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HYDROGEOLOGY OF THE TUSAS MOUNTAINS, RIO ARRIBA COUNTY, NEW MEXICO

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ABSTRACT—The Tusas Mountains in Rio Arriba County provide a significant portion of the streamflow for the Rio Chama, however most communities in the Tusas Mountains obtain groundwater from saturated stream alluvium, which is typically localized and limited in supply. Groundwater occurs in four geologic settings: 1) alluvial deposits, 2) Tertiary sediments and weakly cemented volcanic rocks, 3) regional NW-SE trending fault and fracture systems, and 4) localized fractured, brittle Precambrian rocks such as quartzite. In many areas the Precambrian rocks and Tertiary sedimentary and volcanic rocks are not water bearing or do not sufficiently yield water to wells. The solidified and cemented Tertiary rocks typically are not water bearing or have poor groundwater yield (< 1gpm), the weakly cemented Tertiary rocks commonly have fair groundwater yield (1 to 10 gpm), and the unconsolidated Tertiary sediments have good groundwater yield (> 10 gpm).

INTRODUCTION

The Tusas Mountains in Rio Arriba County, New Mexico, are composed of uplifted Precambrian rocks flanked by basement-derived gravel and Tertiary volcanic and volcaniclastic strata related to the Rio Grande rift. Quaternary alluvium occupies the floors of valleys, and glacial deposits can be found in the highlands of the northern Tusas Mountains. The study area includes the highlands in Rio Arriba County, New Mexico, located north of Ojo Caliente and between U.S. Highway 84 and U.S. Highway 285 (Fig. 1).

The total area of the Tusas Mountain region is approximately 1,050 square miles or about 668,000 acres. Land ownership is predominately Carson National Forest, land grants, and smaller parcels of private land. Communities in this remote region include El Rito, Ojo Caliente, Tres Piedras, La Madera, and other small settlements along the Rio Brazos, Rio Vallecitos, and Rio Tusas (Fig. 1).

Most of the Tusas Mountains region is within the Rio Chama watershed (Subbasin) (Fig. 1). The exception is the northeastern portion that includes the Conejos Subbasin that drains into the Rio Grande.

Previous work has been largely limited to geologic studies and mapping. Smith et al. (1961) and Bingler (1968) provide good summaries of the geology and stratigraphy. Recently, more detailed mapping has been performed by the New Mexico Bureau of Geology and Mineral Resources (e.g. Aby et al., 2010; Kempter et al., 2008; and Koning et al., 2007). The Rio Chama Regional Water Plan by La Calandria Associates, Inc. (2005) is the first regional assessment of the water resources for the Tusas Mountains. This paper combines a review of available well logs for the region, local hydrogeologic studies, such as those by JSAI (2003) and Finch (2004), with the review of community water systems in Rio Arriba County by JSAI (2010) and the hydrogeologic information from Rio Chama Regional Water Plan. Furthermore, the hydrogeologic concepts presented herein incorporate recent mapping by the New Mexico Bureau of Geology and Mineral Resources.

SURFACE WATER

Average annual precipitation falling on the Tusas Mountains is 20 to 30 inches (La Calandria Associates, Inc., 2005). Nearly 20 percent of the average annual precipitation results in stream flow, and approximately 7 percent of the precipitation becomes groundwater recharge (La Calandria Associates, Inc., 2005). Distribution of estimated average annual stream flow, watershed yield, and recharge is presented in Table 1. Location of streams within the Rio Chama subbasin are shown on Figure 1. Watershed yield is derived by the surplus precipitation method described in South Central Mountain RC&D Council, Inc. (2002) and by Finch (2003). Surplus precipitation equals the potential

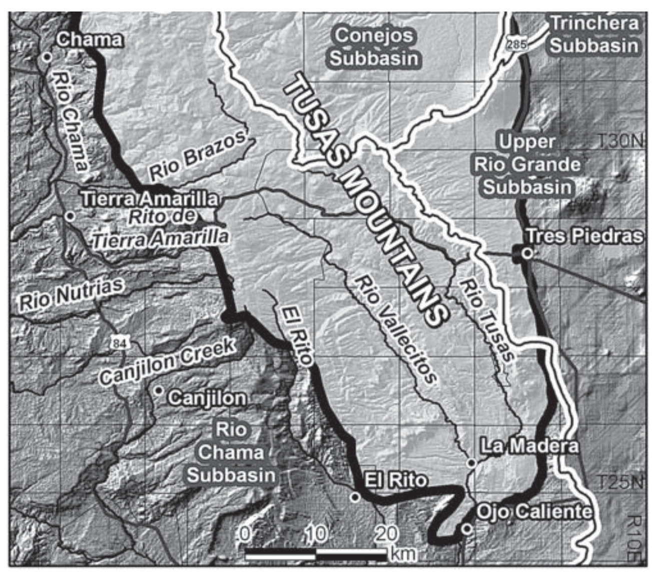

FIGURE 1. Map showing watersheds, rivers, towns, and geographic features for the Tusas Mountains region, northern New Mexico. The thick black line represents the Tusas Mountains region, and the white-outlining-black line denotes subbasins.

TABLE 1. Summary of estimated stream flow, watershed yield, and groundwater recharge for watersheds in the Tusas Mountains region that are tributary to the Rio Chama.

