Where is the water? - A preliminary assessment of hydrogeologic characteristics of lithostratigraphic units near Espanola, north-central New Mexico

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WHERE IS THE WATER? – A PRELIMINARY ASSESSMENT OF HYDROGEOLOGIC CHARACTERISTICS OF LITHOSTRATIGRAPHIC UNITS NEAR ESPAÑOLA, NORTH-CENTRAL NEW MEXICO

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Abstract — For lithostratigraphic units near Española, potential hydrologic differences were assessed by estimating hydraulic conductivity (K) from transmissivity values. These transmissivity values were obtained from aquifer tests of wells (120-1500 ft deep) screened across one or more of these lithostratigraphic units, which include Quaternary valley-fill sediments and units in Santa Fe Group basin-fill sediments (late Oligocene to late Miocene). Depths of particular Santa Fe Group lithostratigraphic units vary with location due to faulting and west-tilting of the Española half-graben. Values of hydraulic conductivity ranged over two orders of magnitude, from 0.1 to 34 ft/day. The Quaternary valley fill has the highest hydraulic conductivity (0.7 to 34 ft/day, averaging 10 ft/day). The Chamita Formation and middle to upper Ojo Caliente Sandstone of the Tesuque Formation may provide the most productive water-bearing zones in the Santa Fe Group (with K ranging from 0.7 to 7.3 ft/day), followed by a combined unit consisting of interbedded Ojo Caliente Sandstone-Cejita Members and underlying lithosome B of the Pojoaque Member of the Tesuque Formation (K of 0.7 to 1.4 ft/day). In general, hydraulic conductivity for the remaining lithostratigraphic units, located in a lower stratigraphic position, range from 0.1 to 3 ft/day, with lithosome B of the Pojoaque and Skull Ridge Members being on the higher end of that range. Hydraulic conductivity generally decreases with stratigraphically lower units. Other influences on hydraulic conductivity and well yields include, but are not limited to, faults that act as barrier boundaries and secondary mineralization (cementation).

INTRODUCTION

Numerous lithostratigraphic units in the Santa Fe Group have been differentiated near Española during recent STATEMAP geologic mapping. These units are based primarily on their composition and gross texture. Textural properties influence the permeability of clastic materials and groundwater flow to wells. For example, a well-sorted, clean sand or gravel can more readily release groundwater from storage and allow faster groundwater flow than a silty-clayey, poorly sorted sand. If mapped lithostratigraphic units are differentiated in part on properties that also influence groundwater flow, then there may be significant differences in hydraulic parameters between these units. This study addresses that possibility near the city of Española by comparing values of hydraulic conductivity (K) derived from aquifer test data in wells screened across recognizable lithostratigraphic units.

The city of Española lies in the heart of the Española Basin (Fig. 1), one of several basins near the Rio Grande formed by tectonic extension associated with the Rio Grande rift (Kelley, 1956; Spiegel and Baldwin, 1963; Chapin, 1971). The Española Basin is filled with relatively thin Quaternary deposits, resting upon siliciclastic sediment (primarily sand, with lesser mud and gravel) of the Santa Fe Group of Spiegel and Baldwin (1963), which ranges in age from late Oligocene through late Miocene (Smith, 2004; Koning et al., 2004). Galusha and Blick (1971) subdivided the Santa Fe Group into the Tesuque Formation and overlying Chamita Formation. The Tesuque Formation, in turn, was subdivided into various members, including the Chama-El Rito and Ojo Caliente Sandstone Members in the northwestern part of the basin, and the Pojoaque, Skull Ridge, and Nambe Members in the eastern part of the basin. Cavazza (1986) recognized that basin-fill sediments in the eastern part of the basin, represented by the Pojoaque, Skull Ridge, and Nambe Members in the Galusha and Blick (1971) stratigraphic scheme, could be differentiated lithostratigraphically into two units having different composition and provenance: lithosome A and lithosome B (Figs. 2, 3). Recent mapping in the central and eastern parts of the basin found the lithosome stratigraphic scheme of Cavazza (1986) more recognizable and easier to differentiate in the field,

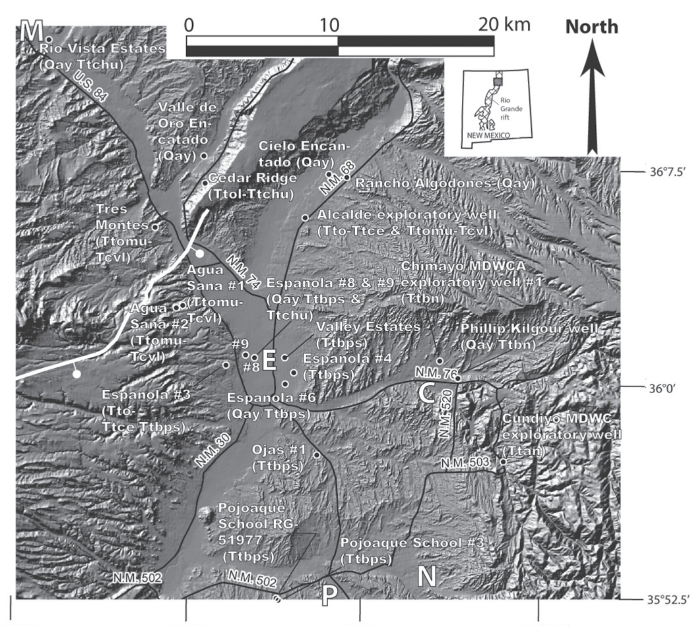

FIGURE 1. Map showing locations of wells with pump-test results in the study area, with primary pumped comparative lithostratigraphic units shown in parenthesis. Wells depicted as circles. Town abbreviations: M = Medanales, E = Española, C = Chimayo, P = Pojoaque, and N = Nambe. The thick white line illustrates the Santa Clara fault.

