4 WATER SUPPLY

REGIONAL WATER PLAN • RIO CHAMA WATERSHED

CHAPTER 4

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FIGURES

INTRODUCTION

The following discussion of water supply available within the Rio Chama watershed is based on research conducted from 1999 to 2001 by David Morgan of La Calandria Associates, Inc., and Linda Fluk, with assistance from C. Martinez and Dr. W.J. Stone. The USGS performed a flow duration analysis for the gaging stations at La Puente and Chamita on the Rio Chama mainstem, and La Madera on the Rio Ojo Caliente. Geological cross-sections were drawn by Andrea Kron.

This chapter on water supply is organized into four principal subsections concerning surface water supply, ground water supply, water quality, and a discussion of geohydrology and water resources in individual communities throughout the planning region. Information presented here is summarized, along with water demand information, in the **WATER BUDGET** chapter.

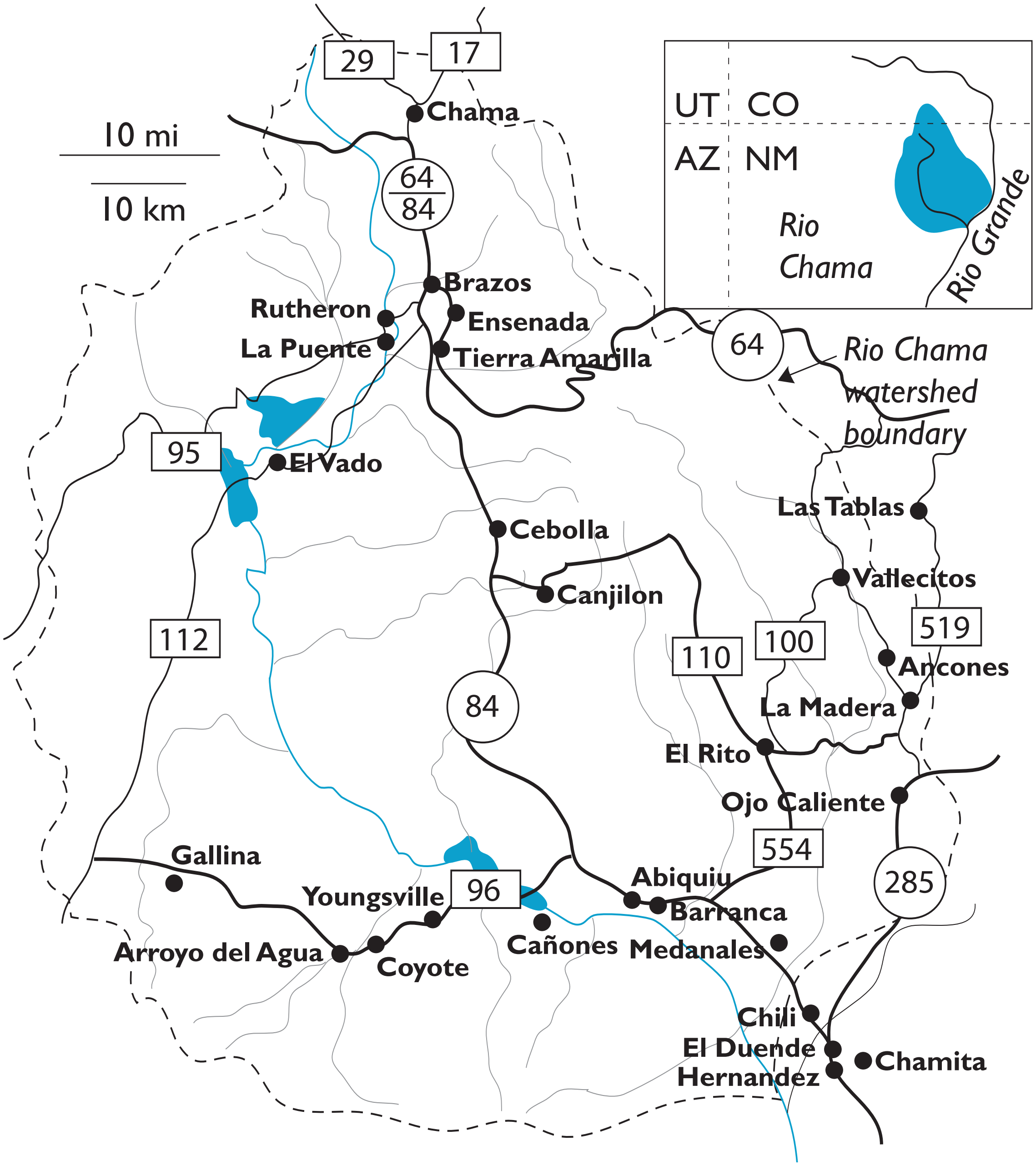


FIGURE 4-1: RIO CHAMA WATERSHED MAP

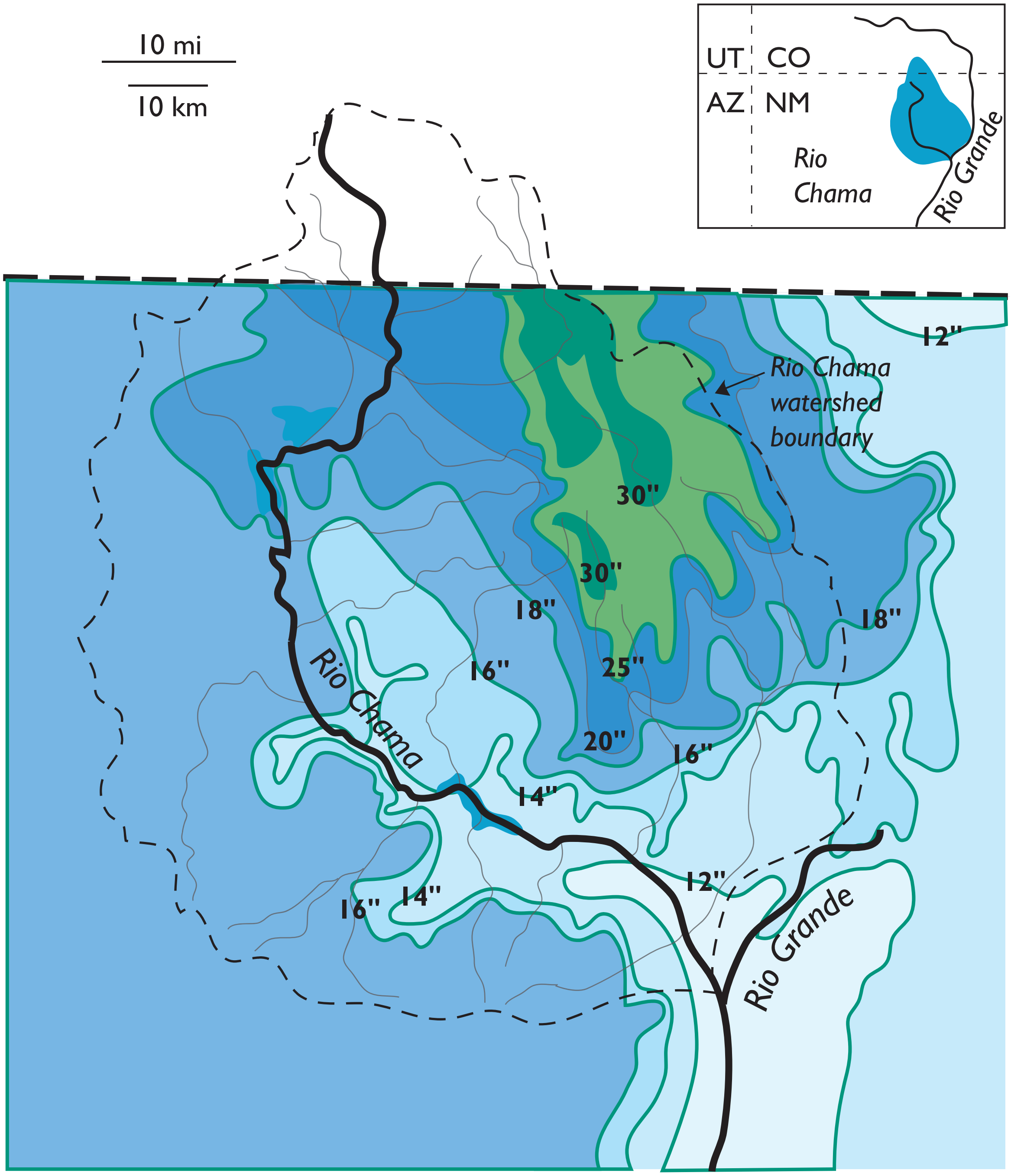


FIGURE 4-2: AVERAGE ANNUAL PRECIPITATION MAP

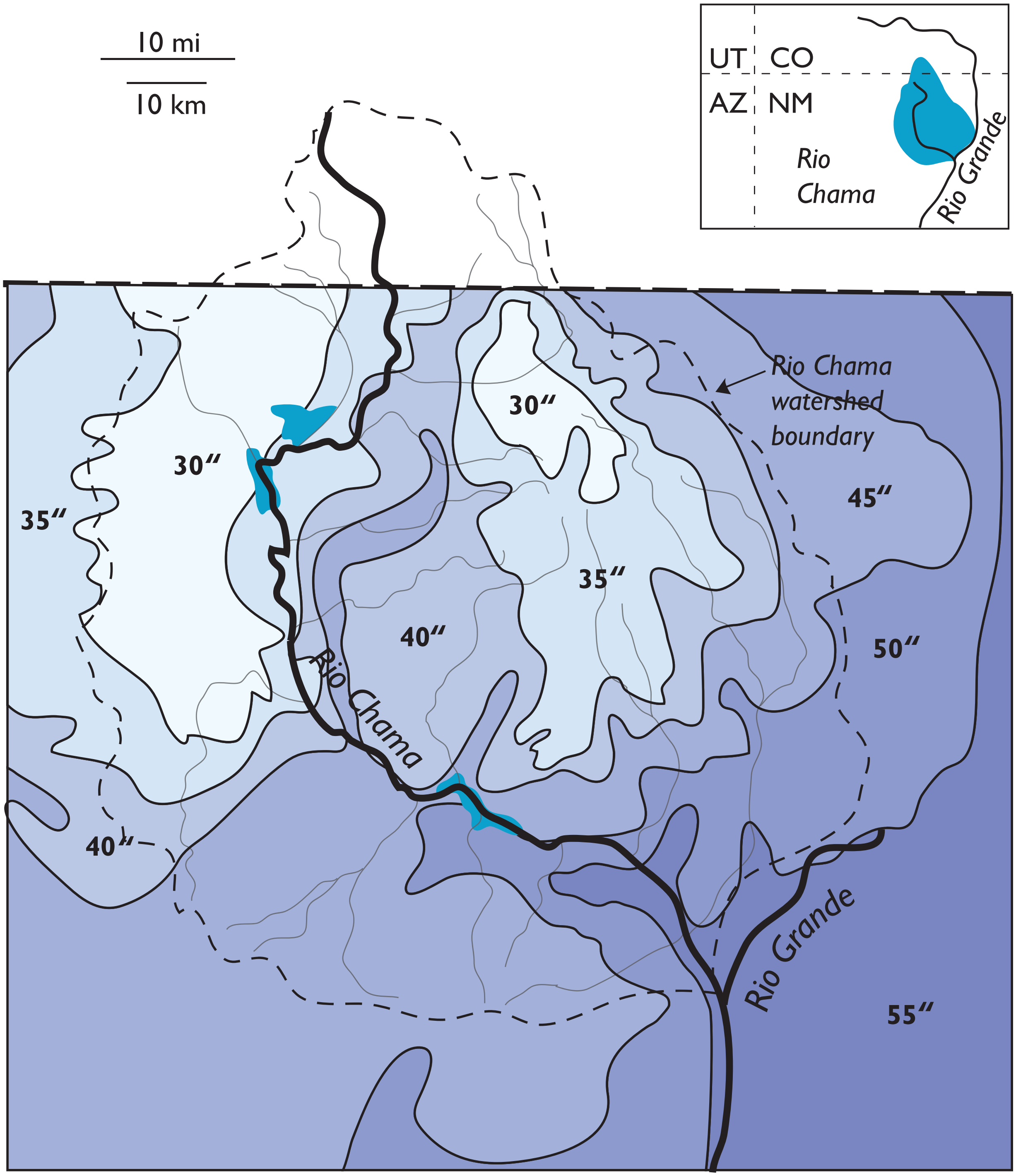


FIGURE 4-3: AVERAGE ANNUAL LAKE EVAPORATION MAP

SURFACE WATER SUPPLY

DRAINAGE BASINS AND WATERSHED

A map of the Planning Region, showing the watershed boundary and principal tributaries, appears above as Figure 4-1. The total land area of the Rio Chama watershed is approximately 3,157 square miles (EPA *Surf Your Watershed web site*), or 2,020,480 acres. Elevations in the planning region range from 11,410 feet at the top of Brazos Peak to 5,620 feet at the confluence of the Rio Chama and the Rio Grande.

The watershed of the Rio Chama and its tributaries define our planning region and provide the only surface water supplies available, except for water imported by the San Juan-Chama Project. San Juan-Chama water is diverted into the Rio Chama but for all practical purposes is not available for use within the Region. The Rio Chama has thirteen tributaries that can support any appreciable irrigated agriculture: Cañones Creek, Rio Brazos, Rito de Tierra Amarilla, Rio Nutrias, Rio Cebolla, Rio Gallina, Rito de Canjilon, Rio Puerco de Chama, a second Cañones Creek, El Rito, Rio del Oso, Abiquiu Creek, and Rio Ojo Caliente (which itself is fed by the Rio Vallecitos and the Rio Tusas). Willow Creek, although supporting little irrigation or settlement itself, assumed new importance after the San Juan-Chama Project since Heron Reservoir was constructed on Willow Creek immediately above its confluence with the Chama. Water from the San Juan River system is diverted into Willow Creek via the Azotea Tunnel. Some limited irrigation also occurs in small tributaries just south of Willow Creek, such as those draining Stinking Lake or Horse Lake, located on the Jicarilla Apache Reservation.

The great majority of the landscape within the Rio Chama watershed is rugged, hilly to mountainous, and wooded. Woodland types vary from piñon-juniper, sparse at lower elevations, through Ponderosa pine and some Douglas fir at intermediate elevations, to alpine spruce-fir forest, aspen groves, and montane grassland meadows at the higher elevations above Chama and Tierra Amarilla. There are substantial areas dominated by aspen in the highlands above Canjilon and in the Tusas Mountains. All appreciable irrigated acreage in our region is located in alluvial valley bottoms where hand-dug acequias were practical. Approximately 30,000 acres are irrigated altogether (RCAA, 1997). Elevations of irrigated fields range from over 8000 feet in the area above Chama and nearly 7500 feet in large areas near Tierra Amarilla, to about 5650 feet around Hernandez and Chamita. Because of this difference in altitude, the growing season varies from about 105 days in Chama and Tierra Amarilla to over 140 days near Española (Henderson and Sorensen, 1968).

The Rio Chama itself is gaged in several places, and the trans-mountain water diverted by the San Juan-Chama Project into Willow Creek, Heron Reservoir, and ultimately in to the Rio Chama, is monitored both above and below Heron reservoir. The only tributary that is now gaged, however, is the Rio Ojo Caliente near La Madera (just below the confluence of Rio Vallecitos and Rio Tusas). Several stations now report only peak flows, and do not record daily flow data. These stations are Wolf Creek, Rito de Tierra Amarilla, Rio Nutrias, Canjilon Creek, and Arroyo Seco. See the discussion of **Gaging station information** below for more details.

Ground water resources in the Rio Chama watershed are not as well explored as in most other parts of New Mexico because historic water use here has been much more oriented towards surface water. Our lack of widespread dependence on ground water stems from several factors: there are no major urban areas within the planning region (Española is just outside it); agriculture and the entire community structure of the region have evolved over generations around the acequia system; and surface water resources are relatively more available than in much of New Mexico. However, even though the great majority of the water diverted or consumed in the region is surface water, the great majority of all households, institutions, and businesses derive domestic water from wells, either individually or through community water systems. For that reason, communities are highly dependent on ground water sources. In some cases they are not plentiful, and in other cases they suffer from water quality problems. These issues are discussed more fully in the **GROUND WATER SUPPLIES** and **WATER QUALITY** sections below.

PRECIPITATION AND EVAPORATION

The ultimate source of all the water in our Region, just as everywhere else on earth, is precipitation that falls as part of the hydrologic cycle. Except in the higher elevations of the Rio Chama watershed, natural precipitation is generally less than the rate of evaporation from the land surface, resulting in an arid climate where open water is scarce and agriculture generally requires irrigation. Most other human uses of water in the Region depend on access to ground water, geologically stored beyond the reach of evaporation.

