUBSURFACE TEMPERATURE LOGS IN THE VICINITY OF TAOS, NEW MEXICO

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INTRODUCTION

Temperature logs (T logs) measure temperature as a function of depth in wells. Temperature logging technique, equipment, and interpretation methodology are described in Reiter et al. (1980) and Reiter (2001). The variation of rock thermal conductivity can affect the T log profile, but because we do not know the thermal conductivity of the rocks along the bore hole wall, we consider only the most pronounced T log characteristics which suggest the influence of ground water flow. In a subsurface environment of constant thermal conductivity, characterized by only conduction heat transfer, the temperature profile with depth (T log) is a straight line. Both surface temperature change and ground water flow can perturb the temperature depth profile. The movement of ground water along faults, fractures, thin layers, and within the borehole is usually observed as abrupt changes in the T log. Vertically downward flow and cooling sub-horizontal flow, over tens of meters depth, will produce a concave upward curvature in the T logs; whereas, vertically upward flow and warming sub-horizontal flow over tens of meters depth will produce a convex upward T log. Surface temperature change can also produce curvature in the T log which is most profound near the surface; these effects are not obvious at the Taos sites. Quantitative analysis of T logs to estimate ground water flow characteristics typically assumes steady state conditions below the water table, a reasonable approximation in many areas (Reiter, 2001).

Subsurface temperatures (T logs) were measured in wells at eight sites in the vicinity of Taos, New Mexico, in 2001 and 2002 (Figure 1). From these T logs (Figures 2 and 3) several characteristics regarding the hydrogeology of the area may be suggested.

T LOG DATA

There are several trends noted in the T log data in Figures 2 and 3 for the eight well sites depicted on Figure 1.

1) At BOR 4 the convex upward curvature in the T log from ~280 m to ~410 m depth suggests upward or warm sub-horizontal ground water flow across the depth interval.

2) A somewhat less noticeable zone, but similar in character, appears in the T log from the **Taos Airport** site, from ~160 m to ~240 m depth.

3) The very high temperature gradient above 250 m depth at the **BOR 7** site suggests cool ground water flow near the well water surface, with possible upward flow from depth to ~250 m and/or a zone of warm sub-horizontal ground water flow at ~250 m depth.

4) The two discontinuities in the T log at **BOR 5** indicate a zone of cool sub-horizontal water flow at about 200 m depth and cool sub-horizontal flow or down flow at ~450 m depth. The bottom flow interval is screened.

5) At the **K 3** site the well is screened below ~250 m to near the bottom of the well. Because of the very low gradient shown in the T log it appears that ground water is flowing down the well, entering the well at ~250 m and leaving the well near the bottom. This flow suggests a downward hydrologic gradient.

6) A convex upward T log profile is noticed for **BIA 6** from ~120 m to ~230 m depth which indicates up flow or warm sub-horizontal flow.

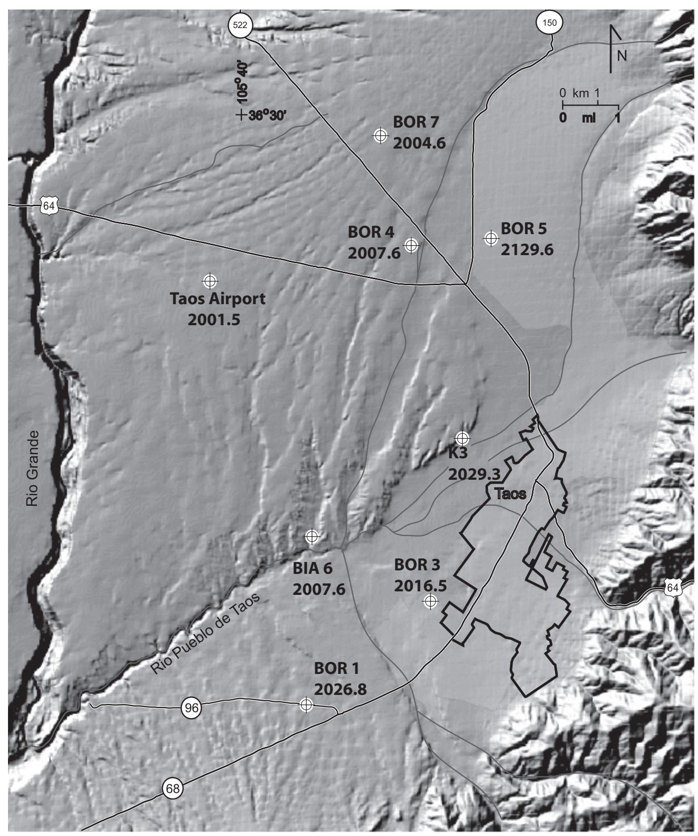

FIGURE 1. Location of wells logged within the study area. Numbers beside wells indicate water elevation in the well in meters. Note these numbers do not necessarily relate to the unconfined ground water table elevation. Tributaries of the Rio Grande and Rio Pueblo de Taos are denoted by gray lines.