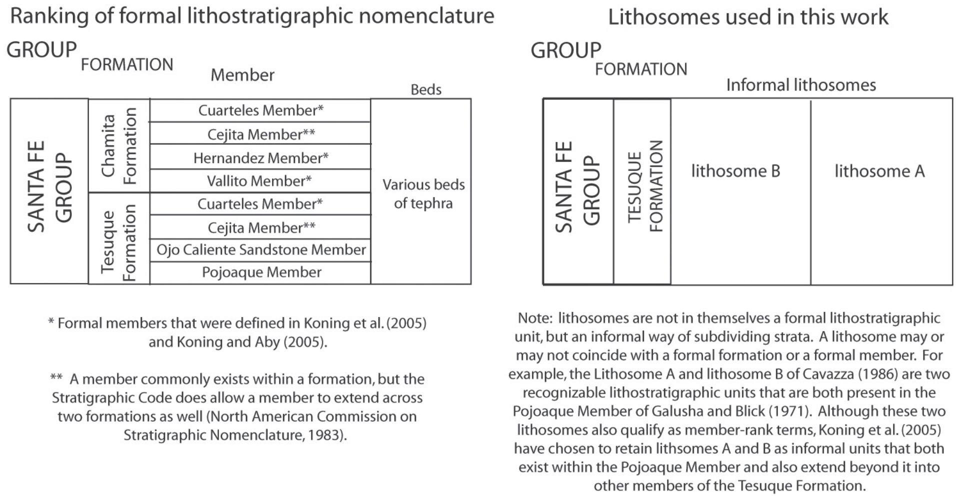

FIGURE 2. Santa Fe Group stratigraphic nomenclature in Española Basin.

but this mapping also preserved, where possible, the previous nomenclature of Galusha and Blick (Koning and Maldonado, 2001; Koning, 2002a; Koning et al., 2002; Koning and Manley, 2003; Koning, 2003).

Ongoing studies in the southern Española Basin indicate a statistically significant relationship between mapped lithosome units (within the Tesuque Formation and overlying Ancha Formation) and hydraulic conductivity estimated from aquifer tests (Johnson and Koning, 2005). For this study, we compiled information from existing well records and consultant reports that incorporated aquifer test data of Santa Fe Group units. We focused our search in the Española Basin north of the Pojoaque River and south of Velarde, and between Española and Medanales in the Abiquiu embayment (note that the Ancha Formation is not present in this area). The study area lies to the north of a previous hydrogeologic study conducted by Johnson and Koning (2005) south of the Pojoaque River. Aquifer test data (from pumping tests) were used for a preliminary correlation of hydraulic conductivity and lithostratigraphic units.

METHODS

We searched the library of the Office of the State Engineer (OSE) for hydrogeologic consultant reports associated with proposed subdivisions in the study area, and noted those that had raw aquifer test data and/or analyses of these data (e.g., calculated transmissivity values). Typically, aquifer tests were performed by pumping wells at a given discharge and measuring drawdown in the well as a function of time. Additional consultant reports not found in the OSE library were generously provided by Glorieta Geoscience Incorporated and John Shomaker and Associates. Table 1 lists consultant reports that had usable data. Table 2 contains a summary of these aquifer test data, and the associated wells are shown on Figure 1. We also determined which of the lithostratigraphic units of Figures 2 and 3 were encountered in the wells with aquifer test data by reviewing drillers' reports, information from the consultant reports, geologic maps of the area, and personal inspection of drill cuttings and down-hole geophysical logs.

For this study, we commonly grouped lithostratigraphic units identified in previous geologic mapping into combined units (Fig. 4) based on practicality. For example, screened intervals might extend across a particular combination of previously identified lithostratigraphic units, resulting in the inability to isolate the hydrologic characteristics of a single unit in that combination. However, that combination might be commonly encountered in screened intervals of other wells and thus serves as a useful comparative unit. A screened interval may not fully penetrate all units in these combinations. Such groupings of lithostratigraphic units may yield a somewhat heterolithic combination of otherwise distinctive lithostratigraphic units (in our case, eolian and fluvial strata), but it allows one to compare similar stratigraphic

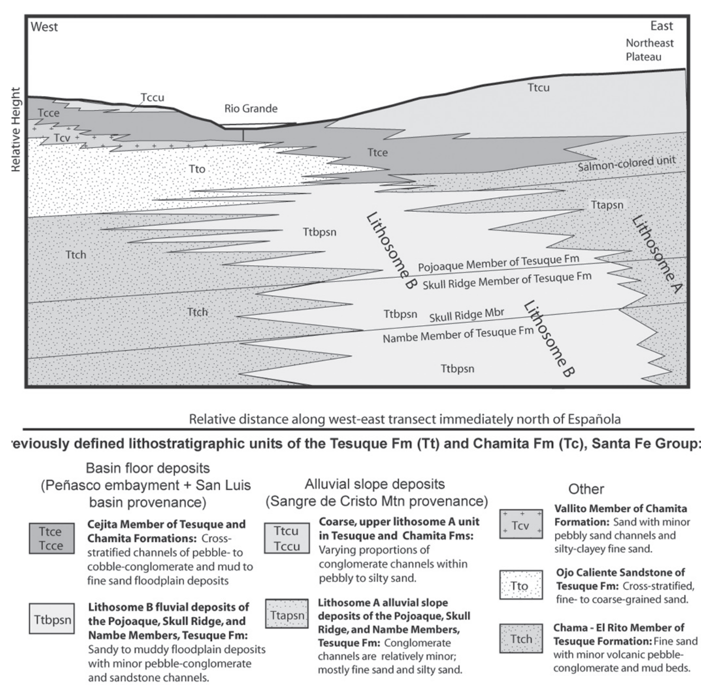

FIGURE 3. Schematic cross-section near Española illustrating the main lithostratigraphic units differentiated in the area by Koning (2002a, 2003), Koning and Manley (2003), and Koning et al. (2002, 2005).

intervals (Fig. 4). We refer to these combined and uncombined lithostratigraphic units as "comparative lithostratigraphic units" in this paper. The comparative lithostratigraphic units used in this study (Table 3; Fig. 4) include 1) lithosome A of the Nambe Member (Ttan); 2) lithosome B of the Nambe Member (Ttbn); 3) lithosome B of the Pojoaque and Skull Ridge Members (Ttbps); 4) lower Ojo Caliente Sandstone and upper Chama-El Rito Member (Ttol-Ttchu); 5) interfingering Cejita Member and Ojo Caliente Sandstone overlying lithosome B of the Pojoaque Member (Tto-Ttce/Ttbp); 6) middle to upper Ojo Caliente Sandstone and the overlying lower Vallito Member of the Chamita Formation (Tcvl-Ttomu); and 7) relatively young Quaternary valley-fill sediments (Qay).