Both ground and surface water depend almost entirely on precipitation that falls on the higher elevations in the region. Average annual precipitation varies from around 10 inches per year at the confluence of the Rio Chama and the Rio Grande near San Juan Pueblo to over 35 inches per year in the Tusas, San Juan, and Jemez Mountains (Western Regional Climate Center, web site, 2001). It is the higher-elevation, higher-precipitation areas that yield a moisture surplus in the form of surface water runoff and ground water recharge and storage and make possible our uses of water, even though those uses take place downstream or downgradient at lower elevations.

The climate in our region, as in most of the western part of the country, is not only arid but highly variable. The old saw about "…we only get a normal year about one in twenty" is quite literally true here. The arithmetic mean annual precipitation in any given location is not an amount that will occur often – usually significantly more or less than the mean will occur. It is also worth noting that in precipitation as well as in streamflow the mean value is usually higher than the median. In other words, the long-term average is raised by infrequent wet years, and more years of precipitation or streamflow will occur below the average than above it.

The variability of climate in our planning region can be seen in the National Climatic Data Center (NCDC) and the Western Regional Climate Center (WRCC) "monthly normals" for El Rito, for example (see Appendix B). The mean annual precipitation is 12.2 inches, but the minimum during the period from 1961 to 1990 is 8.1 inches while the maximum is 17.7. In any given month, the range of variability is even greater. For instance, in August the minimum precipitation recorded was 0.23 inches (in 1962) while the wettest August (in 1967) had 6.85 inches. The statistical average for August is 2.2 inches, so the minimum for the period of record is 1/10 of the average, while the maximum is over 3 times the average. This range of variability is quite typical of the region as a whole, although in general the drier the location the greater the variability.

Temperature and Precipitation Monitoring Stations

There are eleven National Weather Service (NWS) cooperative observer network stations now active in the region. Most record daily measurements of maximum and minimum temperature and total precipitation, although three (Brazos Lodge, Canjilon Ranger Station, and Ghost Ranch) record only precipitation. There are also seven more now-inactive stations for which data are nevertheless available for varying periods of record. Information about the currently active stations is summarized in Table 4-1, while the inactive stations are summarized in Table 4-2.

Statistical summaries for the active stations are presented in Appendix B. Figures 4-2 and 4-3 illustrate long-term average precipitation (SCS, 1951) and lake evaporation levels (SCS, 1972) in the Rio Chama watershed.

The average precipitation map in Figure 4-2 is based on data compiled by National Oceanic and Atmospheric Administration (NOAA) for the period 1921 through 1950. Data are also available from NOAA for the period from 1961 through 1990, and the averages from the 1961-90 data set are generally wetter than the earlier data. The average precipitation values in the 1951 map were the ones used for estimating total precipitation, mean winter precipitation, streamflow, and recharge elsewhere in this report because we believe it prudent in planning to use the driest reasonable data set rather than the wettest. The average annual evaporation map in Figure 4-3 is based on the map entitled Gross Annual Lake Evaporation, New Mexico published by the USDA Soil Conservation Service in April of 1972.

Snowpack Monitoring Stations

There are four "SNOTEL" snowpack monitoring stations located in the Rio Chama valley although one of them (the Cumbres trestle site), located just over the state line in Colorado, is therefore strictly speaking just outside the planning region. Its information is, however, quite useful for our purposes. The stations are maintained, and data published, by the Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture. Station information is presented in Table 4-3 below.

TABLE 4-1: ACTIVE NWS CO-OPERATIVE OBSERVER NETWORK STATIONS

NWS no.	Station	Lat.	Long.	Elev.	Period of continuous record	Notes
290041	Abiquiu Dam	36°14′	106°26′	6380	1986 - present	Discontinuous records 1957 -1986
291180	Brazos Lodge	36°44′	106°27′	7980	1970 – present	Precipitation only
291389	Canjilon R.S.	36°29′	106°27′	7830	1946 - present	Precipitation only
291664	Chama	36°55′	106°35′	7850	1969 – present	Discontinuous records 1946 –1969
292608	Dulce	36°57′	107°00′	6790	1978 - present	Discontinuous records 1946 –1978
292820	El Rito	36°20′	106°11′	6870	1946 – present	
292837	El Vado Dam	36°36′	106°44′	6740	1973 – present	Discontinuous records 1946 –1973
293031	Española	36°00′	106°05′	5640	1981 – present	Discontinuous records 1938 –1981
293511	Ghost Ranch	36°20′	106°23′	6460	1963 – present	Precip. only; Disc. records 1947 – 1963
294960	Lindrith	36°17′	107°02′	7360	1988 – present	Discontinuous records 1971 –1988
298845	Tierra Amarilla	36°46′	106°33′	7460	1989 – present	

TABLE 4-2: INACTIVE NWS STATIONS FOR WHICH DATA ARE AVAILABLE

NWS no.	Station	Latitude	Longitude	Elevation	Complete period of record (including discontinuous periods)
290606	Aspen Grove Ranch	36°39′	106°11′	9710	1946 – 1972
290795	Bateman Ranch	36°31′	106°19′	8910	1946 – 1970
291690	Chamita	36°04′	106°07′	5870	1979 – 1981
294650	La Madera	36°21′	106°03′	6600	1947 – 1949
296321	Ojo Caliente	36°18′	106°03	6300	1949 – 1982
297346	Regina	36°11′	106°57′	7450	1946 - 1969
298555	Stinking Lake	36°28′	106°51′	7210	1948 – 1956

TABLE 4-3: SNOTEL SNOWPACK MONITORING STATIONS

Station	Latitude	Longitude	Elevation
Bateman	36°01′	106°19′	9300
Chamita	36°57′	106°39′	8400
Cumbres Trestle (Colorado)	37°01′	106°27′	10020
Hopewell	36°43′	106°16′	10000

The NRCS uses the data collected from the SNOTEL stations to prepare "Snow – Precipitation Updates" presenting data on snowpack depth and water content on a daily basis. These are available on-line, and an example is included in Appendix B. The data are also interpreted on a regular basis to prepare "Basin Outlook Reports" for major stream systems (the Chama is included in the Rio Grande Basin Outlook Report) and "Surface Water Supply Index" maps. Examples of these products are also included in Appendix B. In addition, data can be downloaded in the form of a graph of any or all of snow depth, snow water content, and temperature at an individual SNOTEL station. Such a graph appears in Appendix B for the Cumbres Trestle site for the period from October 1, 1994 through October 1, 2000.