Watershed	Area (mi^2)	Average elevation (ft amsl)	Estimated average annual stream flow (ac-ft/yr)*	Estimated watershed yield (ac-ft/yr)**	Potential ground-water recharge (ac-ft/yr)
Rio Brazos***	163.1	9,500	83,900	65,240	--
Rito de Tierra Amarilla	63.1	8,500	9,850	20,870	11,020
Rio Nutrias	119.4	7,900	12,650	30,570	17,920
Canjilon Creek	153.5	7,800	26,830	36,020	9,190
El Rito	143.9	7,800	19,100	33,770	14,670
Rio Vallecitos	175.1	8,700	44,200	63,500	19,300
Rio Tusas	198.5	8,400	31,730	65,640	33,910
Total	1,016.6	--	228,270	315,610	87,340

* from Rio Chama Regional Water Plan (La Calandria Associates, Inc., 2005)
** derived using surplus precipitation method developed by Finch (2003)
*** no recharge calculated because estimated stream flow is greater than watershed yield

stream flow plus groundwater recharge. The potential groundwater recharge is the difference between watershed yield and stream flow. The surplus precipitation method is a monthly accounting of precipitation and potential evaporation data from weather stations in the area. The average monthly surplus precipitation (precipitation less potential evaporation) is summed for a water year. The surplus precipitation was determined for each elevation interval in the watershed and multiplied by the land area to obtain yield. The sum of the yields for each elevation interval equals the watershed yield. Surplus precipitation increases with elevation, but is not considered to occur below a land surface elevation of 6400 ft amsl in the Tusas Mountains.

Prior to the San Juan Chama Project (pre-1971), the Rio Chama watershed generated an average stream flow of 372,700 ac-ft/yr (La Calandria Associates, Inc., 2005). As described in the Rio Chama Regional Water Plan and detailed in Table 1, the Tusas Mountains provides approximately 60 percent of the Rio Chama stream flow and is potentially a significant source of recharge to the surrounding area: the Chama Basin, Española Basin and San Luis Basin (Rio Grande).

HYDROGEOLOGIC SETTING

The geologic descriptions for the area are largely based on geologic mapping; very little data exists from holes drilled for oil, gas, or water exploration. The geologic history is well defined by Koning et al. (2007). Mesozoic and Paleozoic rocks were eroded from the Precambrian highlands prior to deposition of Tertiary volcanic and sedimentary rocks. The volcanic rocks included basalt and andesite flows and rhyolitic ignimbrites (described by Muehlberger (1968) as the Potosi Volcanic Series). Paleovalleys draining to the southeast were filled with Tertiary volcaniclastic sediments. Locally, Quaternary glacial till and alluvium were deposited in the valleys and on the highlands.

Figure 2 illustrates the distribution of crystalline (Precambrian) and Tertiary rocks. These rock types affect the distribution of both surface water and groundwater resources. Perennial streams appear to be associated with Precambrian rocks and cemented volcanic rocks in the northern Tusas Mountains, whereas the basalt and unconsolidated deposits in the eastern and southern Tusas Mountains do not contain perennial streams. As determined from limited well drilling records, the unconsolidated volcanic deposits are the most viable aquifer units in the Tusas Mountains. The Tertiary deposits cover approximately 80 percent of the Tusas Mountain region (Fig. 2), but a significant portion of the area only contains a thin veneer of volcanic deposits overlying Precambrian rocks.

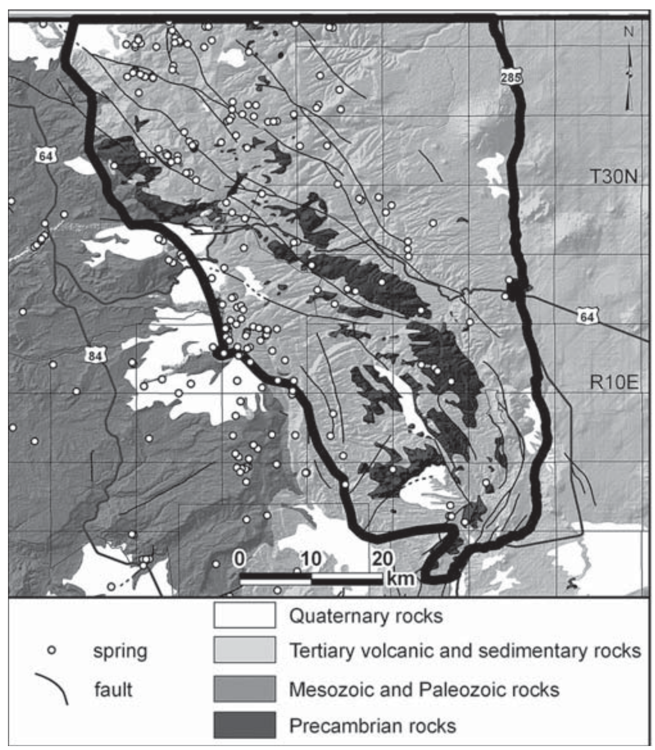

FIGURE 2. Generalized geologic map of the Tusas Mountain region. General geology from Green and Jones (1997). Spring locations from Simley and Carswell (2009). Fault data from USGS (2009)

Drilling of water supply wells in the Tusas Mountain region has been largely limited to alluvial deposits, although a few have been drilled in the volcaniclastic and Precambrian rocks (JSAI, 2010). A list of data and information obtained from well logs, pumping tests, and water right files is appended. Locations of wells with data are shown on Figure 3. A brief description of the hydrogeologic characteristics for the most common rocks in the Tusas Mountains is presented below.

Precambrian Rocks

Precambrian rocks of the Tusas Mountains include a variety of igneous and metamorphic rocks, most commonly granite, gneiss, schist, quartzite, and pegmatite (Bingler, 1968; Koning et al., 2007; and Kempter et al., 2008). Most wells drilled into the Precambrian rocks do not find adequate yield (Wingard, 1959; La Calandria Associates, Inc., 2005; JSAI, 2010). Wells drilled in