From the transmissivity data in Table 2, we calculated a range of hydraulic conductivity values by dividing the transmissivity by the length of the saturated filter pack (for a minimum value) and by the length of the saturated screen interval (for a maximum value). In some wells, we had to make educated guesses regarding the depth interval of the filter pack (italicized in Table 2). Hydraulic conductivity values calculated from the aquifer tests were then depicted for each of the comparative lithostratigraphic units on two box-and-whisker plots (Figs. 5, 6), where the lithostratigraphic units are arranged approximately from youngest (on top) to oldest (on bottom).

RESULTS

Twenty-two wells in the study area contained both aquifer test data and useful lithologic logs. We were able to correlate pumping test results to all seven of our comparative lithostratigraphic units. However, four of these units have data from only one or two pumping tests: lithosome A of the Nambe Member, lithosome

TABLE 1. Consultant reports for Española area with pump test data. Well locations are in Township, Range, Section, and quarter section.

Subdivision or Well Name Well Location	Title of report	Author(s)	Year
Solacita/Ojas #1 well 20.08.13.3333	Submittals for Solacito Subdivision	C Hagerman	1983?
Española #6 20.8.1.411	No 6 replacement Test well pumping test results,City of Española New Mexico.(Letter to Doug Albin)	John Shomaker and Associates, Inc	NA
Española #8 21.8.27	Drilling and testing report for Española Well no 8 Carter Ranch Production Well RG-3067-S15	Glorieta Geoscience Incorporated	2002
Española # 3 and 4 21.08.32.4223/ 21.08.36.42131	Well Report, City of Española Well 4 and 3, Española New Mexico	John Shomaker and Associates, Inc	1998
Espanola #9 21.08.27.341	Letter report to the City of Espanola	John Shomaker and Associates, Inc	2003
Cielo Encantado 22.9.19	Geohydrologic investigation in the vicinity of the Cielo Encantado Subdivision, p. 41	Wolf Engineering,	1997
Agua Sana #1	Geohydrologic Evaluation of Proposed Well Sites (Agua Sana Users Assoc.)	Glorieta Geoscience Incorporated	
Agua Sana #1	Agua Sana south well #1 production update report, Hernandez, NM	Souder, Miller, and Associates	2002
Agua Sana #1 21.08.19.12131	Hydrologic assessment of Granting Emergency Authorization to divert 500 AFY Under Perm RG-3067-S-14 from well RG 68591	Glorieta Geoscience Incorporated	1998?
Agua Sana #2 21.08.19.11233	Well report for Well #2 Agua Sana water users association, Rio Arriba County, Hernandez, NM	Souder, Miller, and Associates	2003
Tres Montes 22.7.36.114	Evaluation of Geohydrology and Water Availability Assessment for Tres Montes Subdiv Rio Arriba Co., NM	Glorieta Geoscience Incorporated	2000
Cedar Ridge subdivision 22.08.29.1223	Hydrogeologic report Cedar Ridge Subdivision	Frost and Associates	1996
Valle de Oro Encantado (exploratory well #1) 22.8.20	Geohydrologic investigation in the vicinity of the Valle de Oro Encantado Subdivision, p. 28	Wolf, Douglas, P.E.	1996
San Juan Casino 21.8.12.243	Well Report, San Juan Pueblo Casino Well 1, San Juan Pueblo, NM.	John Shomaker and Associates, Inc	1998
Greater Chimayo MDWCA 21.9.36.12431	Phase II Hydrogeologic Evaluation for water supply:Testing existing wells and drilling, completion, and testing of Exploratory wells No. 2 and No. 3, Chimayo, NM (includes PHILLIP KILGOUR WELL DATA	John Shomaker and Associates, Inc	2004
Rancho Algodones 22.9.19	Geohydrology and water availability Rancho Algodones subdivision, Rio Arriba County New Mexico.	Glorieta Geoscience Incorporated	2000
Cundiyo MDWA 20.10.20.211	Report on Driling and Test Pumping Exploratory Well, Cundiyo MDWC Association, Santa Fe County, New Mexico		
Alcalde Well 22.8.36	None -- unpublished data	John Shomaker and Associates, Inc	??
Rio Vista Estates** 23.7.29	Geohydrology and water availability Rio Vista Estates Subdivision, Rio Arriba County, NM	Glorieta Geoscience Incorporated	2003
Pojoaque Valley School well 19.08.14.32234	Results of pumping test, Pojoaque School well, Santa Fe County, NM.	Glorieta Geoscience Incorporated	1990
Pojoaque Valley Sch. Well # 3 19.08.14.342	Well Report for the Pojoaque Valley School District, Jacona Campus Well no. 3, RG-41225-S-5, Pojoaque, NM	John Shomaker and Associates, Inc	2005
Valley Estates 21.08.35.222	Well Report for Supplemental Water Well RG-01466-S-2, Valley Estates Mutual Water and Sewer Association, Inc., Española, Rio Arriba Co, NM	Souder, Miller, and Associates	2005

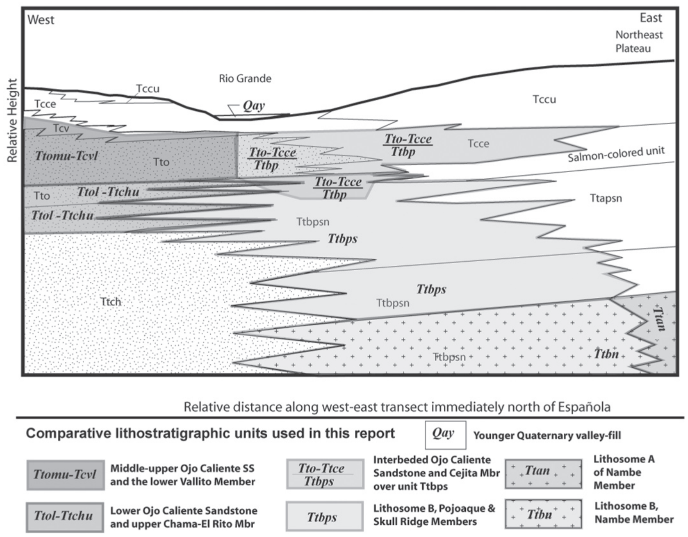

FIGURE 4. Comparative lithostratigraphic units used in this study, superimposed upon the lithostratigraphic units depicted in Figure 2.