Snowpack is obviously a critical variable in determining streamflow. It is not the only variable, however. Summer rainfall is important in affecting the distribution of the runoff throughout the year as well as the total annual runoff in all the tributary basins to the Rio Chama. Snowpack largely determines the volume of springtime runoff available. By the end of June, most of the water resulting from snow melt has run off, and streamflow during the critical summer growing season is strongly influenced by summer rainfall in the upper reaches of the subbasins and by the degree of moisture storage in the soil and shallow aquifers of the upper watersheds.

Snowpack, as with other aspects of climate in the Southwest, is highly variable. A glance at the Cumbres Trestle graph in Appendix B shows that just in the winters from 1994-5 to 1999-2000 the range of annual accumulated snow water content varies by almost a factor of three, from about 16 inches to about 42 inches of water equivalent (Western Regional Climate Center web site).

Evaporation Monitoring Stations

Only one of the NWS cooperative stations listed in Table 4-1 above, Abiquiu Dam, monitors pan evaporation (Joe Alfieri, personal communication, 2002). However, two additional stations (not part of the NWS system) measure pan evaporation within the Rio Chama watershed, in addition to the station at Abiquiu Dam. Pan evaporation is measured daily at El Vado and Heron Dams, and lake evaporation is estimated from the pan data. The brief description of the procedure given below is based on information supplied by personnel from National Weather Service, Bureau of Reclamation, and Army Corps of Engineers. The general procedure for calculating reservoir evaporation is the same; however equipment, assumptions, and mathematical modeling performed by the three agencies may differ. The general procedure is as follows:

- The height of the reservoir water surface level is measured daily (the average water surface area is computed using an equation or curve that correlates gage height with reservoir surface area).
- Wind movement, precipitation, and temperature, are measured daily at the damsite weather stations.
- Evaporation pans are located at the dams, and pan measurements are taken daily in accordance with National Weather Service protocols.
- Adjustment is made for the effects of ice cover during winter months. The ice cover is estimated and monthly winter averages are used.
- The gross lake evaporation rate is computed by multiplying the observed pan evaporation by the pan coefficient (0.7 is commonly used).
- The net evaporation rate is computed by subtracting the measured rainfall from the gross evaporation.
- The net volume of water evaporated is computed by mutiplying the exposed surface area by the net lake evaporation rate.

Table 4-4 presents the available pan evaporation data from within the watershed. Data are from the New Mexico Climate Center (NMCC) web site *(weather.nmsu.edu/Pan_Evaporation/), and BOR and ACE (www.spa.usace.army.mil/urgwom/).* Evaporation rates are greater at lower elevations, and typically peak in June. The June average pan evaporation rates for Heron, El Vado, and Abiquiu Dam sites, respectively, are 7.5 inches, 8.7 inches, and 10.8 to 11.4 inches. The annual average pan evaporation rates for Heron, El Vado, Abiquiu Dams are 40.4 inches, 47.6 inches, and 63.5 to 76.5 inches, respectively. The two values given for Abiquiu Dam represent differing data collected by the Corps of Engineers and NMCC, respectively.

Pan evaporation rates, shown in Table 4-4, are greater than actual lake evaporation. Pan evaporation is observed at a standard Class A pan installation. A Class A pan is 47.5 inches in diameter, 10 inches deep, and made of 22-gauge unpainted galvanized iron. It is supported on a wooden pallet so that the bottom of the pan is

TABLE 4-4: PAN EVAPORATION DATA

Station	Statistic	Pan Evaporation (inches)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abiquiu Dam Elev: 6380 ft.	Maximum			4.8	9.4	12.5	13.9	12.6	10.4	9.1	7.3	3.6	
	Minimum			4.8	5.9	7.5	8.8	7.9	7.6	5.7	3.1	2.2	
1964 – 1995	Mean				7.4	9.8	11.4	10.7	8.9	7.2	5.3	2.9	

New Mexico Climate Center data

Station	Statistic	Pan Evaporation (inches)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abiquiu Dam Elev: 6380 ft.	Daily mean	0.08	0.13	0.2	0.24	0.31	0.36	0.33	0.27	0.23	0.17	0.12	0.07
	Monthly mean	2.5	3.60	6.20	7.20	9.60	10.80	10.20	8.40	6.90	5.30	3.60	2.20
1964 – 1995													

Corps of Engineers data

Station	Statistic	Pan Evaporation (inches)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
El Vado Dam Elev: 6740 ft.	Maximum				7.9	10.2	10.8	10.9	9.3	7.8	4.9	1.8	
	Minimum				3.2	0.5	7.0	6.8	5.1	3.8	2.1	1.2	
1948 – 1995	Mean				5.3	7.2	8.7	8.5	6.9	5.6	3.8	1.5	

New Mexico Climate Center data

Station	Statistic	Pan Evaporation (inches)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heron Dam Elev: 7190 ft.	Daily mean				0.15	0.19	0.25	0.25	0.2	0.17	0.11		
	Monthly mean				4.50	5.89	7.50	7.75	6.20	5.10	3.41		
1964 – 1995													

Bureau of Reclamation data

raised six inches above the ground to allow air circulation under the pan. The pan is filled with water to within two inches of the top and is refilled as soon as the water level drops one inch. The depth of the water is measured, as well as the wind velocity, precipitation, and temperature (Wilson and Lucero, 1997).

A Class A pan differs from an open body of water in many respects. The pan permits transfer of heat to and from its sides and bottom due to radiation exchange and to transfer of sensible heat. The pan color and water depth affects the emission and absorption of radiant energy, air turbulence, and convection of heat within the water. These effects produce an evaporation rate that is greater than that of a natural open body of water. The ratio of lake evaporation to pan evaporation is referred to as the pan coefficient. A pan coefficient of 0.70 is typical for large water bodies, and 0.80 for small water bodies such as ponds or stock tanks (Wilson and Lucero, 1997).

A map of gross annual lake evaporation for the Rio Chama Watershed is included as Figure 4-3 above. Evaporation rates shown in the map are lower than those in Table 4-4 above because the figures in the table are pan evaporation while the map values are for lake evaporation, derived by reducing pan evaporation by an appropriate pan coefficient. Evaporation from area reservoirs is discussed further below in the **Reservoir Evaporation** section of this chapter.

Precipitation Data

Precipitation was estimated for the thirteen tributary basins in the watershed. This was done by producing an isohyetal precipitation map at a scale of 1:250,000 and overlaying this map with a USGS map of tributary watersheds and 1/8″ graph paper. Graph paper squares were counted in each isohyetal band within each tributary watershed. The total number of squares in each isohyetal band in each tributary watershed was converted to square miles, corrected proportionally so that the total area of counted squares matched the known total watershed area, and multiplied by the average precipitation in that isohyetal band. Total precipitation in each isohyetal band was summed for the tributary watersheds. Estimated average annual precipitation for the Rio Chama sub-watersheds is shown in Table 4-5.

Upland Evapotranspiration Data

Native or upland evapotranspiration is very difficult to measure, and no direct measurements have been reported in the Rio Chama watershed. However, some studies have been made of evapotranspiration in geographically, ecologically, and topographically similar areas to parts of the planning region, and a summary of results from these studies is presented in Table 4-6.

Many factors influence evapotranspiration rates, including available precipitation or other moisture, vegetation type, vegetation density, total leaf area, soil type, temperature, humidity, day length, solar radiation intensity, and wind velocity. In the southwest many but not all of these factors vary systematically with altitude. Total leaf area in the vegetation community may be the most influential single variable in predicting evapotranspiration rates (Dr. Cliff Crawford, personal communication, 2002). However, no measurements of leaf area index or any of the other principal variables affecting evapotranspiration have been reported in the Rio Chama watershed. Table 4-7 summarizes the results of a compilation of information including evapotranspiration rates (from Table 4-6), available precipitation (from Table 4-5), predominant vegetation type (from field visits and BLM vegetation mapping), and typical basin elevations (from USGS topographic maps) for the Rio Chama tributaries. Using best available information for these variables, evapotranspiration rates were estimated for the different tributary watersheds in the region.

Table 4-7 presents the results from a simplified model that assumes, as a first approximation, that all precipitation in areas receiving less than 16 inches per year is evaporated or transpired. Chloride studies suggest that recharge in areas receiving less than 16 inches of annual precipitation

TABLE 4-5: AVERAGE PRECIPITATION BY TRIBUTARY BASIN

Tributary watershed	Area (sq. mi.)	Avg. precip. (in.)	Total precip. (acre-ft/yr)
Rio Chama above Cañones Cr.	181.0	28.1	271,304
Cañones Creek	28.7	25.5	39,086
Rio Brazos	163.1	27.6	240,083
Rito de Tierra Amarilla	63.1	21.7	73,062
Horse Lake etc.	366.0	17.5	341,581
Willow Creek	113.7	20.1	121,908
Rio Nutrias	119.4	18.0	114,595
Rio Cebolla	124.3	15.8	104,735
Canjilon Creek	153.5	17.9	146,560
El Rito	143.9	18.0	138,182
Rio Gallina	277.8	17.8	263,725
Rio Puerco de Chama	213.9	21.1	240,754
Cañones and Polvadera	82.3	24.5	107,513
Rio del Oso	49.9	21.6	57,439
Abiquiu Cr. and Barranco	51.3	19.9	54,489
Rio Vallecitos	175.1	22.7	212,024
Rio Tusas	198.5	20.8	220,169
R. Ojo Caliente below La Madera	202.6	13.4	144,820
Area not in major tributaries	448.8	15.6	373,368
Totals	**3,157.0**	**20.4**	**3,265,398**

TABLE 4-6: REPORTED EVAPOTRANSPIRATION ESTIMATES

Vegetation type	Average annual ET* (inches)	Location	Elevation range (feet)	Avg. annual precip. (in)	Method of estimating ET*	Reference
Aspen-Herbaceous meadow	18.7	Utah	7,000-10,000	53	Soil-moisture and runoff plots	Croft and Monninger, 1953
Herbaceous meadow	14.8	Utah	7,000-10,000	53	Soil-moisture and runoff plots	Croft and Monninger, 1953
Juniper	16.3	Arizona	4,900	17	Lane and Barnes (1987) model	Stone, 1995
Juniper	17.0	Arizona	6,200	22	Lane and Barnes (1987) model	Stone, 1995
Ponderosa	19.4	Arizona	7,400	25	Lane and Barnes (1987) model	Stone, 1995
Ponderosa, Piñon-Juniper, Aspen	16.6	Santa Fe area, NM	6,500-12,600	24	Troendle and Leaf	Wasiolek, 1995