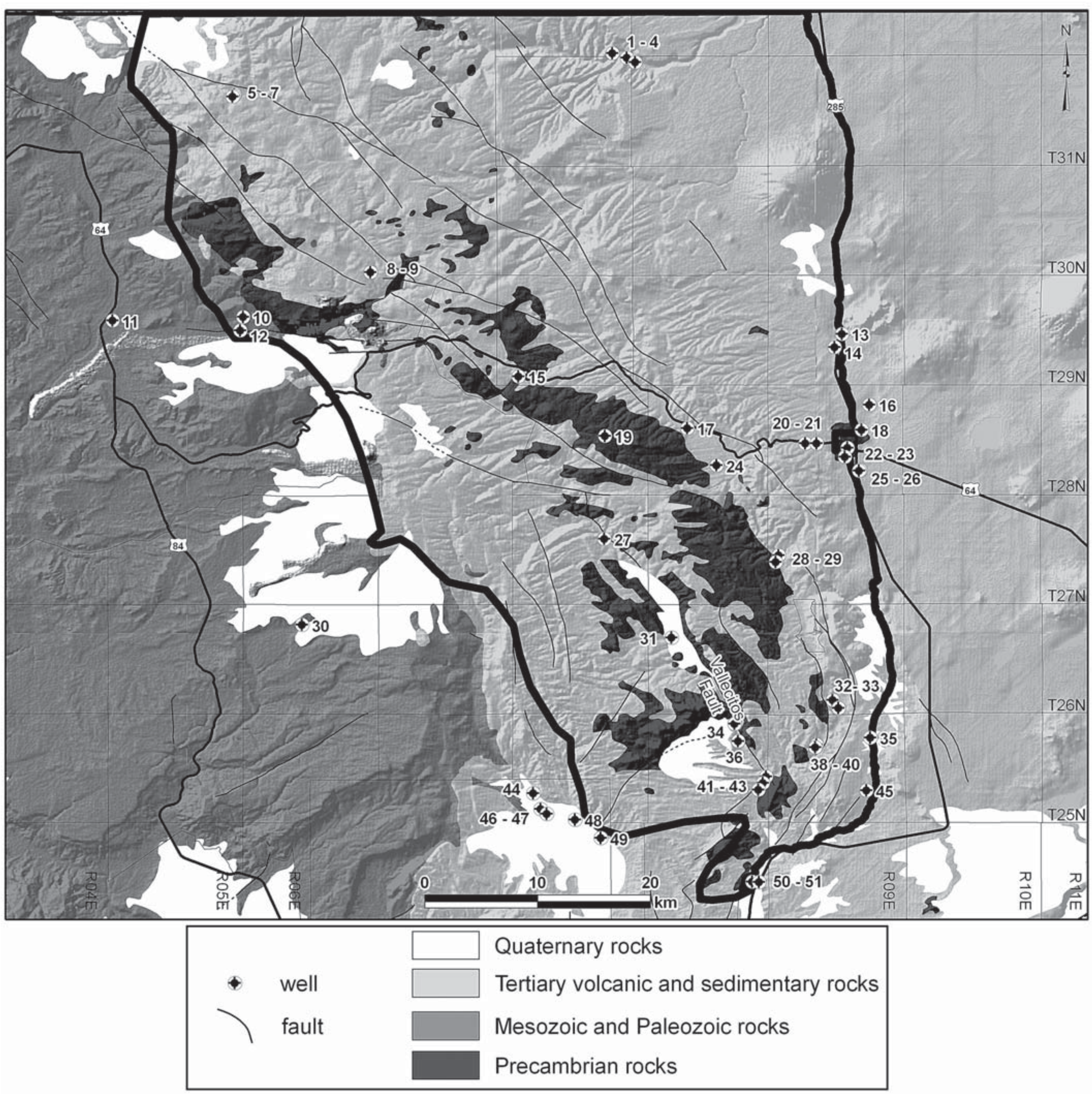

FIGURE 3. Map of the Tusas Mountains region showing location of wells with geologic and hydrologic information, northern New Mexico. See Appendix 1 for well data.

the vicinity of Tres Piedras only found groundwater in sand- and gravel-filled depressions in the granite. The underlying granite was not water bearing (Winograd, 1959). Domestic wells logs near La Madera and Ojo Caliente indicate similar results, with the exception of wells drilled into fractured quartzite (JSAI, 2010). Where groundwater is found, the yield of wells drilled into the Precambrian rocks varies between 1 and 50 gallons per minute (gpm). There are no known pumping test data and calculated hydraulic properties for the Precambrian rocks of the Tusas Mountains (Appendix 1).

Brittle Precambrian rocks, such as fractured quartzite, may contain groundwater locally where readily recharged from snowmelt or runoff. The location of Precambrian rocks potentially containing groundwater in the Tusas Mountains has not been defined, but recent mapping of the Valle Grande Peak, La Madera, Servilleta Plaza, and Las Tablas 1:24,000 quadrangle sheets in the southern Tusas Mountains provides geologic information for delineating potential groundwater zones in the Precambrian rocks (see Aby et al., 2010; Kempter et al., 2008; Aby, 2008, and Koning et al., 2007).

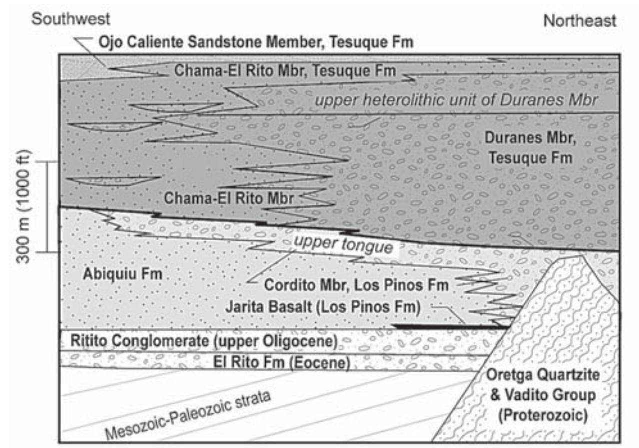

FIGURE 4. Stratigraphic correlation chart of Tertiary sediments in the southern Tusas Mountains region. Modified from Koning et al. (2008 and 2011).

Tertiary Deposits

Tertiary deposits of the Tusas Mountains are complex and have many overlapping names and descriptions that have resulted from regional and local geologic mapping over the years. The names and descriptions presented by Bingler (1968) are used for the northern Tusas Mountains and those presented by Koning et al. (2007) and Kempter et al. (2008) are used for the southern Tusas Mountains. Correlation of Tertiary sediments in the southern Tusas Mountains can be referenced from the stratigraphic chart presented as Figure 4.