B of the Nambe Member, the intercalated Ojo Caliente-Cejita Member together with underlying lithosome B of the Pojoaque Member, and the lower Ojo Caliente Sandstone-upper Chama El-Rito Member (Tables 2, 3). Absence of data for these units means that our interpretations of their hydrogeologic character must be considered as tentative and preliminary. The remainder of the comparative lithostratigraphic units had three or more aquifer test data: lithosome B of the Pojoaque-Skull Ridge Members, the lower Vallito Member and middle-upper Ojo Caliente Sandstone, and the Quaternary valley-fill sediments. Six pump-tests could not be used because the screen extends across two saturated units, one common case being saturated Quaternary valley-fill and the underlying Santa Fe Group; in that case one cannot isolate hydrologic data for a single unit and these units are sufficiently different to consider combining them.

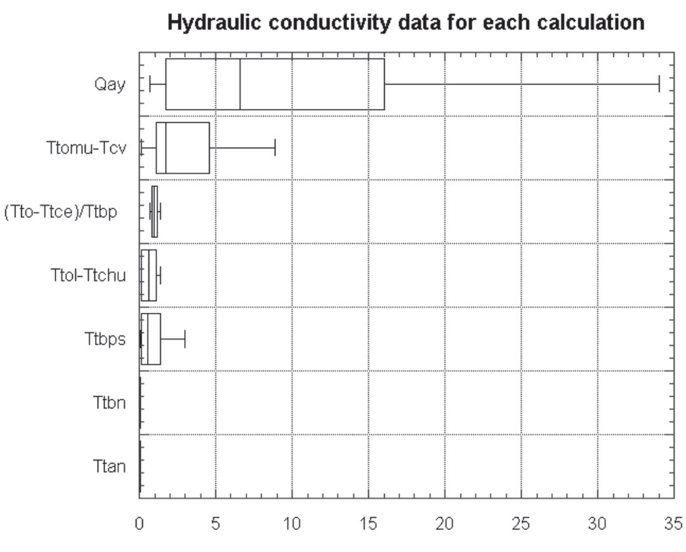

FIGURE 5. Box-and-whisker plot showing hydraulic conductivity values for each comparative lithostratigraphic unit using various calculations illustrated in Table 2 (aside from values potentially affected by flow barriers). For each calculation, both the maximum and minimum values are plotted. The vertical line in the larger rectangle is the median, the length of the larger rectangle represents the upper and lower quartile (25% above and 25% below the median), the bracket(s) represent the 95% range, and circles are outliers.

Santa Fe Group

The Santa Fe Group includes the Tesuque and Chamita Formations. These formations are generally composed of fluvial sediments derived from the Sangre de Cristo and Tusas Mountains. The Ojo Caliente Sandstone of the Tesuque Formation is primarily an eolian dune field deposit. The fluvial parts of these units are generally poorly to moderately sorted and locally may contain appreciable thicknesses of claystone or mudstone beds and volcanic ash beds (Table 3). The Ojo Caliente Sandstone is a moderately well-sorted, upper fine- to lower coarse-grained sand. The middle and upper part of the Ojo Caliente Sandstone is generally a medium- to coarse-grained sand and grossly coarser than underlying strata (Table 3).

Hydraulic conductivity in the range of ~0.1 to 3 ft/day typify most sediments in the Santa Fe Group, consistent with estimates of Hearne (1980) in the Pojoaque River valley. Exceptions are values of 0.7 to 9 ft/day (mostly 0.7-7.3 ft/day) obtained in the Agua Sana #1 and #2 wells, which draw from the middle and upper parts of the Ojo Caliente Sandstone together with the lower part of the Vallito Member of the Chamita Formation (Table 2). However, this same comparative lithostratigraphic unit produced lower values of 0.1-1.0 ft/day at the Tres Montes well (RG-74486). The comparative lithostratigraphic unit consist-

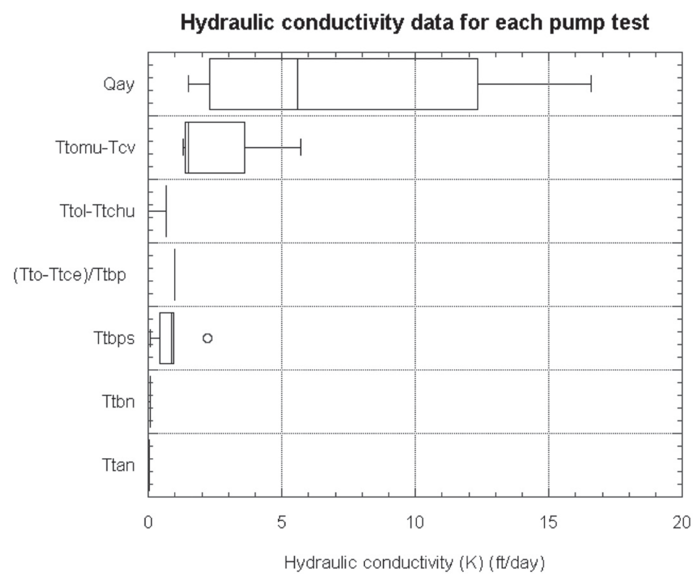

FIGURE 6. Box-and-whisker plot using the average of hydraulic conductivity values for each comparative lithostratigraphic unit for each pump test. The vertical line in the larger rectangle is the median, the length of the larger rectangle represents the upper and lower quartile (25% above and 25% below the median), the bracket(s) represent the 95% range, and circles are outliers.