**ET is evapotranspiration*

TABLE 4-7: ESTIMATED EVAPOTRANSPIRATION

Watershed	Area (Sq. mi.)	Est. ET (in.)	Total precip. (acre-ft/yr)	Total Est. ET (acre-ft/yr)	Est. yield (acre-ft/yr)
Rio Chama above Cañones Cr.	181.0	16.0	271,304	154,479	116,825
Cañones Creek	28.7	16.0	39,086	24,525	14,562
Rio Brazos	163.1	16.0	240,083	139,179	100,905
Rito de Tierra Amarilla	63.1	16.0	73,062	53,871	19,192
Horse Lake etc.	366.0	17.5	341,581	339,019	2,563
Willow Creek	113.7	18.5	121,908	112,325	9,583
Rio Nutrias	119.4	18.0	114,595	108,839	5,757
Rio Cebolla	124.3	17.0	104,735	103,729	1,006
Canjilon Creek	153.5	18.5	146,560	139,628	6,933
El Rito	143.9	18.5	138,182	126,121	12,062
Rio Gallina	277.8	17.5	263,725	254,596	9,129
Rio Puerco de Chama	213.9	19.5	240,754	206,186	34,568
Cañones and Polvadera	82.3	19.5	107,513	87,699	19,813
Rio del Oso	49.9	19.0	57,439	45,328	12,111
Abiquiu Cr. and Barranco	51.3	19.0	54,489	47,109	7,830
Rio Vallecitos	175.1	19.5	212,024	178,671	33,353
Rio Tusas	198.5	19.5	220,169	195,514	24,655
R. Ojo Caliente below La Madera	202.6	17.0	144,820	144,820	0
Area not in major tributaries	448.8	19.0	373,368	366,784	6,585
Totals	**3,157.0**		**3,265,398**	**2,828,419**	**436,979**

may in fact be greater than zero, but it is likely to be quite small (Dr. W. J. Stone, personal communication, 2002). In areas that get more than 16 inches of average annual precipitation, estimated evapotranspiration values were subtracted from the estimated average precipitation for those areas. Land areas and average precipitation in areas with more and less than 16 inches of annual precipitation were calculated using the isohyetal map overlay system described above. Any of the precipitation volume left after subtracting estimated evapotranspiration from estimated precipitation in areas with over 16 inches was considered potential watershed yield, but no attempt was made to estimate how this yield would be apportioned between surface runoff and ground water recharge. These yield values are presented in the last column of the table.

It is important to note that the values presented in Table 4-7 are not based on direct measurements or site-specific data: total upland evapotranspiration in the Rio Chama watershed is not exactly 2,828,419 acre-feet per year; and watershed yield is also not exactly 436,979 acre-feet per year. There are many sources of uncertainty in the inputs, especially for the ET rates, which are plausible numbers within the range of relevant published estimates, considering tributary basin altitude, precipitation, and vegetation characteristics. The table is only meant to suggest that total upland evapotranspiration in the watershed may be approximately 2,800,000 acre-feet a year on average, and total yield in the watershed may be approximately 437,000 acre-feet per year, with unknown ranges of error. Table 4-7 is not meant primarily as a way to estimate runoff or total watershed yield, but the resulting figure of about 437,000 acre-feet per year as average yield compares closely with other estimates, as discussed in the **Estimates of total watershed yield** subsection later on.

A separate, independent estimation of upland evapotranspiration for the watershed as a whole can be made by subtracting known or estimated values for watershed yield, depletions, and flows out of the basin from estimated total precipitation. Calculation of depletions is discussed in detail in the **WATER DEMAND** chapter and summarized in the **WATER BUDGET** chapter. Principal depletions and outflows are listed in Table 4-18 on page 4-26, and the calculation can be summarized as follows:

3,265,000 acre-feet per year precipitation
– 417,500 acre-feet per year depletions and outflow
2,847,500 acre-feet of upland evapotranspiration.

While neither upland ET estimate can be confirmed by actual measurement, the closeness of the two independent estimates lends credibility to the idea that on the average, 2,800,000 acre-feet of water evaporates annually from the Rio Chama watershed without ever contributing to runoff or aquifer recharge within the watershed.

Drought History

The natural variability of the climate in the Rio Chama watershed has perhaps been belabored already, but it is an important point in understanding how drought can affect our region, and even how we might usefully define the term. The National Weather Service defines the term "normal" to mean a rolling 30-year average for a climate variable, such as precipitation. In other words, a precipitation "normal" is the average of the 30 past years' precipitation. However, the "normal" value is not common; it will not occur often. We have already discussed how dry years – years of precipitation below the weather service normal – will be more frequent than wet years, and how precipitation will naturally fluctuate fairly widely. These realities about our climate affect what we would even call a drought. In more humid areas, where agriculture in particular depends on natural precipitation, a drought is often defined simply as some period of below-average or absent precipitation (Thomas, 1942). Where agricultural water depends substantially on irrigation, as it does here, a lack of precipitation per se is not the critical issue. What matters is a lack of precipitation in stream headwaters and a lack of available irrigation water; and/or a reduction in available ground water for domestic and municipal uses. These effects are quite separate from precipitation at the locations of fields and homes.

A brief description of hydrologic processes occurring in arid climates will serve as a framework for discussion of droughts. People cope with arid climates by taking advantage of various kinds of water storage. Water is stored naturally in soil and aquifer systems. Snowmelt and rain infiltrate into the soil and eventually percolate into an aquifer. The top of the aquifer, or the water table, is usually fairly near the land surface in headwater areas in the mountains, and it doesn't take long before precipitation falling on the land surface causes water tables to rise and water to discharge into stream channels. However, some time does pass between the infiltration of water into the soil and the discharge of water into streams, and water is stored in the ground to be released somewhat gradually.

We are all familiar with the spring runoff that happens rapidly in response to snowmelt, but what may not be so apparent is the storage of a sizable fraction of the melted snow for release more gradually, along with summer rain water, later in the year. This natural shallow-aquifer storage is what supports perennial streamflow.

Before the construction of reservoirs and the digging or drilling of wells, this kind of water storage was what permitted agriculture and permanent human settlement, which for obvious reasons took place along perennial streams. The other form of water storage that was, and is, significant for agricultural purposes is soil moisture where crops are grown, whether the moisture entered the soil from recent precipitation, snowmelt at the end of winter, or irrigation.

The acequia systems built by Spanish settlers in the region depend on the perennial flow of the Rio Chama and its tributaries, now just as when they were originally dug; and this flow depends on the storage and gradual release of water from the shallow aquifers in the upper reaches. Other technology has been brought to bear on the problem of water storage more recently. Hand-dug wells that provide access to otherwise inaccessible ground water have always been attractive for domestic water supplies; and now well drilling and pump technology permit greatly expanded use of ground water. The other major water storage technologies that have been developed in recent decades are dams and reservoirs. Three large dams have been built in our region: El Vado, completed in 1935, Abiquiu, completed in 1963, and Heron, completed in 1971. These reservoirs, however, do not directly serve any water storage needs within the region. They are owned and operated by entities outside our region, and rights to water stored in them are also owned outside the region. Details of the reservoirs and their operation are discussed below.

A drought, then, for our purposes is not simply a dry summer or lack of snow in the winter at a community, farm, or ranch. It is a lack of precipitation in the headwaters of a stream used for irrigation, or a demand for ground water that exceeds what is locally available, that is sustained enough in duration to adversely affect the uses of water within local communities.

New Mexico has an appointed Drought Task Force made up of Department heads or their designees from the Office of the State Engineer and the Departments of Energy, Minerals, and Natural Resources, Public Safety, and Agriculture. There is an official State Drought Plan, and a drought coordinator at the Office of the State Engineer. Details of the Plan, current Task Force membership, and staff contacts can be found on the New Mexico State University (NMSU) drought web site at *weather.nmsu.edu/drought/index.htm.*

There is also a Drought Monitoring subcommittee that reports to the Drought Task Force, and many ways to track and report the relative dryness or wetness of climatic conditions. Some of the most readily accessible data sources are:

- National Weather Service historical and current data and predictions can be found on the Weather Service web site at *www.srh.noaa.gov/abq.*
- New Mexico State University hosts a New Mexico Climate Center web site at http://weather.nmsu.edu that contains or has links to a great variety of weather-related information, including weather data and predictions.
- Natural Resource Conservation Service snowpack reports, updated daily, are available at www.wrcc.dri.edu/snotel/. NRCS also reports on reservoir storage at *www.nm.nrcs.usda.gov/snow/resv/.*
- The U.S. Geological Survey provides streamflow information, both current and historical, on its web site at *www.dnmalb.cr.usgs.gov/public/.*
- The New Mexico Department of Agriculture compiles weekly and monthly crop status and soil moisture information, which is available at *www.nass.usda.gov/nm.*
- Links to several water, climate, and drought information sources can be found on the Office of the State Engineer web site at *www.ose.state.nm.us/water-info/ISC-H2O/ climate.*

The most widely used index of the degree of water shortage or surplus, relative to average conditions, is the Palmer Drought Severity Index (PDSI), developed in the mid-1960's. It is based on a formula using data about precipitation, temperature, and soil moisture content; and is designed to relate particularly to agricultural needs. It does not take into account anything relating to irrigation water availability, water in storage, ground water levels, or other hydrological or water storage phenomena. It does, however, provide a systematic and consistent way to compare drought-related climatic conditions over time.

The formula yields an index number that can vary between approximately +6 and –6. Numbers greater than +3 indicate a very wet period while a value less than –3 indicates a severe drought; beyond +4 or –4 indicates an extremely wet year or an extreme drought (NMSU-NMCC web site, Palmer Drought Index description).

The Palmer Drought Severity Index has been calculated retroactively using recorded weather data back to 1895 (NCDC, web site), and inferred using paleoclimatological techniques (primarily analyzing tree-ring widths to determine relative growing season moisture levels) back to 1700 (NOAA web site). Tree-ring precipitation data has even been compiled for the past two thousand years (Grissino-Mayer, 1996).

Graphs based on both the weather and tree-ring data are presented in Appendix B. The weather data graph is available on-line from the NCDC, while the paleoclimatological data is available from the NOAA Paleoclimatology Project (URL addresses in the References section at the end of this chapter). To begin with, it should be noted that calculations in the two graph series appear to have been made somewhat differently since the same periods in this century, appearing in both graphs, reach different values. The wet spell in 1941 and 1942, for example, reaches over 8 on the NCDC graph while it barely exceeds 2 on the paleoclimate graph.

Nevertheless, a visual inspection of the NCDC graph shows that, for the 20th century, the lengthiest periods of relative drought occurred from 1899 to 1904 and from 1950 till early 1957, with the most severe individual years coming at the end of these periods, i.e. 1904 and 1956. Since 1900, some 27 or 28 years have been appreciably below average in PDSI, while 29 or 30 have been similarly above average. The wet peaks have been greater than the dry ones (exceeding 8 in 1915, 1942, and 1943).