When considering hydrogeologic characteristics, the Tertiary deposits can be divided into 1) solidified volcanic rocks (basalt, wielded tuff, etc), 2) cemented sedimentary or volcaniclastic rocks, and 3) unconsolidated or weakly consolidated sedimentary and volcaniclastic deposits.

Based on detailed review of well logs by JSAI (2010), the solidified and cemented rocks typically have poor groundwater yield (less than one gpm), the weakly cemented rocks commonly have fair groundwater yield (1 to 10 gpm), and the unconsolidated rocks have good groundwater yield (greater than 10 gpm). Table 2 is a summary of Tertiary rocks in the Tusas Mountains and assessment of their groundwater yield; supporting data can be referenced from the appended table.

Groundwater potential for the Blanco Basin, Conejos, and Treasure Mountain Formations (Table 2) in the northern Tusas Mountains are derived from the hydrologic assessment by Finch (2004). Brief descriptions of the more common Tertiary rocks in the central and southern Tusas Mountains are presented in the following sections.

El Rito Formation

The El Rito Formation was deposited on top of the Precambrian rocks of the Tusas Mountains and Late Cretaceous rocks near the western margin of the Tusas Mountains. The El Rito Formation consists primarily of breccia, conglomerate, and sandstone (Bingler, 1968). The silica and hematite cement matrix of the El Rito Formation provides the distinctive red color. The El Rito Formation is overlain by the Ritito Conglomerate. There are limited data available from wells drilled into the El Rito Formation, although the well-cemented portions of the formation in the El Rito area are known to be a poor source of groundwater (JSAI, 2003; JSAI, 2010).

Ritito Conglomerate

The Ritito Conglomerate is an unconsolidated sedimentary unit consisting of detritus derived from Precambrian bedrock (Bingler, 1968). To the north, where it intertongues with the Conejos Formation, the Ritito Conglomerate can be separated and identified by the lack of volcanic detritus. There are no known data from wells drilled into the Ritito Conglomerate, but the formation should have high permeability where saturated.

Los Pinos Formation

The Tertiary Los Pinos Formation is a grayish-pink and grayish-brown, poorly sorted, tuffaceous conglomerate that includes most of the volcanic rocks in the Tusas Mountains (Bingler, 1968). Grain sizes can range from fine sand to large boulders. The thickness of the Cordito Member of the Los Pinos Formation in the Valle Grande Peak quadrangle is approximately 300 ft (Kempter et al., 2008). Where the Los Pinos Formation is unconsolidated and poorly sorted, it is a potential aquifer for community supply (JSAI, 2003).

Los Pinos Formation is a markedly heterogeneous unit consisting of graywacke, tuffaceous graywacke and sandstone, siltstone, pebble-to-boulder conglomerate, breccia, basaltic-to-rhyolitic flow rock, and minor intrusive masses (Bingler, 1968; Kempter et

TABLE 2. Summary of Tertiary rocks in the Tusas Mountains.

Name	Location	General description*	Thickness (m)*	Range in well yield (gpm)
El Rito Formation	throughout Tusas Mtns	cemented breccia and conglomerate	20 to 60	<5
Blanco Basin Formation	northwestern portion of Tusas Mtns	cemented arkosic sandstone and conglomerate	70 to 100	unknown, potentially poor yield
Ritito Conglomerate	most common in southern half of Tusas Mtns	conglomerate consisting of Precambrian rocks	<50	unknown, potentially good yield
Conejos Formation	northwestern portion of Tusas Mtns	tuff, quartz latite flow breccias, agglomerate	300 to 450	unknown, potentially poor yield
Treasure Mountain Formation	northern Tusas Mountains	quartz latite, andesite, tuff, tuff breccia	20 to 100	dry to 10
Los Pinos Formation; also includes Abiquiu Formation and Chama-El Rito Member of the Tesuque Formation	throughout Tusas Mtns	variety of volcanic and volcaniclastic rocks. Permeability fair where unconsolidated and absent of volcanic detritus	< 500	1 to 70

Note: Data compiled from Aby (2008), Aby et al. (2010), Bingler (1968), Kempter et al. (2008), Koning et al. (2007), Muehlberger (1967, 1968), and Smith et al. (1961).

al., 2008). Conglomerate beds thicken and become more numerous from west to east across the Tusas Mountains. Pyroclastic material and flow breccia of the Los Pinos Formation are essentially limited to the Petaca-Tres Piedras area, where a thickness of 1,700 feet is projected (Bingler, 1968). The Los Pinos Formation was deposited on top of the Treasure Mountain Formation in the northern Tusas Mountains, and lies above the Ritito Conglomerate in the southern portion of the Tusas Mountains. The Cordito Member of the Los Pinos Formation intertongues with the Abiquiu Formation in the southern part of the study area (see Fig. 4). Tertiary basalt (Hinsdale Series) overlies the Los Pinos Formation in the northeast portion of the Tusas Mountains (Bingler, 1968).

The yields from wells drilled into the Los Pinos Formation vary significantly, as evidenced by the order of magnitude range of known hydraulic conductivity values (0.03 to 3.3 ft/day). Near El Rito, a 605-ft well was drilled into the Los Pinos Formation and yielded 25 gallons per minute (gpm) with a calculated transmissivity of 52 feet squared per day (ft^2/day) (map No. 47 on Fig. 3 and Appendix 1). Many of the wells in the El Rito area are drilled into the Los Pinos Formation and are reported to yield adequate quantities of groundwater for domestic and community supply (JSAI, 2003).

Quaternary Deposits

Quaternary sediments of the Tusas Mountains include stream alluvium, terrace deposits, and glacial deposits. Isolated patches of glacial gravel, sand, and silt are present in the northern Tusas Mountains from upper Rio Vallecitos north to the Colorado line. Most of these deposits represent terminal, lateral, recessional, and ground moraines related to alpine glaciers of probable Wisconsin age (Muehlberger, 1967). Only Muehlberger (1967, 1968) has mapped glacial deposits in Rio Arriba County in any detail. The Canjilon Till in the Magote Peak area is "lag gravel" resulting from the erosion of El Rito and Ritito Formations (Smith et al., 1961). The glacial deposits are characteristically poorly sorted and consist of gravel, arkosic sand, and silt. Gravel clasts range in age from Precambrian through Tertiary. Individual masses of till seldom exceed 20 meters in thickness.