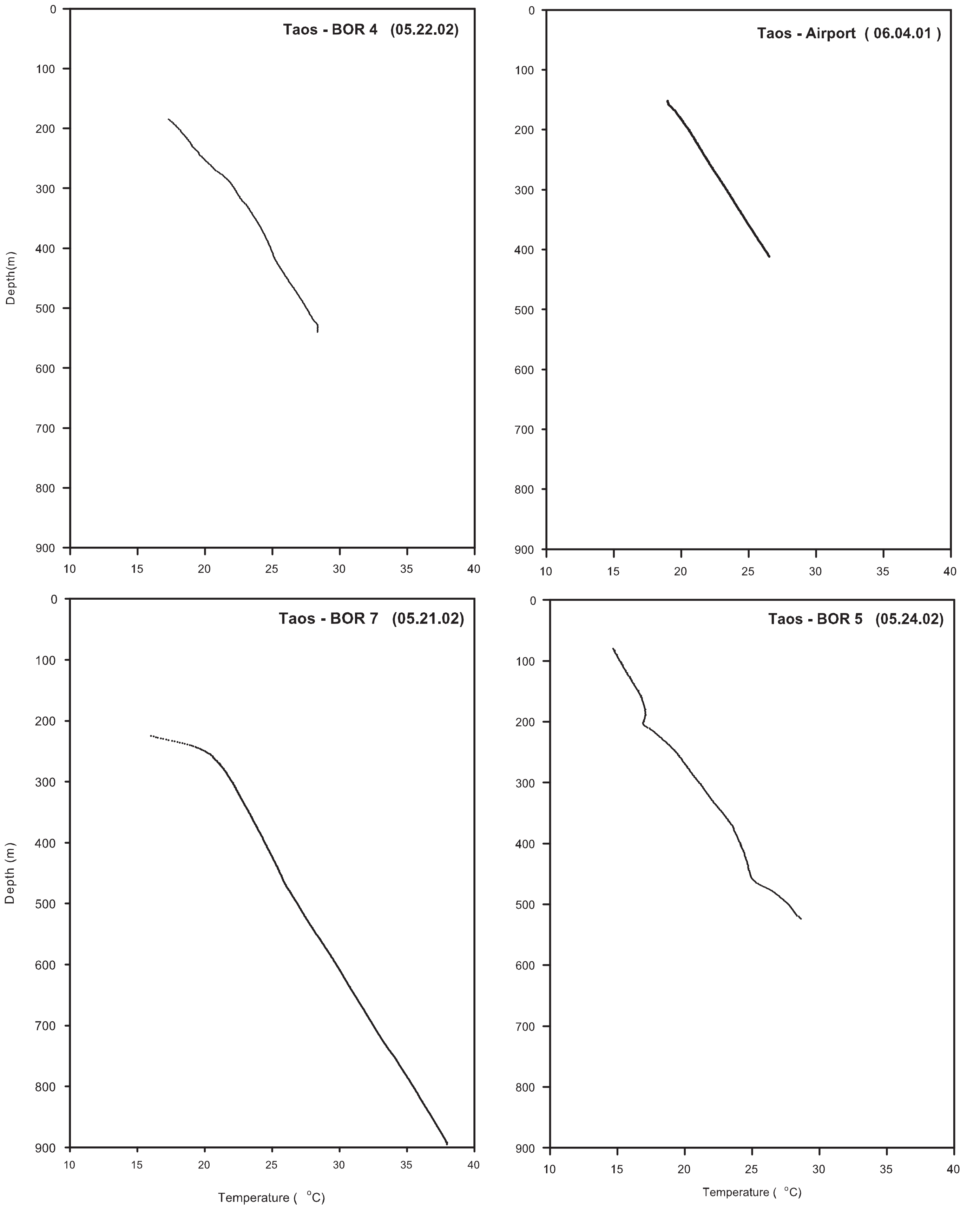

FIGURE 2. T logs for wells at sites BOR 4, Taos Airport, BOR 7, and BOR 5. Note all temperature data are taken in water. Note: 3.28 ft = 1 m. Date of temperature log in parentheses.