The paleoclimatological graph series confirms the nearly equal distribution of wet and dry years in the 20th century through 1978, but suggests that the 19th century was generally drier: 25 years fell below –2 while only 11 years were above +2. The driest year of all according to these calculations occurred in 1847 (was this in response to American annexation?) at a PDSI of –5.7. By comparison, the driest year in the 20th century by their reckoning was 1956, at –4.0. It may be interesting to note that in the other (NCDC) graph which includes observations through 1998, 1956 rated approximately –6 while the recent dry winter and spring of 1996 rated only –4. There have been some mighty dry years in the past.

The 18th century apparently saw a more even succession of wet and dry years, with 12 less than –2 and 13 over +2. There were two years where the PDSI was below –5, however: 1729 and 1735. 1720, on the other hand, earned a +4.7 while the monumental (in living memory) wet year of 1942 was rated only +2.2. We have had some sopping wet years in the past too.

Archaeological analysis of tree rings in the more distant past, while not adequate to support calculation of PDSI indices, do document major droughts affecting the entire southwest during approximately the years 700-720, 1070-1100, 1275-1300, and 1570-1600.

Dr. Neal Ackerly, an anthropologist with extensive experience in irrigation and water use, presented a paper at the 1999 New Mexico Water Resources Research Institute Conference entitled “Paleohydrology of the Rio Grande: A First Approximation,” which correlates streamflow in the Rio Grande with paleoclimatological information from tree-ring analysis. He demonstrates that flows in the Rio Grande have correlated reasonably well with tree-ring widths through the period of record at the San Marcial gaging station (1896 - 1964), and then estimates streamflows back to 1480 based on the tree ring record. He makes two particularly important points in regard to drought planning: one, that long-term average annual discharge based on his retrodictions to 1480 is about 13 percent less than the average for the period of record; and two, that variability in streamflow (and, one might add, precipitation) has been significantly greater in the past than it has been in the 20th century. As he puts it, "…we may think that the Rio Grande does not fluctuate wildly when, in point of fact, longer-term data suggest that [recent history] represents a short-lived anomaly." (Ackerly, 1999)

The PDSI, numerically appealing as it is to scientists, is only part of the story about droughts and our responses to them. It is focused primarily on agricultural needs and soil and atmospheric moisture. Domestic and municipal needs in our region are met largely by ground water, and the PDSI is only indirectly related to ground water levels and availability. While some U.S. Geological Survey (USGS) monitor well and other water level data do exist and can

TABLE 4-8: USGS STREAM GAGING STATIONS IN THE RIO CHAMA BASIN

ID number	Station name	Latitude	Longitude	Elev.	Period of record and notes
08281200	Wolf Creek near Chama	36°57′	106°32′	8310	1959 – 1971; peak flow only
08281500	Rio Chama near Chama				1912-1916
08282000	Rio Brazos near Brazos				1913-1917
08282500	Chavez Creek near Brazos				1914-1915
08283000	Rio Brazos at Brazos				1912-1913
08283500	Rio Chama at Park View	36°44′	106°34′	7280	1913- 1915; 1930-1955 Replaced by nearby La Puente gage in 1955
08284000	Rito de Tierra Amarilla	36°41′	106°33′	7520	1957-1983; peak flow only
_08284100_	_* Rio Chama near La Puente_	_36°40′_	_106°38′_	_7083_	_1955-present_
08284150	Willow Creek above Azotea Creek	36°48′	106°93′	7404	1971-1973
08284160	Azotea Tunnel at Outlet near Chama	36°51′	106°40′	7520	(10/1/70-9/30/83) (4/1/84-9/30/85) (1/1/84-9/30/97)
_08284200_	_Willow Creek above Heron Reservoir_	_36°44′_	_106°37′_	_7196_	_1962-present_
08284300	Horse Lake Creek above Heron Res. near Los Ojos	36°42′	106°44′	7189	Continuous 1962-1973 discontinuous 1974-present
08284500	Willow Creek near Park View	36°40′	106°42′	6945	1942-1971
_08284520_	_Willow Creek below Heron Dam_	_36°40′_	_106°42′_		_1971-1983_ _1984-present_
_08285500_	_Rio Chama below El Vado Dam_	_36°34′_	_106°43′_	_6696_	_1935-present_
08286000	Rio Nutrias near Cebolla	36°34′	106°30′		1980-1986 Peak flow only
_08286500_	_* Rio Chama above Abiquiu Reservoir_	_36°19′_	_106°36′_	_6275_	_1961-present_
08286650	Canjilon Creek above Abiquiu Reservoir	36°19′	106°29′	6300	1965-1994 Peak flow only
08286600	Canjilon Creek near Canjilon				1911-12; 1913
08286700	Arroyo Seco near Abiquiu	36°17′	106°28′		1953-1964 Peak flow only
_08287000_	_* Rio Chama below Abiquiu Dam_	_36°14′_	_106°25′_	_6040_	_1961-present_
08287100	Canjilon Creek near Canjilon				1895-1897
08287500	* Rio Chama near Abiquiu	36°13′	106°15′	5873	1941-1967
08288000	* El Rito Creek above El Rito	36°23′	106°14′	7400	1931-1950
08288500	Rio Vallecitos at Vallecitos				1911-1914
_08289000_	_* Rio Ojo Caliente at La Madera_	_36°21′_	_106°02′_	_6359_	_1932-present_
08289500	Chamita Ditch near Chamita	36°04′	106°06′	5690	(1964-1967) (1967-1968)
08289800	* Hernandez Ditch at Hernandez	36°04′	106°07′	5670	1963-1968
_08290000_	_* Rio Chama near Chamita_	_36°04′_	_106°06′_	_5654_	_Discontinuous 1912-1929; 1929-present_

Source: USGS-NWIS web site and USGS Water Resources Data, New Mexico, Water Year 2000.

be related to recent wet and dry years, no equivalent to paleoclimatological analysis or even weather station records exists for ground water. Information is presented in the Community ground water resources section below on the recent experiences of local community water systems as a qualitative indication of the vulnerability of domestic water supplies to droughts.

STREAMFLOW

Streamflow data available within the watershed are taken from gaging stations. At present, the only tributary of the Rio Chama that is gaged and reporting daily flows is the Rio Ojo Caliente. The Rio Brazos, Willow Creek, Canijon Creek, El Rito, and Rio Vallecitos were historically gaged for only brief periods.

Gaging Station Information

Information on gaging stations for which information is readily available from USGS (for instance, at the usgs.gov web site) is presented in Table 4-8 (page 4-17). Many stations in the table are no longer active; their periods of record are indicated in the right-hand column. Some other stations record only peak flows and this also is noted. Currently active stations reporting year-round daily flows are highlighted in italics. An asterisk by the station name indicates a station for which a hydrograph is included in Appendix B.

All the stations in the table are located downstream of substantial irrigation diversions. Table 4-9 shows the approximate total irrigated acreage upstream of the major gaging stations.

Instantaneous Peak Flows

The highest reported peak flows for stations where data are available from the USGS are summarized in Table 4-10. It is interesting to compare the timing of peak flows on the Chama mainstem with those on the tributaries. Peak flows on the mainstem, except for those just below Abiquiu Dam, occurred during spring runoff, in May of 1920, 1926, and 1979. Six of the ten recorded tributary peaks occurred in summer, after runoff would have been over. Of the four springtime tributary peaks, three (Wolf Creek, Rito de Tierra Amarilla, and Willow Creek beneath what is now Heron Reservoir) drain relatively high-altitude, mountainous basins. The other springtime tributary peak, for El Rito, occurred in the great runoff year of 1942. The pattern suggests that for the Chama river as a whole, peak flows are very likely to occur in response to runoff of heavy snowpack (especially in years when heavy snowpack melts quickly), but that for tributaries, particularly lower-altitude tributaries, peak flows occur in response to thunderstorms or other prolonged rainstorms.

Additional peak flow information, including monthly peaks for some stations, is available from USGS on their web site. Low flows on many tributaries are zero, and are not reported as a parameter in the same way as peak flows.

Flow Duration Analysis

While streamflow may not be as intensively analyzed as baseball, in a statistical sense, it must be a close second. Hydrographs are available for periods ranging from one day to an entire period of record that may approach a century. Mean flow values have been computed for every calendar day within the varying periods of record, as well

TABLE 4-9: IRRIGATED ACREAGE UPSTREAM OF GAGING STATIONS

ID number	Station name	Irrigated acreage upstream (approximate)
08284100	Rio Chama near La Puente	11,400
08286500	Rio Chama above Abiquiu Reservoir	13,600
08289000	Rio Ojo Caliente at La Madera	3,300
08290000	Rio Chama near Chamita	25,370

Source: RCAA 1997; original figures from hydrographic surveys and Wilson and Lucero, 1992, 1997, 2000, and 2003.

TABLE 4-10: MAXIMUM RECORDED PEAK FLOWS

ID number	Station name	Period of record	Peak flow (cfs)	Date
08281200	Wolf Creek near Chama	1959 - 1971	1,900	Apr. 20, 1965
08283500	Rio Chama at Park View[1]	1913 - 1955	10,000	May 21, 1926
08284000	Rito de Tierra Amarilla at T. A.	1957 - 1983	1,000	May 9, 1975
08284100	Rio Chama near La Puente	1956 - present	11,200	May 28, 1979
08284200	Willow Creek above Heron Res.	1963 - 1994	1,600	Aug. 11, 1967
08284300	Horse Lake Creek near Los Ojos	1963 - 1991	3,960	Jul. 30, 1968
08284500	Willow Creek near Park View	1937 - 1970	4,500	Apr. 23, 1942
08285500	Rio Chama below El Vado Dam	1914 - present	9,000	May 22, 1920
08286000	Rio Nutrias near Cebolla	1980 - 1986	232	Apr. 29, 1985
08286500	Rio Chama above Abiquiu Res.	1962 - present	6,680	May 8, 1985
08286650	Canjilon Creek above Abiquiu Res.	1965 - present	4,620	Jul. 7, 1998
08286700	Arroyo Seco near Abiquiu[2]	1953 - 1964	810	Apr. 16, 19622
08287000	Rio Chama below Abiquiu Dam	1962 - present	2,990	Jul. 1, 1965
08287500	Rio Chama near Abiquiu	1942 - 1967	7,870	Jul. 28, 1952
08288000	El Rito above El Rito	1932 - 1970	1,240	Apr. 23, 1942
08289000	Rio Ojo Caliente at La Madera	1932 - present	3,990	Jul. 8, 1998
08290000	Rio Chama near Chamita[1]	1915 - present	15,000	May 22, 1920

Note 1: There are no records for the Park View gage for 1920 (the peak flow year for the Chamita and El Vado gages); and conversely no 1926 records for the Chamita and El Vado gages, making it impossible to compare upstream and downstream flows in these two wet years.

Note 2: The highest computed flow rate in the Arroyo Seco was 810 cfs at a gage height of 4.44 feet, but a gage height reading of 10.1 feet was recorded on July 29, 1953.

as monthly and annual averages. Annual total discharges are computed and averaged. With all these numbers, a great variety of statistical analyses are possible. To illustrate this, Tables 4-11, 4-12, 4-13, and 4-14 were developed to present what are hopefully some useful analyses of flow data at three important gaging stations--the gaging station at La Puente (the furthest upstream on the Rio Chama); the gaging station on the Rio Ojo Caliente near La Madera (the only daily-flow gaged tributary); and the Chamita gage near the mouth of the Chama.