TABLE 2. Selected well data*

Well name (see figure 4 for location)	TD (feet)	Lithostratigraphic unit *hydrostratigraphic units being pumped (Fig. 2)*	Depth to water prior to test (ft)	Pump discharge rate (gpm)	Total gallons pumped	Drawdown or recovery?	T (ft^2/day) (method of calculation)	Saturated filter pack thickness (ft)**	Saturated screen thickness (ft)	Hydraulic conductivity (K)*** Minimum (ft/day)	Maximum (ft/day)
Ojas #1	300	Pojoaque Mbr, lith A: 0-50?	53	25.2	14523	drawdown	49 (Jacob)	*247*	40	0.20	1.2
(Solacita)		Pojoaque Mbr, lower lith B: 50-300				recovery	221 (Jacob)	*247*	40	0.89	5.5
		(Ttbps)				recovery	59 (Jacob)	*247*	40	0.24	1.5
Espanola Well #6	360	Pojoaque Mbr, mix of lith B,	26	300	432000	recovery	3209 (NA)	335	211	10	15
		axial river, and eolian; Quat gravel					3183 (NA)	335	211	10	15
		(Qay and Ttbps)									
Espanola Well #8	450	Quaternary alluvium and inter-	15.38	275	253770	drawdown	809 (NA)	435	255	1.9	3.2
		bedded Ojo Caliente and Cejita Mbrs				recovery	748 (NA)	435	255	1.7	2.9
		(Qay & Ttbps & Ttch)									
Espanola Well #4	700	Lithosome B of Pojoaque Mbr	-1.16	418	601920	drawdown	139 (Jacob)	338	200	0.41	0.70
		(Ttbps)				recovery	335 (Jacob)	338	200	1.0	1.7
Espanola Well # 3	750	Ojo Cal SS-Cejita Mbr: 0-517 ft	355.91	418	8926222.8	drawdown	270 (Jacob)	395	240	0.68	1.1
		Lithosome B + eol sed: 517-800 ft				recovery	330 (Jacob)	395	240	0.84	1.4
		(Tto-Ttce)/Ttbp									
Espanola Well #9	340	Quaternary alluvium: 0-90 ft	10.43	50	16200	drawdown	39 (Jacob)	*310*	160	0.13	0.24
		Interbedded Ojo Caliente Sand and				recovery	39 (Jacob)	*310*	160	0.13	0.24
		Lithosome B of Pojoaque Mbr								not used in plots b/c of	
		(Tto-Ttce)/Ttbp								of pronounced GW barrier	
Agua Sana #1	1300	Ojo Caliente Sandstone and	467	464	5064000	average	3212 (Theis?)	726	460	4.4	7.0
	1300	Vallito Mbr ***(Ttomu-Tcvl)***	435.3	464	201979.2	drawdown	4095 (NA)	726	460	5.6	8.9
	1300		437.2	464	202860.8	drawdown	3343 (NA)	726	460	4.6	7.3
	1300		439.2	464	203788.8	drawdown	3343 (NA)	726	460	4.6	7.3
	1300		441.2	464	204716.8	drawdown	2824 (NA)	726	460	3.9	6.1
	1300		441.2	464	204716.8	drawdown	2776 (NA)	726	460	3.8	6.0
	1300		441.2	464	204716.8	drawdown	3276 (NA)	726	460	4.5	7.1
	1300		441.2	464	204716.8	drawdown	2824 (NA)	726	460	3.9	6.1
Agua Sana #1	1300	Ojo Caliente Sandstone and	477.49	292	8365624.8	drawdown	642 (Jacob)	726	460	0.88	1.4
(test shortly after		Vallito Mbr ***(Ttomu-Tcvl)***				recovery	1003 (Jacob)	726	460	1.4	2.2
completion)											
Agua Sana #2	1210	Ojo Caliente Sandstone and	511.8	326.6	NA	drawdown	704 (Theis)	639	410	1.1	1.7
		Vallito Mbr ***(Ttomu-Tcvl)***				recovery	469 (Theis)	639	410	0.73	1.1
							740 (Theis residual drawdown visual)	639	410	1.2	1.8
							709 (Theis confined)	639	410	1.1	1.7
							703 (Theis unconfined)	639	410	1.1	1.7
							540 (Theis residual drawdown computer)	639	410	0.84	1.3
							720 (Theis residual drawdown visual)	639	410	1.1	1.8