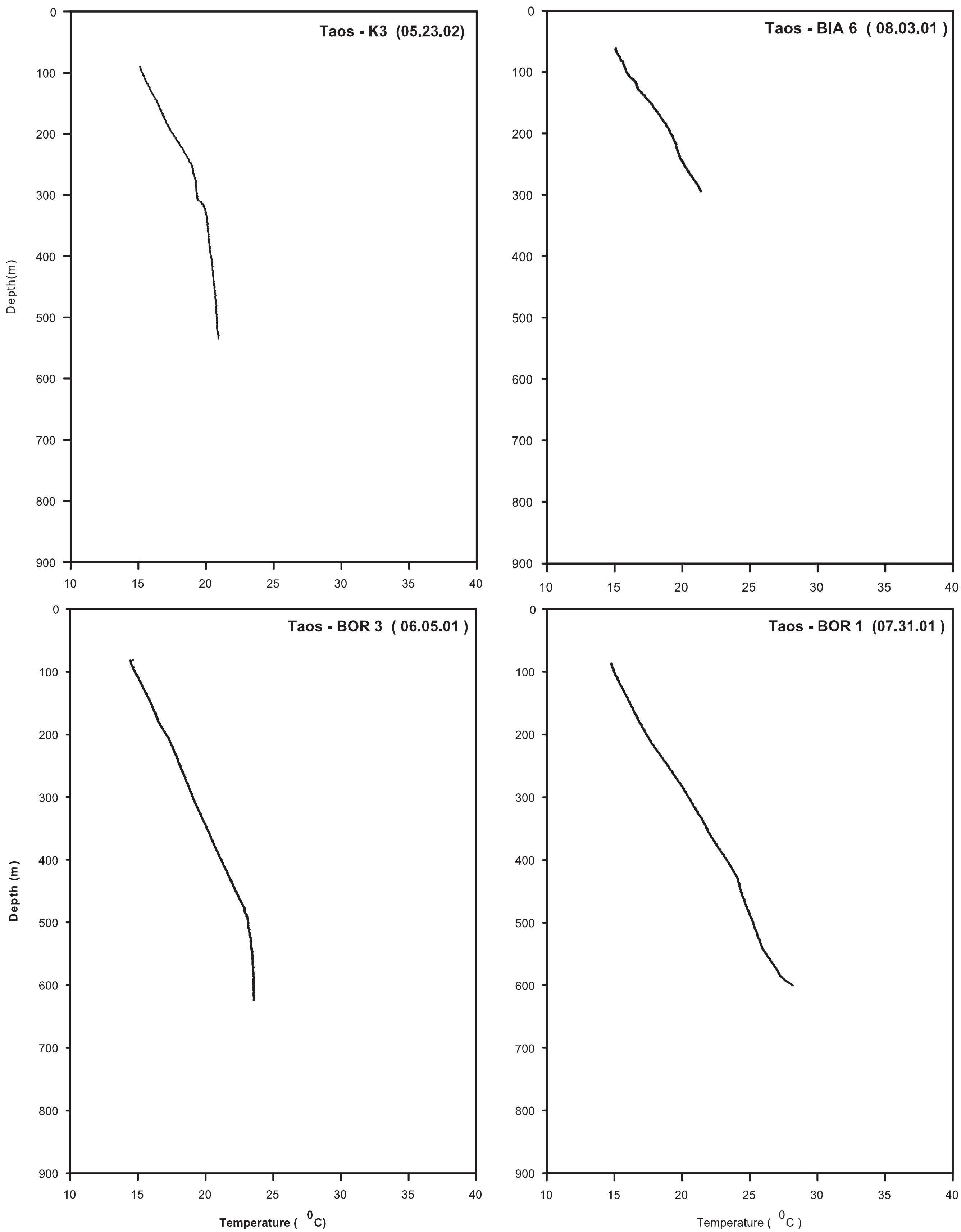

FIGURE 3. T logs for wells at sites K 3, BIA 6, BOR 3, and BOR 1. Note all temperature data are taken in water. Note: 3.28 ft = 1 m. Date of temperature log in parentheses.

7) At the **BOR 3** site the low temperature gradient below ~480 m depth suggests water is entering the well near the top of the screens and leaving near the bottom of the well.

8) At the **BOR 1** site the concave upward curvature in the T log below ~420 m indicates possible down flow in the formation, and/or cool sub-horizontal ground water flow, likely complemented with vertical downward flow in the well along the depth of the screens below 420 m.