For each month in a water year (October 1 through September 30), the long-term average flow in cubic feet per second (cfs) is shown in the first column. This figure is calculated by adding up all the daily reported flows in any October, divided by 31 days to yield the average daily flow during that particular October; and then adding all the October average flows for the period of record and dividing by the number of years. Similar calculations are made for the other months. The next column is the streamflow, again in cfs, that is exceeded 90% of the time during all the Octobers (or other months) on record. For example, Table 4-11 shows there was at least 24 cfs in the Rio Chama at the La Puente gage 90% of the time during October as far back as the records have been kept (1956, in this case). The next column is the streamflow that was exceeded 50% of the time – half the time there was more water than this, half the time there was less. This is the median value (or the midpoint of the data). For the La Puente gage in October, this has been 64 cfs. Note, as discussed above, this figure is considerably lower than the arithmetic mean of 92 cfs – another illustration that there are usually more years of precipitation and runoff below the arithmetic mean than above it. This is not surprising since the median value is not as sensitive to outlier values such as high peak flows. The mean flows are skewed to the

TABLE 4-11: FLOW DURATION ANALYSIS, RIO CHAMA AT LA PUENTE (1955-98)

All flow data are in cubic feet per second

Month	Mean flow*	90% exceedance	50% exceedance(median)	10% exceedance	Minimum monthly mean
October	92	24	64	190	9.8 (1957)
November	85	33	61	165	24.8 (1957)
December	61	31	52	101	25.9 (1964)
January	56	32	48	86	15.8 (1963)
February	70	40	56	105	26.3 (1964)
March	188	52	125	410	49.9 (1964)
April	835	205	620	1,900	244.0 (1964)
May	1,821	400	1,120	3,950	123.0 (1977)
June	761	63	310	2,050	19.1 (1977)
July	134	17	80	360	9.2 (1956)
August	99	14	63	201	9.0 (1972)
September	79	21	51	160	8.0 (1956)

*Source: USGS flow-duration analysis performed for the Regional Water Plan, except * Mean flow data from USGS Water Resources Data for New Mexico, Water Year 2000; water years 1954-2000*

TABLE 4-12: FLOW DURATION ANALYSIS, RIO CHAMA AT CHAMITA PRIOR TO SAN JUAN-CHAMA DIVERSIONS (1913-1971)

All flow data are in cubic feet per second

Month	Mean flow*	90% exceedance	50% exceedance (median)	10% exceedance	Minimum monthly mean
October	178	8	90	520	1.6 (1957)
November	270	33	92	1000	20.7 (1951)
December	166	32	79	330	25.2 (1951)
January	90	40	70	110	29.8 (1936)
February	195	50	102	340	49.8 (1955)
March	372	85	200	1,100	44.5 (1951)
April	1,127	195	720	3,100	57.0 (1951)
May	1,743	205	1,090	3,900	188.0 (1950)
June	964	100	705	2,050	70.9 (1934)
July	452	10	340	1,020	24.7 (1934)
August	414	16	235	1,200	10.5 (1934)
September	266	6	100	740	2.2 (1953)

*Source: USGS flow-duration analysis performed for the Regional Water Plan, except *Mean flow data from USGS - NWIS web page*

TABLE 4-13: FLOW DURATION ANALYSIS, RIO CHAMA AT CHAMITA AFTER SAN JUAN-CHAMA DIVERSIONS (1971-1998)

All flow data are in cubic feet per second

Month	Mean flow*	90% exceedance	50% exceedance (median)	10% exceedance	Minimum monthly mean
October	319	62	210	700	37.3 (1979)
November	318	65	180	800	60.6 (1990)
December	329	80	200	1,000	77.3 (1975)
January	224	63	140	560	63.5 (1975)
February	280	80	135	540	66.6 (1978)
March	483	115	320	1,150	85.1 (1977)
April	1,114	205	890	2,450	120.0 (1977)
May	1,571	400	1,850	2,750	204.0 (1972)
June	1,079	190	1,050	2,020	117.0 (1976)
July	624	125	435	1,550	170.0 (1972)
August	476	68	420	900	95.5 (1979)
September	434	55	400	830	83.1 (1974)

*Source: USGS flow-duration analysis performed for the Regional Water Plan, except * Mean flow data from USGS Water Resources Data for New Mexico, Water Year 2000; Water Years 1954-2000*

TABLE 4-14: FLOW DURATION ANALYSIS, RIO OJO CALIENTE AT LA MADERA (1933-1985 [mean]; 1933-1998 [other parameters])

All flow data are in cubic feet per second

Month	Mean flow	90% exceedance	50% exceedance (median)	10% exceedance	Minimum monthly mean
October	14.9	5	10	25	4.0 (1957)
November	18.	10	16	25	8.8 (1957)
December	17.8	13	18	22	11.2 (1957)
January	18.6	1	18	23	10.0 (1964)
February	23.1	17	21	30	12.0 (1955)
March	58.8	20	39	250	16.0 (1981)
April	280.0	48	185	650	44.5 (1955)
May	325.0	29	220	810	9.3 (1977)
June	51.7	5	20	135	5.1 (1954)
July	10.1	4	6	20	2.6 (1951)
August	14.4	4	8	30	3.1 (1956)
September	10.8	4	8	20	2.3 (1956)

Source: USGS flow-duration analysis performed for the Regional Water Plan, except
** Mean flow data from USGS Water Resources Data for New Mexico, Water Year 2000; water years 1954-2000*

higher values and are therefore larger than the median flows. The next column is the flow that has been exceeded only 10% of the time in a given month. The last column is the lowest monthly mean ever recorded, and the year it occurred.

How to use this information for water planning is open to discussion. The minimum monthly mean is a pretty good indication of the worst that can be expected, but it is likely to be very infrequent. A conservative planner might use the 90% exceedance value as a flow to plan for, in the confidence that there would be more water than that at least 90% of the time. Certainly it would be unwise to plan for any greater flow value than the median, since it would be unavailable the majority of the time.

The flow duration analysis presented above was undertaken by the USGS specifically for Region 14 water planning in May of 1999. While a similarly detailed flow duration analysis was not performed for all gaging stations, mean monthly and annual flow values are available from USGS. These values are summarized below in Table 4-15.

Another parameter readily available from USGS is the total annual discharge for active gaging stations. Year-by-year graphs of annual discharge volume for La Puente, Ojo Caliente, and Chamita, the three stations in the flow duration analysis, are shown in Appendix B. Table 4-16 summarizes mean, minimum, and maximum annual discharges for these stations. Separate entries are given for the Chamita gage before and after 1971 are because of the diversion of San Juan-Chama Project water beginning in 1972. This added flow is not reflected in the La Puente or Ojo Caliente flow measurements, but it does affect flow at Chamita since essentially all the water added to the Rio Chama is actually used downstream of where the Rio Chama enters the Rio Grande. The San Juan–Chama Project has added an average of 92,740 acre-feet of flow-through per year to the Rio Chama system (USGS, 2000).

Since 1972 San Juan-Chama Project flows averaging about 67,900 acre-feet per year have been added to streamflow at the Chamita gage, since contractor deliveries are made downstream of the gage (USGS, 2001). Average flow for the period of record prior to 1972 was 372,718 acre-feet per year (USGS, 2002). Since 1972, the average annual flow has been 439,500 acre-feet per year (USGS, 2001). Subtracting 67,900 acre-feet per year of San Juan - Chama flows from 439,500 acre-feet per year total flows results in an average native flow since

TABLE 4-15: MEAN MONTHLY AND ANNUAL FLOWS

All flows in cubic feet per second

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean annual flow*
Rio Chama at Park View	45	54	116	913	1683	725	139	65	57	75	54	45	330.9
Rio Chama near La Puente	56	70	188	835	1821	761	134	100	79	92	85	61	356.8
Willow Creek abv. Azotea Cr.	0.06	5.45	11	23	16	2.57	1.91	1.54	1.05	2.86	1.02	0.10	5.5
Azotea Tunnel at Outlet	1.38	1.11	19	253	542	505	129	44	17	21	6.01	2.00	128.4
Willow Creek, NR Los Ojos	2.07	7.51	70	262	428	398	105	41	16	18	6.67	2.12	113.0
Horse Lake, NR Los Ojos	0.42	0.58	6.50	7.46	1.67	0.39	0.53	1.29	0.58	0.58	0.66	0.31	1.7
Willow Cr. below Heron Dam	559	75	276	421	30	58	83	58	68	26	53	300	167.2
Willow Creek, NR Park View	1.72	5.31	47	72	10	4.72	6.07	13	4.08	2.88	2.42	0.82	14.1
Rio Chama below El Vado	92	151	272	637	1319	820	453	432	304	172	228	198	423.2
Rio Chama above Abiquiu	150	175	319	838	1613	838	386	389	293	197	241	278	476.4
Rio Chama below Abiquiu	166	214	375	828	1178	1007	570	451	374	257	351	309	506.7
Rio Chama below Abiquiui	63	200	314	630	983	723	462	431	264	140	341	210	396.8
El Rito NR El Rito	2.09	2.61	8.73	81	102	15	3.33	2.17	1.67	3.06	2.43	1.89	18.8
Ojo Caliente at La Madera	19	23	59	280	325	52	10	14	11	15	18	18	70.3
Rio Chama near Chamita	140	227	413	1122	1679	1013	517	437	329	232	286	228	551.9

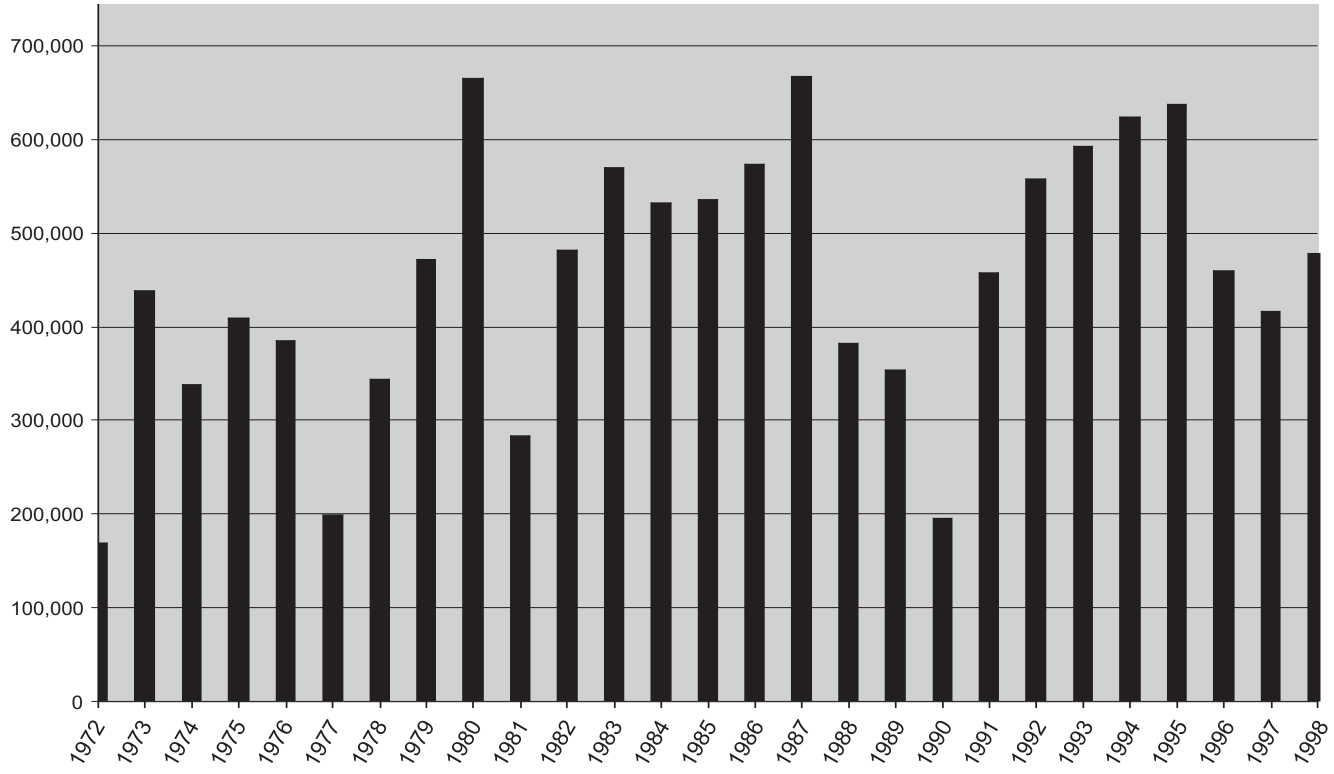
**Mean flow data from USGS Water Resources Data for New Mexico, Water Year 2000; water years 1954-2000*