TABLE 2. (cont'd). Selected well data*

Well name (see figure 4 for location)	TD (feet)	Lithostratigraphic unit *comparative lithostratigraphic units being pumped (Fig. 2)*	Depth to water prior to test (ft)	Pump discharge rate (gpm)	Total gallons pumped	Drawdown or recovery?	T (ft^2/day) (method of calculation)	Saturated filter pack thickness (ft)**	Saturated screen thickness (ft)	Hydraulic conductivity (K)*** Minimum (ft/day)	Maximum (ft/day)
Tres Montes	505	middle of Ojo Caliente Sandstone	74	16	71040	drawdown	63 (NA)	*431*	60	0.15	1.0
(RG-74486)		***(Ttomu-Tcvl)***				recovery	56 (NA)	*431*	60	0.13	0.94
Cedar Ridge	600	Ojo Caliente SS: 0-300 ft (est)	180	28	302400	drawdown	86 (Jacob)	420	60	0.20	1.4
(MFM-Finch Well;		Chama-El Rito Mbr: 300-600 ft (est)				recovery	62 (Jacob)	420	60	0.15	1.0
RG-64461)		***(Ttol-Ttchu)***				recovery	66 (Theis)	420	60	0.16	1.1
Valle de Oro Encantado	225	Ojo Caliente and Quaternary	12.2	29	21228	drawdown	146 (NA)	209	10	0.70	15
(Exploratory well #1)		***(Qay)***				recovery	157 (NA)	213	10	0.74	16
San Juan Casino Well 1	1038	Ojo Caliente SS-Cejita Mbr: 0-517 ft	57.78	400	1386720	drawdown	706 (Jacob)	658	581	1.1	1.2
		Lith B + eolian sed (Poj Mbr): 517-800 ft				recovery	519 (Jacob)	658	581	0.79	0.89
		(Tto-Ttce)/Ttbp									
Phillip Kilgour well	115	Qay & Tesuque Fm (***Qay*** & ***Ttbn***)	35	NA	NA	NA	201 (NA)	*80*	20	2.5	10
Chimayo MDWCA	420	Qay to 37 ft, then Tesuque	150	NA	NA	NA	16 (NA)	270	200	0.061	0.082
(Exploratory well #1)		Fm below ***(Ttbn)***									
Rancho Algodones	250	240 ft Quaternary alluvium	84.22	35	176862	drawdown	190 (Jacob)	166	150	1.1	1.3
(RG-73133)		underlain by 10 ft Cejita Mbr clay (***Qay***)				recovery	281 (Jacob)	166	150	1.7	1.9
Cundiyo MDWC	405	Lithosome A of Nambe Mbr, Tesuque	146.2	25 for 5 hr	2590	drawdown	4 (Jacob)	*259*	80	0.015	0.050
(Exploratory well)		Fm (***Ttan***)		then 14		recovery	6 (Jacob)	259	80	0.022	0.070
Alcalde well	1501	Interbedded Vallito Mbr,	100	147	103194	drawdown	49 (Jacob)	1401	NA	0.03	NA
(RG-23017)		Cejita Mbr, and the Ojo Caliente SS				recovery	142 (Jacob)	1401	NA	0.10	NA
		(Ttomu-Tcvl and Tto-Ttbc/Ttbp)									
Rio Vista Estates	520	Quaternary alluvium over	37	~13.6	58735	No drawdown		*50-520*	300-500	No T calculated b/c of very	
(RG-80162)		upper Chama-El Rito Mbr ***(Qay & Ttchu)***								little drawdown	
Pojoaque Valley Sch.	673	Lithosome B, Pojoaque &	154	44	126720	recovery	86 (NA)	519	133	0.17	0.65
(RG-51977)		Skull Ridge Mbrs ***(Ttbps)***									
Pojoaque Valley Sch.	630	Lithosome B, Pojoaque &	198	51	510000	drawdown	49 (Jacob)	432	370	0.11	0.13
well #3; RG-41225-S-5		Skull Ridge Mbrs ***(Ttbps)***				recovery	25 (Jacob)	432	370	0.058	0.068
Valley Estates	423	Lithosome B, Pojoaque &	43	93.65	94,127	drawdown	364 (Jacob)	252	120	1.4	3.0
(RG-01466-S-2)		Skull Ridge Mbrs ***(Ttbps)***									
Cielo Encantado #1	120	Quaternary alluvium, lower 10 ft	84.59	23	116734.2	drawdown	4060 (NA)	*35*	20	116	203
		is Cejita Mbr clay (***Qay***)				drawdown	677 (NA)	*35*	20	19	34
						drawdown	156 (NA)	*35*	20	4.5	7.8
						recovery	625 (NA)	*35*	20	18	31
						recovery	232 (NA)	*35*	20	6.6	12

Notes:

T = Transmissivity; NA = not available.

*For a complete list of well data, including specifics of individual tests, see Koning et al. (2006, unpublished report for the NM Office of the State Engineer)

** Italicized numbers for saturated filter pack depths are speculative.

***Multiple values are derived for individual wells from different parts of the drawdown and/or recovery curves

TABLE 3. Comparative lithostratigraphic units near Española used in this study

Lithostratigraphic unit	Geologic character	Number of pump tests
Younger Quaternary valley-fill (Qay)	Valley-fill alluvium of loose to weakly consolidated sand, silt, and gravel.	3
Middle-upper Ojo Caliente Sandstone and the lower Vallito Member (Ttomu-Tcvl)	Cross-stratified, relatively clean and well-sorted, fine- to coarse-grained sand that is mostly medium- to coarse-grained (middle-upper Ojo Caliente Sandstone) overlain by laterally extensive, tabular beds of fine- to coarse-grained sand, minor silty very fine- to very coarse-grained sand, and minor silt-clay beds (lower Vallito Member of the Chamita Formation).	4
Lower Ojo Caliente Sandstone and upper Chama-El Rito Member (Ttol-Ttchu)	Well-sorted, cross-stratified to massive, fine- to medium-grained sand (lower Ojo Caliente Sandstone) overlying very fine- to medium-grained sand intercalated with minor sandy pebble-pebbly sand, volcaniclastic channel-fills and minor silt-clay beds (upper Chama-El Rito Member).	1
Interbedded Ojo Caliente Sandstone and the Cejita Member and the upper part of underlying lithosome B of the Pojoaque Member ((Tto-Ttce)/Ttbp)	Well-sorted, cross-stratified to massive, fine- to medium-grained sand (lower Ojo Caliente Sandstone) interbedded with silt-clay and muddy very fine- to fine-grained sand and channel-fills of sand and pebbly sand-sandy pebbles of the Cejita Member; this interfingering interval overlies lithosome B of the Pojoaque Member (which consists of interbedded silt-clay floodplain deposits with laterally extensive sand and pebbly sand channel-fills and very fine- to medium-grained eolian deposits). Pebbles lack granite and are mostly Paleozoic sedimentary rocks, quartzite, and volcanic clasts.	2
Lithosome B of the Pojoaque and Skull Ridge Members (Ttbps)	Interbedded silt-clay floodplain deposits with laterally extensive sand and pebbly sand channel-fills; pebbles lack granite and are mostly Paleozoic sedimentary rocks, quartzite, and volcanic clasts.	4
Lithosome B of the Nambe Member (Ttbn)	Generally clay, silt, and very fine- to fine-grained sand and muddy sand floodplain deposits that are intercalated with subordinate sand and pebbly sand channel-fills that are generally laterally extensive.	1
Lithosome A of Nambe Member, Tesuque Formation (Ttan)	Silty-clayey, poorly sorted sand in medium to thick beds interbedded with abundant channel fills of sandy pebbles to pebbly sand that are commonly weakly to strongly cemented by calcium carbonate; pebbles are mostly granitic.	1

ing of interbedded Ojo Caliente Sandstone-Cejita Members and underlying lithosome B of the Pojoaque Member appears to have slightly higher hydraulic conductivity (0.7-1.4 ft/day) relative to underlying lithostratigraphic units.