Most communities in the Tusas Mountains obtain groundwater from stream alluvium (La Calandria Associates, Inc., 2005; JSAI, 2010). The grain-size distribution of the stream alluvium is highly variable in the Tusas Mountains. Wells completed in alluvium significantly vary in yield (1 to 20 gpm) due to variations in saturated thickness and grain size (see Appendix 1). In the vicinity of El Rito, stream alluvium contains large cobbles and may require special drilling methods for constructing wells. Where present, the storage capacity of the stream alluvium is limited and it may drain off (due to high transmissivity and stream gradient) or dry up during droughts. Due to this, reliable groundwater withdrawals for community supply are not feasible from most alluvial aquifers; one exception is supply for the community of Canjillon, located on Canjillon Creek, where the stream alluvium appears to have adequate thickness, a low stream gradient, and recharge.

One of the important roles of the terrace and glacial deposits in the Tusas Mountains is providing storage for stream flow. Many of the alluvial deposits in the higher elevations store and release infiltrated snowmelt water. This store-and-release mechanism provides stream flow long after the seasonal effects of spring runoff.

Finch (2004) performed a detailed hydrologic study of alluvium in the Brazos highlands (northern Tusas Mountains; see map nos. 5 though 7 on Fig. 3), and identified several complex groundwater flow paths (Fig. 5). Approximately 7 meters of alluvium overlying volcanic rocks becomes fully saturated during late spring snowmelt. After spring runoff, alluvial groundwater locally discharges as springs from groundwater systems perched on clay layers in the alluvium. The underlying volcanic rock (predominately rhyolite) only contains groundwater where frac-

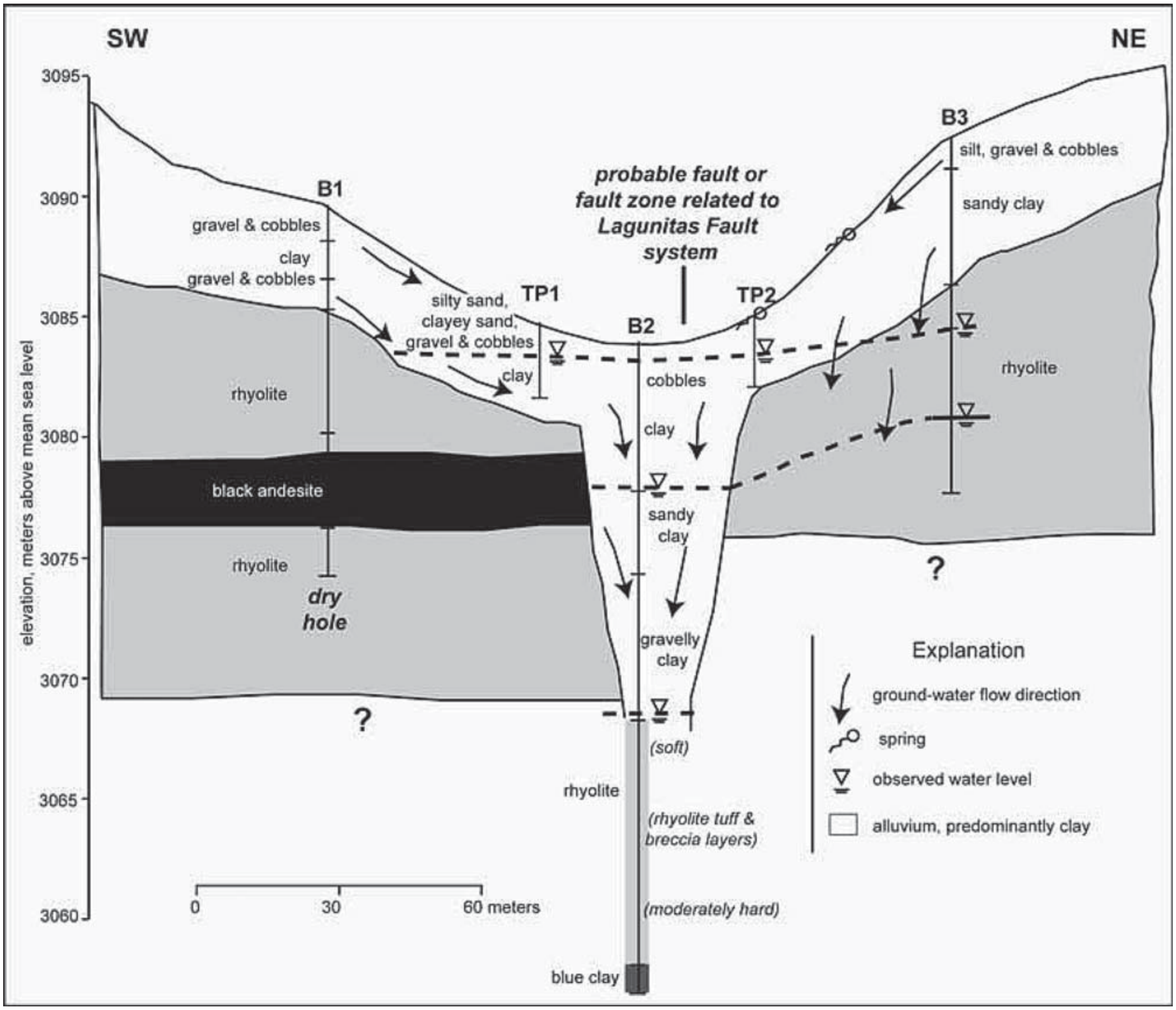

FIGURE 5. Hydrogeologic cross-section of high mountain alluvium and underlying volcanic rocks in the northern Tusas Mountains (well nos. 5 though 7 on Fig. 3 and Appendix 1; from Finch, 2004).

tured and is not water bearing elsewhere. During the remainder of the year, groundwater in the alluvium drains vertically into a fault zone which discharges to springs lower in elevation than the Brazos highlands. The spring flows from the alluvium and underlying fractured volcanic rock regulate groundwater discharge and maintain perennial tributaries to the Rio Brazos and Rio Chama.