HYDROGEOLOGIC INTERPRETATIONS

Beginning in the northeastern part of the study area, it appears that the BOR 5 site is hydrogeologically separated from the BOR 4 and BOR 7 sites (Figure 1). The cool sub-horizontal flow and down flow at BOR 5 are not observed at nearby sites BOR 4 and BOR 7 (within ~2 – 4 km). The warming trend noticed at site BOR 4 is unlikely to be derived by flow from BOR 5 because of the cooler ground water temperatures at BOR 5. We suggest ground water flow from BOR 5 to BOR 4 and BOR 7 is restricted, possibly by a sealed fault that is relatively impermeable to ground water flow. This suggestion is supported by the very large difference in the well water elevations between BOR 5, and BORs 4 and 7 (Figure 1), about 122 m over ~2-4 km (e.g., Haneberg, 1995). Paul Drakos (written communication, 2004) suggests a fault between BOR 4 and BOR 7 with 200 m – 300 m offset.

Between the BOR 4 and the BOR 7 sites, the relatively small difference in the elevation of the well water (~3 m over ~3 km distance) suggests that these two sites are not as hydrologically disconnected with each other as with the BOR 5 site (Figure 1). However, the T logs suggest a less than straightforward hydrologic relation between the BOR 4 and BOR 7 sites. The character of the T logs from the two sites is notably different between depths of ~210 m to ~350 m. The likelihood of cool groundwater flow near the top of the water in well BOR 7 may result from more immediate mountain recharge. The temperature near the well water surface at BOR 7 is about 1.4°C cooler than the equivalent temperature at BOR 4. Slightly higher temperatures in BOR 7 than in BOR 4, at equivalent depths below the well water surface, could warm the interval from ~280 m to ~410 m depth at BOR 4 with flow from BOR 7. This flow direction would be contrary to the flow direction one might initially expect from water elevations in the wells (Figure 1); although the two sites may well be cross-gradient sites without flow occurring between the sites. It should also be noted that water elevations in the wells result from screened intervals at depth and may not represent the same formations or the unconfined water table elevation. Therefore the sub-horizontal flow direction is uncertain. The temperature logs suggest some type of hydrogeologic disconnect between the BOR 4 and BOR 7 sites.

The BOR 4 and BIA 6 sites appear to have the same well water elevation. At the Taos Airport site, water well elevation is ~6.1 m lower than the well water elevation at BOR 4; however, the two sites are likely separated by one or more of the Los Cordovas faults having 20 m - 30 m offset (Paul Drakos, written communication, 2004). If the curvature in the T logs of BOR 4, BIA 6, and the Taos Airport site result from a sub-horizontal warming ground water flow, it is presently uncertain how this flow occurs. The well water at the Taos airport site is about 4°C warmer than the well water at the BIA 6 site; this difference in temperature can be attributed to the difference in the depth to water. The surface of the well water at the Taos Airport site is also about 2°C warmer than the surface of the well water at BOR 4; although the two site temperatures become nearly equal at ~90 m to ~100 m below the well water surface. Presently, the limited and ambiguous ground water elevation data, and the limited subsurface temperature data, appear uncomplimentary in determining flow characteristics for the area. It is not clear how the warming trends noticed at the BOR 4, Taos Airport, and BIA 6 sites occur. Piezometric data from different depths at different locations will be valuable in determining both vertical flow directions and sub-horizontal flow patterns.

The well water elevation at site K3 is about 21.7 m higher than the well water elevation in the well at site BIA 6. The temperatures near the surface of the well water in the two wells are about the same, with temperatures at BIA 6 becoming about 1°C greater than temperatures at site K3 about ~120 m below the surface of the well water. Comparison of temperatures and the T log curvature are not complementary to a possible flow direction suggested by the difference in the elevation of well water in the wells at the two sites (Figure 1), although the well water levels at the different locations may come from different formations at different depths. The T logs suggest that the flow at BIA 6 does not come from the K3 site.

The sites at BOR 1 and BOR 3 are separated from the other well sites in the study by the Rio Pueblo de Taos. Ground water temperatures at BOR 3 are cooler than temperatures at BOR 1, which might result because of different rock thermal conductivity or a more direct influence of mountain recharge. Both of the wells are screened over long depth intervals. BOR 3 is screened starting at ~480 m depth and BOR 1 is screened starting ~425 m depth. Vertical downward flow is noted in both of these wells from the T logs.