Quaternary valley-fill sediments

Wells drawing water exclusively from the younger Quaternary valley-fill sediments generally have high hydraulic conductivity that ranges from 0.7 to 34 ft/day and averages approximately 10 ft/day. These data support earlier inferences regarding the relative hydraulic conductivity of this unit (Hawley, 1995)

DISCUSSION

Quaternary valley-fill alluvium

The Quaternary valley-fill alluvium tapped by the examined wells is between 40 and 240 ft thick, whereas the maximum saturated thickness of Quaternary alluvium is 116 ft. Some units reported as Quaternary alluvium are not axial river gravel but include sediment derived from tributary arroyos (e.g., east of the Rio Grande in the Alcalde area). This tributary Quaternary alluvium may be less coarse-grained than axial-type fluvial deposits and therefore may have somewhat lower hydraulic conductivity values.

We conclude that the Quaternary alluvium underlying the modern river valleys generally constitutes the most permeable (i.e. highest-yielding) sediments in the northern Española Basin. Both its range of hydraulic conductivity (0.7 to 34 ft/day) and its average (10 ft/day) are significantly higher than those of the Santa Fe Group units. This result is probably due to the relatively coarse-grained nature of the valley-fill alluvium, together with its general lack of cementation and compaction.

The Quaternary valley-fill aquifer is also the most vulnerable to contamination because most people live on top of this shallow unit in the valleys. Specific water quality problems associated with this unit include high nitrates or coliform due to improperly spaced or sited septic tanks, and infiltration of solvents in some industrial areas.

Influence of faults on hydraulic conductivity

Analysis of drawdown curves of aquifer test data for the Agua Sana #1, Ojas #1, and the Española #8 and #9 wells showed that impermeable boundaries or low-permeability units were encountered, as indicated by steepening of the drawdown curves toward the end of long-term (>90 hr), constant pump-rate tests. Both the original reports and our geologic mapping indicate that the most likely factor causing the steepening of the drawdown curve in these wells is the presence of one or more faults. Faults can act as either barriers to groundwater flow (where cataclasis or crushing of rock or sediment in the fault zone creates a fine-grained, low permeability, steeply dipping zone) or as conduits for enhanced groundwater flow (where fracturing of competent rock enhances porosity). For sediment in the Española Basin, field observations of outcrops in addition to aquifer test analyses suggest that most faults here presently act as barriers to groundwater flow. If a fault initially acted as a conduit for groundwater flow, the relatively high flux of solutes may lead to enhanced cementation and subsequent plugging of flow paths. Therefore, it is possible that an individual fault can initially enhance groundwater flow and then later impede it.

One type of fault common in the Ojo Caliente Sandstone is the sand deformation band fault (Fig. 7). These faults, in addition to cementation effects, may influence hydraulic conductivity values (Goodwin et al., 1999). The middle to upper Ojo Caliente Sandstone has relatively high hydraulic conductivity east of the Santa Clara fault in Agua Sana wells #1 and #2 (0.73 to 8.9 ft/day) and lower hydraulic conductivity west of this fault at the Tres Montes well (0.13 to 1.0 ft/day). A single test of the lower Ojo Caliente Sandstone and uppermost Chama-El Rito Member west of the fault (MFM Finch well at Cedar Ridge) also showed a relatively low hydraulic conductivity (0.15 to 1.4 ft/ day). Field observations indicate more small-scale faults and localized cementation on the western, footwall side of the Santa Clara fault (fault shown in Fig. 1) and this may partly or wholly account for this apparent difference in hydraulic conductivity. It should be noted that the Agua Sana wells are roughly twice as deep as the Cedar Ridge (MFM Finch) and Tres Montes wells, and that the first aquifer test shortly after initial completion the Agua Sana well #1 gave a relatively low hydraulic conductivity (0.88 to 2.2 ft/day). These values and the average of this range, however, are still higher than that of wells in the Ojo Caliente Sandstone west of the Santa Clara Fault. These faults and cementation will probably also result in lower than expected yields in the stratigraphic gradation between the Ojo Caliente Sandstone and the underlying Chama-El Rito Member immediately west of the Santa Clara fault. However, higher values of transmissivity and hydraulic conductivity may be present in the Ojo Caliente Sandstone and Chama-El Rito Members in areas distant from major fault zones.

Hydrogeologic character of the comparative lithostratigraphic units

Our limited data set suggests a steady decrease in hydraulic conductivity with stratigraphically lower comparative lithostratigraphic units in the Santa Fe Group, and that Quaternary valley-fill sediments can be expected to have the highest conductivity (Figs, 5, 6). This is likely due to a general coarsening-upward