Structural Controls on Groundwater

The Tusas Mountains form the boundary between the Colorado Plateau (Chama Basin) and the Rio Grande Rift. This boundary is defined by north-northwest to south-southeast trending faults (Kempter et al., 2008). Strata in the Tusas Mountains are generally tilted to the east because it is part of a eastward–tilted graben (San Luis Basin of the Rio Grande Rift). These regional structures likely control deep groundwater flow paths.

Extension associated with the Rio Grande rift has produced faulting, folding, and tilting from the Oligocene to the present. Koning et al. (2007) interpret the rift-related faulting as having influenced the locations of two drainages during the Miocene and Pliocene, including the Rio Vallecitos and its associated Quaternary aquifer. Faults also control the extent of groundwater distribution and locally serve as a flow path (Smith et al, 1961).

Many springs occur at or near the contact between alluvium and Precambrian rocks, alluvium and solid, well-cemented Tertiary volcanic rocks, or alluvium and Cretaceous Mancos Shale. Very few springs are found where the Los Pinos Formation or Hinsdale Basalt are present (Finch, 2004; JSAI, 2010). Springs also emanate from fault zones, particularly large fault zones trending northwest to southeast (Fig. 2).

GROUNDWATER FLOW PATHS

Groundwater in the Tusas Mountains can be (1) perched in alluvial systems and directly connected to stream flow, (2) found locally in fractured rock, or (3) part of a deep flow path in the Ritito Conglomerate or Los Pinos Formation. Short groundwater flow paths are typically in the alluvium, near surface fracture zones, or locally in saturated portions of the Ritito Conglomerate and Los Pinos Formation. Conceptually, the northern Tusas Mountains contains alluvium underlain by low permeability volcanic and igneous rocks. The only mechanism for the creation of deep flow paths in the northern Tusas Mountains is flow through regional fault systems trending NNW to SSE. Deep groundwater flow paths in the southern Tusas Mountains may also occur in the Ritito Conglomerate and overlying Los Pinos Formation.

In the La Madera 1:24,000 quadrangle Koning et al. (2007) noted a potential difference in hydraulic conductivity between exposed Tertiary rock units west and east of the Vallecitos fault (Fig. 3). West of this fault, most of the exposed sedimentary sequence is weakly to moderately consolidated and non-cemented. East of the Vallecitos fault, Tertiary exposures consist of tuffaceous volcaniclastic sedimentary units that are cemented to varying degrees. Surface discharge is not common in the less consolidated, non-cemented sediment west of the Vallecitos fault, suggesting that most precipitation there infiltrates to the water table, where it then flows relatively deeply.

Recharge from the Tusas Mountains to the Rio Grande Rift (Española Basin) may occur from deep flow paths in the Ritito Conglomerate and Los Pinos Formation where these units are continuous and not disrupted by rift-related faulting. Although, detailed geologic mapping has been completed for most of the southern Tusas Mountains (e.g. Aby et al., 2010; Kempter et al., 2008; and Koning et al., 2007), additional well data and study is needed to fully understand deep groundwater flow paths originating from the Tusas Mountains.

CONCLUSIONS

The Tusas Mountains in Rio Arriba County provide a significant portion of the stream flow for the Rio Chama, particularly the northern portion of the Tusas Mountains where low permeability Precambrian and cemented volcanic rocks limit infiltration and facilitate runoff.

Groundwater occurs in four geologic settings: 1) Quaternary alluvial deposits, 2) Tertiary sediments and weakly cemented volcanic rocks, 3) regional NW-SE trending fault and fracture systems in Precambrian and consolidated Tertiary rocks, and 4) localized fractured Precambrian rocks (most commonly quartzite). A significant portion of the Tertiary sedimentary and volcanic rocks are not water bearing or do not sufficiently yield water to wells. The groundwater resources of the Tusas Mountains region have been poorly understood, and as a result, development of a drought-resistant groundwater supply for communities in the region has been largely unsuccessful where wells have simply been deepened from alluvial systems into low permeability rocks (JSAI, 2010). Examples include wells drilled for the communities of El Rito and Tres Piedras, New Mexico (see Appendix 1).

Most communities in the Tusas Mountains obtain groundwater from stream alluvium. The grain-size distribution of the stream alluvium is highly variable through the Tusas Mountains, and can range from boulders to silty sand. Where present, the storage capacity of the stream alluvium is limited and it may seasonally dewater (due to high transmissivity and stream gradient) or dry up during droughts. Due to this, community system demand can exceed the available groundwater storage for most alluvial systems in the Tusas Mountains (La Calandria Associates, Inc., 2005; JSAI, 2010).

The Tertiary deposits can be divided into 1) solidified volcanic rocks (basalt, welded tuff, etc), 2) cemented sedimentary or volcaniclastic rocks, and 3) unconsolidated or weakly consolidated sedimentary and volcaniclastic rocks. Based on domestic and community water well records, the solidified and cemented rocks typically have poor groundwater yield (less than one gpm), the weakly cemented rocks commonly have fair groundwater yield (1 to 10 gpm), and the unconsolidated rocks have good groundwater yield (greater than 10 gpm). Tertiary rocks best suited for groundwater development are probably the Ritito Conglomerate, and those portions of the Los Pinos Formations that are weakly cemented.

Fractured Precambrian rocks, such as quartzite, may contain groundwater locally where readily recharged from snowmelt or runoff. The location of Precambrian rocks potentially containing groundwater in the Tusas Mountains has not been defined, but in the southern Tusas Mountains recent geologic mapping of the Valle Grande, La Madera, Cañon Plaza, and Las Tablas 1:24,000 quadrangles could provide adequate information for delineating potential groundwater zones in the Precambrian rocks and along faults.