TABLE 4-16: TOTAL ANNUAL DISCHARGE

Data are in acre-feet per water year

Station	Mean	Minimum	Maximum	Period of record
Rio Chama at la Puente	259,400	45,599 (1977)	523,449 (1985)	1955-1998
Rio Chama at Chamita (pre-1971)	372,718	115,590 (1934)	875,752 (1941)	1913-1971
Rio Chama at Chamita (post-1971)	439,500	169,368 (1972)	667,773 (1987)	1972-1998
Rio Ojo Caliente at La Madera	50,970	9,699 (1977)	148,233 (1941)	1933-1998

Sources:USGS flow-duration analysis performed for the Regional Water Plan; except where noted 1) USGS Water Resources Data for New Mexico, Water Year 2000; and 2) USGS- NWIS database, downloaded and supplied by USGS Albuquerque office.



Source: calculated from USGS flow duration analysis

FIGURE 4-4 - TOTAL ANNUAL DISCHARGE, RIO CHAMA AT CHAMITA

1972 of 371,600 acre-feet per year. The average of these two figures is approximately 372,200 acre-feet per year. It is worth noting that irrigation diversions for both the Hernandez and Chamita acequias leave the Rio Chama above the Chamita gage, while return flows from both these ditches flow into the Rio Grande rather than the Rio Chama – thus bypassing the Chamita gage.

Figure 4-4 above illustrates graphically the range of variability in annual Rio Chama streamflows. It is easy to see that the total annual discharge figures continue the pattern of variability demonstrated in other climatic and hydrological attributes of our region. Total annual flow at the Chamita gage has varied from less than 170,000 acre-feet per year in 1972 to almost 668,000 in 1987. The annual volume of discharge past the La Puente gage has varied from a low of 45,599 acre-feet in water year 1977 to 523,449 acre-feet in water-year 1985. The high flow is more than eleven times the low flow. Discharge at the gage on the Rio Ojo Caliente near La Madera has varied from 148,233 acre-feet in 1941 to 9,669 in 1977, more than a fifteen-fold difference.

Estimates of Flows on Ungaged Tributaries

The only real-time recording flow gage on any Rio Chama tributary is the one near La Madera on the Rio Ojo Caliente, so there is a real paucity of data on tributary flows in our region. Trying to arrive at a rigorously quantitative estimation of flows in the tributaries has not been possible given the lack of available data. Nevertheless, for planning purposes it is useful to have estimates of water availability on the tributaries.

Ungaged tributary flow, or water yield, was estimated using a model developed by Hearne and Dewey (1988) for New Mexico streams draining the Taos plateau. Hearne and Dewey developed models for both the Taos Plateau and the Sangre de Cristo Mountains nearer to Santa Fe. Both models were evaluated using data for Rio Chama tributaries. The Taos Plateau model fit better with the limited actual flow data available, however, and was chosen for tributary flow predictions in this region. The Hearne and Dewey model developed a multiple regression curve relating data for area, mean winter precipitation (for October through April), and slope for 16 tributary basins to derive stream flows or yield for the basins (it was assumed that stream flow was essentially equal to total basin yield). The mean winter precipitation used in the model was determined from a map constructed from data for 1931-1960. The period of record for the stream flows were long-term averages for years up to 1980. The correlation coefficient for the logarithmic regression of the model was 0.96. The annual water yield (Q), in cfs was estimated by Hearne and Dewey using this equation:

$$\mathbf{Q} = 1.074 \times 10^{-5}\, \mathbf{A}^{1.216}\, \mathbf{P}_{mw}^{2.749}\, \mathbf{S}^{0.535},$$

where,

$\mathbf{A}$ = area of the tributary (square miles)
$\mathbf{P}_{mw}$ = mean winter precipitation (inches)
$\mathbf{S}$ = slope of the tributary (feet of rise to miles of run).

This equation may be restated to obtain annual water yield (Q) in acre-feet per year:

$$\mathbf{Q} = 0.00779\, \mathbf{A}^{1.216}\, \mathbf{P}_{mw}^{2.749}\, \mathbf{S}^{0.535}.$$

The Hearne and Dewey model for the Taos Plateau is based on an evaluation of 16 tributary basins in New Mexico. One tributary basin in the model is the Ojo Caliente, which is located within the Rio Chama watershed. As the tributaries of the Rio Chama watershed share similar physical properties to those used by Hearne and Dewey, their model seemed to be appropriate for predicting water yield in the ungaged tributaries in the Rio Chama watershed. The basins used in the model are characterized by low precipitation, underlying rocks of low permeability, negligible recharge, and good surface water/ground water connection. Stream flow out of these tributary basins was assumed to represent the entire water yield of the basins.

To adapt this method for use in the Rio Chama watershed, a regression curve for winter precipitation fraction was first constructed from weather station data for the planning region and adjacent areas to the Rio Chama headwaters. A winter precipitation fraction value for each tributary was chosen from the best fit line based on average basin elevation, but the coefficient of determination between winter precipitation fraction and elevation in this area is not particularly strong ($R^2 = 0.59$). Because of this relatively poor correlation and uncertainty in the data, the predicted yield equation was calculated using an estimate of winter precipitation fraction as predicted by the regression line; and then values were calculated again by adding and subtracting the standard error for a 95% confidence interval to (or from) the predicted mean winter precipitation fraction. Average total annual precipitation estimates for the tributary basins were multiplied by the low, mid-range, and high winter precipitation fractions, and the resulting values utilized in the Hearne and Dewey equation. All three resulting yield values are shown in Table 4-17, along with observed streamflow data wherever it was available. Values among these sources sometimes diverge significantly.

Total water yields for the Rio Chama watershed predicted by the Hearne and Dewey model (the sum of the individual predicted tributary yields shown above) ranged from approximately 360,000 acre-feet per year to almost 710,000 acre-feet per year. The Hearne and Dewey equation using uncorrected Rio Chama winter precipitation fractions (the middle "predicted yield" column in Table 4-17), over estimates total watershed yield, as compared to observed streamflow including irrigation depletions. At the same time, it seems to under estimate flows in the upper and wetter tributaries (above the La Puente gage), and to over estimate flows in lower tributaries as compared to observed flows. However, if the prediction for the first four tributaries using high-range winter precipitation is compared to recorded flows at La Puente the correlation is much better; and similarly, if the low-range predictions are compared to flows in the lower tributaries the correlation is reasonably good. However, caution must be used in interpreting any of the predictions of flow in the ungaged tributaries because substantial uncertainties exist, as shown by the range of estimates.

Note that the sum of the four high-range estimates for upper tributaries (245,858 acre-feet), added to the sum of the low-range estimates for the lower tributaries (a total of 232,938 acre-feet) suggests a total watershed yield of just over 481,000 acre-feet. It cannot be stressed enough that the values, presented in Table 4-6 and 4-17, are not based on direct measurements or site-specific data and are merely estimates. This figure can be compared, however, to the watershed yield figure from Table 4-7 and watershed yield estimates calculated independently.

TABLE 4-17: RANGE OF PREDICTED TRIBUTARY FLOWS, HEARNE AND DEWEY METHOD

	Predicted Water Yield (all figures in acre-feet per year)			Observed Flow (if available) (acre-ft/yr, average)
Watershed	Low-range predicted yield (winter precip. minus std. error)	Predicted yield (unmodified Hearne and Dewey calculation)	High-range predicted yield (winter precip. plus std. error)	
Rio Chama above Cañones Cr.	50,378	72,117	99,044	104,400
Cañones Creek	9,185	13,149	18,059	
Rio Brazos	58,611	83,902	115,231	115,600
Rito de Tierra Amarilla	6,879	9,847	13,524	
Sum of flows above: compare to La Puente gaged flows	125,053	179,015	245,858	270,000 (La Puente gage - 08284100)
Horse Lake etc.	23,587	33,765	46,372	
Willow Creek	8,914	12,760	17,524	10,200 (Willow Creek gage - 08284500)
Rio Nutrias	8,839	12,653	17,377	
Rio Cebolla	4,712	6,745	9,264	
Canjilon Creek	18,741	26,828	36,845	6,600
El Rito	13,341	19,098	26,228	13,200
Rio Gallina	21,135	30,256	41,553	
Rio Puerco de Chama	31,408	44,961	61,748	
Cañones and Polvadera	22,351	31,995	43,942	
Rio del Oso	7,091	10,151	13,941	
Abiquiu Cr. and Barranco	6,143	8,794	12,078	
Rio Vallecitos	30,882	44,209	60,715	
Rio Tusas	22,167	31,732	43,581	
Combined Tusas – Vallecitos flows: compare to La Madera gaged flows	53,049	75,941	104,296	56,000 (La Madera gage - 08289000)
R. Ojo Caliente below La Madera	2,686	3,845	5,281	
Area not in major tributaries	12,365	17,700	24,309	
Totals	**359,415**	**514,507**	**706,616**	

**Note: Table values for observed flows have been increased over actual gaged flows by 10,000 acre-feet/yr. at La Puente; by 5,000 acre-feet/yr. at La Madera; and by 34,000 acre-feet/yr. for total flow (i.e. flow at Chamita), to account for upstream irrigation depletions. Stream flow Period of Record: Rio Chama above Canones Creek is 1913-1915; La Puente is1955-2000; Rio Brazos is 1913-1915; Willow Creek is 1943-1970; Canjilon Creek is 1913; El Rito is 1931-1951, Rio Vallecitos is 1913-1914; and Ojo Caliente is 1932-2000.*

Estimates of Total Watershed Yield

De facto estimates of overall watershed yield have emerged from the analysis summarized in Table 4-7 of precipitation and evapotranspiration data and from Table 4-17 of estimated tributary yields, even though the primary purpose of these tables was not to estimate total yield. It should be understood clearly that these discussions consider watershed yield to include both surface runoff and ground water recharge considered together, because insufficient data exist to reliably separate the two yield components without double counting. Aquifer characteristics in much of the region are such that water probably cycles repeatedly between surface and subsurface flows before leaving the watershed, and almost all of the streamflow in the region undoubtedly soaked into the soil and became shallow aquifer recharge before emerging to flow through the watershed. With that in mind, it is more useful to consider total yield rather than attempting to separate the yield into ground or surface water at any arbitrary point in time or space.