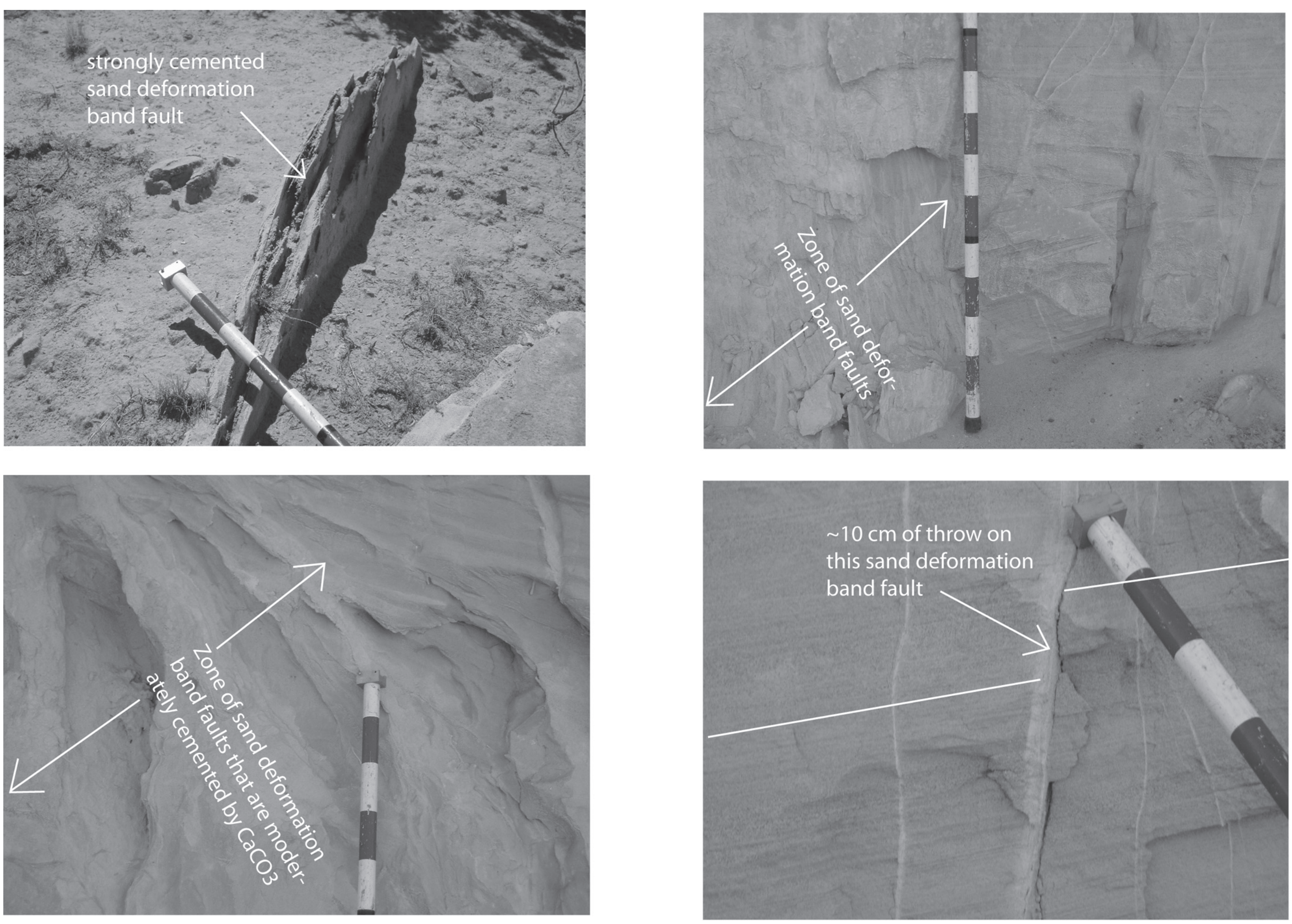

FIGURE 7. Examples of sand deformation band faults near the MFM-Finch Well (upper left) and the Tres Montes Well (remaining three photos). Increments on staff are 10 cm.

trend in the Santa Fe Group (Koning, 2002a, b; 2003; Koning et al., 2005), the relatively well-sorted nature of the stratigraphically high Ojo Caliente Sandstone, and the loss of pore space in stratigraphically older strata owing to more compaction and cementation.

The lower part of the Tesuque Formation is represented by two lithostratigraphic units, one in lithosome A one in lithosome B of the Nambe Member. Each of these units had a single aquifer test in our database; these two tests indicated a low hydraulic conductivity of 0.015 to 0.082 ft/day. These low values may possibly characterize the lower Tesuque Formation unless coarse-grained, high-permeablility channel-fill deposits happen to be encountered that are both extensive and hydraulically connected to other channel fills.

Hydraulic conductivity for lithosome B of the Pojoaque – Skull Ridge Member and the upper Chama-El Rito Member and lower Ojo Caliente Sandstone exhibits a wide range of 0.058 to 3.0 ft/day. Thus, wells in these aquifers potentially may produce slightly higher yields and hydraulic conductivities than the lower part of the Tesuque Formation. However, the paucity of pumping test data for the lower part of the Tesuque Formation makes this comparison tenuous.

The two comparative lithostratigraphic units that include the Ojo Caliente Sandstone had several aquifer tests that yielded a range of hydraulic conductivity of 0.13-8.9 ft/day, which indicate generally higher-yielding units relative to other Santa Fe Group units. However, groundwater movement in the Ojo Caliente Sandstone is also affected by cementation and sand deformation band faults, as discussed above.

CONCLUSIONS

Our preliminary findings are as follows:

1. Quaternary alluvium, where adequately saturated, is the best unit for high-yielding wells. However, it is also the most vulnerable to contamination.

2. Two of our comparative lithostratigraphic units involving the Ojo Caliente Sandstone may offer higher-yielding zones relative to other Santa Fe Group, basin-fill units. These are 1) the Ojo Caliente Sandstone and the overlying Vallito Member of the Chamita Formation; and 2) intercalated Ojo Caliente Sandstone and Cejita Member strata underlain by lithosome B of the Pojoaque Member. Aquifer tests conducted on these two units yielded hydraulic conductivity of 0.13-8.9 ft/day. Factors that may significantly limit well production in these two units include barriers or impermeable boundaries from faults and reduced permeability from secondary mineralization (cementation). Such faults and cementation seem to be relatively common in the vicinity of the confluence of the Rio Ojo Caliente and Rio Chama, located a few kilometers northwest of the Santa Clara fault. These barrier boundary conditions have the potential to reduce yields to nearby wells.

3. Hydraulic conductivity decreases in stratigraphically lower lithostratigraphic units in the Tesuque Formation, with a range from 0.1 to 3 ft/day. Lithosome B of the Pojoaque and Skull Ridge Members is on the higher end of that range. Based on limited data, hydraulic conductivity may generally decrease down section within the Tesuque Formation.

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