Groundwater flow paths in the Tusas Mountains occur in (1) perched alluvial systems directly connected to stream flow, (2) fractured rock, or (3) the Ritito Conglomerate or Los Pinos Formation (shallow or deep flow path depending on structures). Additional well data and study is needed to fully understand deep groundwater flow paths originating from the Tusas Mountains.

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APPENDIX 1. Summary of well data for the Tusas Mountains region.

Map No.*	ID	NMOSE File Number	Town-ship	Range	section	UTM X (meters)	UTM Y (meters)	total depth (ft)	depth to water (ft)	reported yield (gpm)	log descrip-tion	Formation	pumping test rate (gpm)	pumping water level (ft)	Specific capacity (gpm/ft)	Transmis-sivity (ft2/day)	Hydraulic conductivity (ft/day)	QUAD Sheet	source**
1	domestic	RG-74198	32N	7E	36.332	396,605	4,091,282	38	16	10	alluvium (large boul-ders)	alluvium						Toltec Mesa	NMOSE records
2	domestic	RG-74198	32N	7E	36.332	396,605	4,091,282	38	16	10	alluvium	alluvium						Toltec Mesa	
3	domestic	RG-70062	31N	7E	1.221	397,615	4,090,862	100	4	10	fractured volc	Treasure Mountain						Toltec Mesa	NMOSE records
4	domestic	RG-65682	31N	8E	6.132	398,213	4,090,455	186	62	10								Toltec Mesa	NMOSE records
5	Test Boring B3					369,752	4,087,995	51	27		alluvium/ rhyolite	glacial deposits/ Treasure Mtn Rhyo-lite						West Fork Rio Brazos	Finch (2004)
6	Test Boring B2					369,701	4,087,887	92	20		alluvium/ rhyolite	glacial deposits/ Treasure Mtn Rhyo-lite						West Fork Rio Brazos	Finch (2004)
7	Test Boring B1					369,614	4,087,807	52	dry		alluvium/ rhyolite	glacial deposits/ Treasure Mtn Rhyo-lite						West Fork Rio Brazos	Finch (2004)
8	domestic	RG-74372	30N	6E	31.342	379,183	4,072,159	520	380	5	red volc congl	El Rito						Brazos	NMOSE records
9	domestic	RG-74372	30N	6E	31.342	379,183	4,072,159	520	380	5	red volc congl	El Rito						Brazos	
10	Corkin's Lodge	RG-28710				370,081	4,068,346	295	6		alluvium	Quaternary alluvium	20	98	0.2	23		Tierra Amarilla	NMOSE (2011)
11	Los Brazos MDWCA	RG-35222				360,782	4,068,162	21	18	1	sand & gravel	Quaternary alluvium						Tierra Amarilla	NMOSE records
12	Brazos Water COOP	RG-24272	29N	5E	18	369,863	4,067,151	103	38.3		fill/sandstone	Quaternary alluvium and Mesozoic Rocks	48	60.6	2.2	575	8.8	Tierra Amarilla	NMOSE (2011)
13	domestic	RG-72733	29N	9E	22.114	412,609	4,066,307	860	687	35	basalt	Hinsdale Basalt						Tres Piedras	NMOSE records
14	domestic	RG-80377	29N	9E	21.444	412,088	4,065,123	800	661	25	basalt	Hinsdale Basalt						Tres Piedras	NMOSE records
15	Hopewell Lake CG	RG-77913	29N	7E	31.233	389,569	4,062,814	500	67	5	fractured quartzite	Precambrian						Burned Mtn	NMOSE records
16	Foster Ranch		28N	9E	11.2	414,503	4,060,027	359	dry		volc/granite	Los Pinos/ Precambrian						Tres Piedras	Winograd (1959)
17	domestic	RG-77087	28N	8E	16.144	401,540	4,058,101	400	240	25	sand & gravel	Los Pinos						Mule Canyon	NMOSE records
18	domestic	RG-50184	28N	9E	14.134	413,934	4,057,831	780	560			Los Pinos (?)						Tres Piedras	NMOSE records
19	domestic	RG-86964	28N	7E	14.331	395,660	4,057,488	462	242	8	granite	Precambrian						Burned Mtn	NMOSE records

APPENDIX 1. Summary of well data for the Tusas Mountains region -Cont.