CONCLUSIONS

The hydrogeologic disconnect between well sites, as suggested by the T logs, implies the hydrogeology of the Taos Plateau is quite complex. The region may well be divided into hydrogeologic cells by numerous high-angle faults acting as both seals and pathways for ground water flow with three-dimensional variability. The hydrologic interaction between these cells is likely to be variable. The relatively few temperature logs, and the limited ground water elevation data, limit interpretation of the sub-horizontal ground water flow pattern. To better understand the hydrogeology in the region a number of piezometer sites are needed to define both vertical and sub-horizontal ground water flow patterns. From the temperature data one can say it is very likely that hydrogeologic disconnects exist between BOR5, BOR 4, and BOR 7. We can also say the ground water flow over the screened intervals at sites K 3, BOR 1, and BOR 3 is downward. The data suggest that the wells are not simply connected hydrogeologically.

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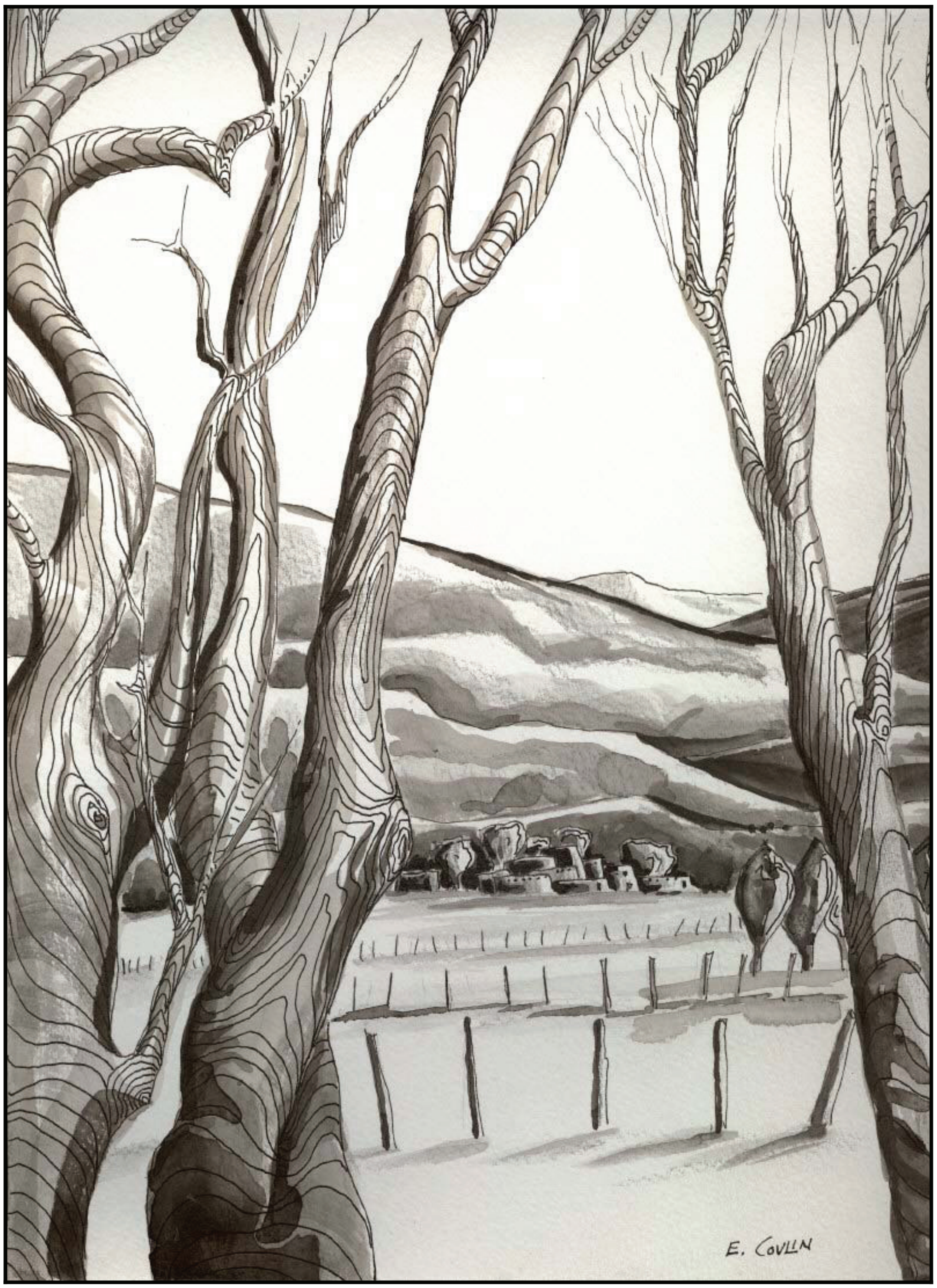

The Buffalo Pasture *by Elise Covlin* *Courtesy Brian and Julie Brister*