Map No.*	ID	NMOSE File Number	Town-ship	Range	section	UTM X (meters)	UTM Y (meters)	total depth (ft)	depth to water (ft)	reported yield (gpm)	log descrip-tion	Formation	pumping test rate (gpm)	pumping water level (ft)	Specific capacity (gpm/ft)	Transmis-sivity (ft2/day)	Hydraulic conductivity (ft/day)	QUAD Sheet	source**
20	Tres Piedras MDWCA	RG-29349-S3	28N	9E	20.214	409,906	4,056,671	570				Los Pinos (?)						Tres Piedras	NMOSE records
21	Tres Piedras MDWCA	RG-29349-S2	28N	9E	21.114	410,710	4,056,662	390			volc rock	Los Pinos (?)						Tres Piedras	NMOSE records
22	Tres Piedras MDWCA	RG-29349	28N	9E	22.233	412,916	4,056,232	25	13.7	goes dry	alluvium/ granite	Quaternary alluvium and Precambrian						Tres Piedras	NMOSE records/ Winograd (1959)
23	Tres Piedras MDWCA	RG-29349-S	28N	9E	22.344	412,707	4,055,432	12	5.4	goes dry	alluvium/ granite	Quaternary alluvium and Precambrian						Tres Piedras	NMOSE records/ Winograd (1959)
24	domestic	RG-78182	28N	8E	27.234	403,576	4,054,790	450	240	30	sand & gravel	Los Pinos						Mule Canyon	NMOSE records
25	Tres Piedras MDWCA	RG-29349-S5	28N	9E	27.222	413,791	4,054,264	320		10		Los Pinos (?)						Tres Piedras	NMOSE records
26	Tres Piedras MDWCA	RG-29349-S4	28N	9E	26.313	413,699	4,054,214	205		1		Los Pinos (?)						Tres Piedras	NMOSE records
27	domestic	RG-49267	27N	7E	14.133	395,517	4,048,393	50	10		alluvium	alluvium						Cañon Plaza	NMOSE records
28	domestic	RG-78717	27N	9E	19.142	407,904	4,046,806	95	60	7	volc rock	Los Pinos (?)						Tres Piedras	NMOSE records
29	domestic	RG-25624	27N	9E	19.323	407,701	4,046,203	95	21	2	cemented gravel	Los Pinos (?)						Petaca Peak	NMOSE records
30	Canjilon MDWCA	RG-22777	26N	5E	9.21	373,870	4,041,086	8		22	sand & gravel	alluvium						Canjil-lion	JSAI files
31	Vallecitos MDWCA	RG-28282	26N	8E	8.443	400,186	4,039,609	50	3		boulders & gravel	alluvium	30	45	0.7	135	3.0	Las Tablas	JSAI files
32	domestic	RG-79873	26N	9E	33.224	411,619	4,033,983	120	12	8	grey volc rock	Los Pinos (?)						Servil-leta Plaza	NMOSE records
33	domestic	RG-79436	26N	9E	34.313	412,036	4,033,272	120	43	70	grey sand-stone	Los Pinos (?)						Servil-leta Plaza	NMOSE records
34	domestic	RG-72270	25N	8E	2.411	404,607	4,031,964	45	38	18	fractured red volc	Upper Chama El Rito Mbr of Tesuque Fm						La Madera	NMOSE records
35	domestic	RG-27286	25N	9E	11.124	414,272	4,030,623	650	560	3	red volc congl	Upper Chama El Rito Mbr of Tesuque Fm						Servil-leta Plaza	NMOSE records
36	El Llanito MDWCA	RG-21730	25N	8E	11.421	404,850	4,030,412	150	12	30	brown fine sand	Ojo Caliente Sandstone Mbr of the Tesuque Fm	30	27	2			La Madera	NMOSE (2011)

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Map No.*	ID	NMOSE File Number	Town-ship	Range	section	UTM X (meters)	UTM Y (meters)	total depth (ft)	depth to water (ft)	reported yield (gpm)	log descrip-tion	Formation	pumping test rate (gpm)	pumping water level (ft)	Specific capacity (gpm/ft)	Transmis-sivity (ft2/day)	Hydraulic conductivity (ft/day)	QUAD Sheet	source**
37	El Llanito MDWCA	RG-21730	25N	8E	11.421	404,850	4,030,412	150	12		brown fine sand	Ojo Caliente Sandstone Mbr of the Tesuque Fm	20	22	1.8	560	5.1	La Madera	JSAI files
38	domestic	RG-55892	25N	9E	9.311	410,448	4,030,044	42	25	20	alluvium	Quaternary alluvium						Servil-leta Plaza	NMOSE records
39	domestic	RG-55892-2	25N	9E	9.311	410,448	4,030,044	80	26.5	8	fractured granite	Precambrian						Servil-leta Plaza	NMOSE records
40	domestic	RG-83598	25N	9E		410,335	4,029,827	100	23		grey volc rock	Los Pinos (?)						Servil-leta Plaza	NMOSE records
41	La Madera MDWCA	RG-17470	25N	8E	24.24	406,793	4,027,266	60		15		Quaternary alluvium						La Madera	NMOSE records
42	domestic	RG-85519	25N	8E	24.423	406,559	4,026,705	61	41.2	17	fine sand & gravel	Quaternary alluvium						La Madera	NMOSE records
43	domestic	RG-88987				406,232	4,026,122	55	32	12	sand & gravel	Quaternary alluvium						La Madera	NMOSE records
44	El Rito Cañon MDWCA	RG-16306	25N	7E	30.242	390,153	4,025,989	22	dry (2003)	20	gravel & boulders	Quaternary alluvium						El Rito	JSAI files
45	Old Amador Well		25N	9E	26	413,947	4,025,968	260					6		1.26			Servil-leta Plaza	NMOSE (2011)
46	Sawmill Well		25N	7E	32	390,667	4,024,603	102	29.3			Los Pinos (?)	13	36.5	1.8	229	3.3	Valle Grande	NMOSE (2011)
47	El Rito Cañon MDWCA	RG-16306-Expl	25N	7E	32.411	391,099	4,024,152	605	12.7	25	tuffaceous congl	Chama-El Rito Mbr Tesuque	25	130	0.22	52	0.44	El Rito	JSAI (2004)
48	El Rito Regional WWA	RG-85433				393,112	4,023,629	32		22		alluvium						El Rito	NMOSE records
49	La Placi-tas well		24N	7E	11.111	394,929	4,021,969	731	24.4		brown congl	Abiquiu	16.5	217	0.09	8	0.03	El Rito	NMOSE (2011)
50	Ojo Caliente MDWCA	RG-1332	24N	8E	24.21	405,711	4,017,999	80	28		sand & gravel	alluvium	55	33	11	3340	74	Ojo Caliente	JSAI files
51	domestic	RG-86506	24N	8E	24.22	406,205	4,017,951	695	133	4	silt and sand	Plaza litho-some of Tesuque Fm	3	500	0.015	0.4	0.003	Ojo Caliente	JSAI files

* Map numbers correspond with labeled wells on Figure 3.

** NMOSE records include drillers logs from well records, water right documents, and excerpts from consultant's reports.

View north along Rio Grande Gorge. Ute Mountain in distance and Sunshine Valley to the upper right. Groundwater discharges into the gorge from Sunshine Valley. The hydrogeology of southeastern Sunshine Valley is discussed in a paper by M. Darr on the next page. Copyrighted photo by Chris Dahl Bredine (http://www.taosaerialimages.com); used with permission.