In addition to the estimates derived from calculations in Tables 4-7 and 4-17, a third estimate of total watershed yield can be made by adding observed streamflow out of the watershed (flow at the Chamita gage) to estimates for other depletions, natural evapotranspiration, and ground water flow out of the watershed. Calculation methods for these depletions are discussed in the **WATER DEMAND** chapter and summarized in the **WATER BUDGET**. The resulting estimate of total yield, 417,500 acre-feet per year, value can be compared to the yield estimates from Tables 4-7 and 4-17, as shown in Table 4-18 below.

The yield estimate of 417,500 acre-feet per year derived from adding flow and depletion components may be the most rigorous or reliable of the three estimates shown above, but it is important to remember that all the figures given are based on estimates and assumptions, and none of them are based entirely on actual measurement. It is also important to recognize that all of these figures represent mathematical averages and that the actual amount of water available in any given year, even if it could somehow be exactly measured, would not likely equal the average value. Water planning will only be valuable if it deals with the highly variable nature of climate, precipitation, and water production in the arid southwest. Table 4-18 should not be interpreted as a firm quantitative estimate of total water supply, but rather as an indication that three different methods of interpreting the available data suggest that the long term average yield from the Rio Chama watershed is in the vicinity of 400,000 acre-feet per year (to be conservative), with a high range of natural variability.

Historical Supply

An important aspect of the water supply for irrigators along the Rio Chama and its tributaries is the distribution of water flows throughout the year. Not surprisingly, perhaps, flows tend to peak in the spring and taper off, some-

TABLE 4-18: ESTIMATED TOTAL WATERSHED YIELD

Component	Acre-ft./year
Surface ouflow (Chamita gaged flow)[1]	372,200
Irrigation depletions[2]	24,000
Reservoir evaporation – native water[2]	5,000
Other lake evaporation[2]	4,700
River surface and riparian evapotranspiration[2]	5,800
Ground water depletions[2]	2,100
Ground water flow out of basin[2]	3,700
Total estimated watershed yield (sum of water budget components shown above)	**417,500**
Estimated yield: Table 4-7 (Precipitation minus evapotranspiration)	**437,000**
Estimated yield: Table 4-17 (Estimated tributary yields)	**481,000**

Note: 1: Calculated on page 4-23

Note 2: Calculations shown in the WATER DEMAND and WATER BUDGET chapters

Note 3: Values have been rounded

Note 4: Table values do not include San Juan-Chama Project water times rapidly, by July or August. This flow pattern results in ample supplies of irrigation water early in the season and often in shortages of water for irrigation requirements in midsummer. This problem has been quantified in most detail for the Rio Ojo Caliente, originally by J.B. Nixon of the Office of the State Engineer in 1978 and more recently by Peggy Barroll of the OSE in a memo dated July 15, 1999.

Taking the land irrigated by the Ojo Caliente below the stream gage at La Madera as a single unit, the overall historical average water supply during the April to November irrigation season has been adequate to supply about 63 percent of the total water needs of the irrigable acreage – in other words, there has been a historical annual shortage of 37 percent. The shortages vary by time of year, as shown in Table 4-19.

TABLE 4-19: HISTORICAL WATER SUPPLY, RIO OJO CALIENTE BELOW LA MADERA

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Avg. shortage (af/y)	0.0	8.1	366.2	881.6	401.9	259.2	0.3	0.0
% supply	100.0	98.9	69.6	32.9	55.8	60.9	99.9	100.0
% shortage	0.0	1.1	30.4	67.1	44.2	39.1	0.1	0.0

Source: Reproduced from Barroll, 1999

The degree of shortage also varies dramatically with position upstream or downstream on the river, from less than 10 percent shortage (over 90 percent of irrigation needs supplied) in the first ditches below La Madera to a maximum shortage of 55 percent (only 45 percent of needed irrigation supply) in the ditches furthest downstream (Barroll 1999). While the Rio Ojo Caliente has been analyzed the most thoroughly in terms of historical supply (no other tributaries have stream gages, among other reasons), the general pattern applies to much of the region, with more severity at lower elevations. More informal computations of estimated historical supplies have been made in the past by OSE staff for some Chama tributaries, including an estimate of 70 percent average historical supply on El Rito and 92 percent for acequias on the Rio Chama below Abiquiu Dam (Wells, 2001, personal communication).

STORAGE RESERVOIRS

There are three significant reservoirs located in the planning region: Heron, El Vado, and Abiquiu. At present all storage rights are owned by entities outside the planning region and primary operational criteria are determined by and for organizations outside the region. Water users within the planning region have water rights to "native flows" in the Rio Chama but not, at least so far, to any water stored within the Region. A small amount of water (about 1360 acre-feet in the 2000 season [Wells, 2000]) has been leased from San Juan-Chama Project contractors as supplemental supply by irrigators within the region. As a result, reservoir operations, yields, and other possible parameters have not been analyzed in the detail that would have been warranted if the reservoirs were directly involved in the water supply for the region. Nevertheless, reservoir operations have considerable potential to affect both consumptive and recreational water users within the Region. Basic reservoir information is shown in Table 4-20.

TABLE 4-20: RESERVOIR INFORMATION

Name	Capacity (acre-feet)	Completion	Owner	Operator
El Vado	196,500	1935	MRGCD	Bureau of Reclamation
Abiquiu	Storage easement: 183,881 Flood control storage: 545,784	1963	Corps of Engineers	Corps of Engineers
Heron	401,320	1971	Bureau of Reclamation	Bureau of Reclamation

Source: USBR and CoE web sites

El Vado Reservoir

El Vado reservoir was the first of the Rio Chama reservoirs to be constructed, in 1934-35. It is 46 miles above Abiquiu Dam, is owned by the Middle Rio Grande Conservancy District (MRGCD), and operated by the Bureau of Reclamation. It was primarily built for water supply storage, and specifically, to capture surplus flows from the Rio Chama and deliver them to MRGCD irrigators. It also stores water for the six southern pueblo tribes irrigating with Rio Grande water. In the 1980's MRGCD rented space to Albuquerque and other contractors for the storage of surplus San Juan-Chama water. A small run-of-the-river hydropower facility has been installed at El Vado Dam by Los Alamos County (Bureau of Reclamation, web page).

There are two provisions in the Rio Grande Compact that restrict the operation of El Vado Dam and Reservoir from time to time. If total usable water in storage in Caballo and Elephant Butte Reservoirs available for release to meet irrigation demand is less than 400,000 acre-feet, no additional water can be stored at El Vado (or any other reservoir built after 1929). In addition, if New Mexico has built up a debit under the Rio Grande Compact – in other words, if less water has been delivered to Texas than owed – water must be kept in storage in New Mexico to cover the amount of the debit. Some of this storage could be required to be in El Vado Reservoir. This provision could limit the amount of water that could be released from El Vado Reservoir (Rio Grande Compact Commission, 2000).

It should also be noted that El Vado Reservoir stores water for the Indian Pueblos of Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, and Isleta. These Pueblos have prior and paramount rights to water in the Rio Grande sufficient to irrigate 8,847 acres of land. Water for this purpose is released and moved downriver independent of any constraints by the Rio Grande Compact. In addition, no storage can take place at El Vado that would impair senior water rights held downstream. Most water rights on the Rio Chama have seniority dates prior to the construction of El Vado Dam, so natural flows in the Rio Chama must be bypassed undiminished, and storage losses in El Vado Reservoir must be made up to downstream users (Fogg et al., 1992).

Abiquiu Reservoir

Abiquiu Dam was authorized under the 1948 and 1950 Flood Control Acts, which authorized the Middle Rio Grande Project. It became operational in 1963 and is owned and operated by the Army Corps of Engineers. Abiquiu Dam is an earthen embankment with a gated outlet and ungated spillway; it also houses a 12.4-megawatt (MW) run-of-the-river hydropower generating facility owned by Los Alamos County. It was intended to control potential flooding along the Rio Chama and Rio Grande, although it is now also used to store up to 183,881 acre-feet of water for the City of Albuquerque. Other entities, including the Rio de Chama Acequias Association, have indicated an interest in storing water there. It is located on the Rio Chama, 32 miles above the confluence with the Rio Grande. Its total spillway crest potential storage capacity is as much as 1.2 million acre-feet. However, the Rio Chama above the reservoir is a legally protected Wild and Scenic River and impoundment of water to levels above the currently authorized maximum of 545,784 acre-feet would submerge part of the Wild and Scenic reach of the river. Abiquiu Dam (along with El Vado) must be operated in conformance with provisions of the Rio Grande Compact and any deviation from the plan not considered an emergency requires unanimous consent of the Rio Grande Compact Commissioners. Operation of the Dam is integrated with those at Cochiti, Galisteo and Jemez Canyon reservoirs for flood control purposes. Natural Rio Chama flow and releases from upstream reservoirs are passed through Abiquiu Dam with minimum regulation (U.S. ACE, 1995).

In 1981 Abiquiu Dam was authorized to store San Juan-Chama water under the authority of PL 97-140. This new authorization was a result of San Juan-Chama water project contractors, including the City of Albuquerque, not needing all the project waters being diverted from the project and, therefore, wanting to store project water in a reservoir. San Juan-Chama Project water is regulated by the Albuquerque District in accordance with a contract between the United States and the City of Albuquerque. The land at Abiquiu Reservoir was still in private hands. Therefore, the City of Albuquerque secured easements resulting in 183,881 acre-feet of non-flood-control storage at the Reservoir. The majority of this storage is used by the City of Albuquerque but other users include Santa Fe, Taos and the Department of Energy.

Heron Reservoir

San Juan-Chama Project water discharges into a tributary of the Rio Chama, Willow Creek, and flows almost directly into Heron Reservoir, which began operations in 1971. Heron Reservoir stores project water only: in other words no "native" water from the Rio Chama is stored at the Reservoir. It is located five miles above El Vado Dam and is owned and operated by the Bureau of Reclamation. The Bureau releases waters based on user demand and in accordance with contracts under the Project. Heron Reservoir has a capacity of just over 400,000 acre-feet.

San Juan-Chama Project

The San Juan-Chama Project consists of a system of three diversion dams, two siphons, and a tunnel system for trans-mountain movement of water from tributaries of the San Juan River to the Rio Grande Basin. Water is diverted from the San Juan Basin under the continental divide into Willow Creek in the Rio Chama Basin, where it is stored in Heron Reservoir until released for the benefit of Project contractors. The Project's yield to contractors is currently calculated as 96,200 acre-feet of water per year, allocated as shown in Table 4-21. Since Heron Reservoir can store just over 400,000 acre-feet of water, the Project can normally guarantee delivery of 96,200 acre-feet per year into the reservoir regardless of actual diversions in any given year. This ability to deliver full allocations could be put to a severe test by a succession of dry years, however.

The primary purposes of the San Juan-Chama Project are to furnish a water supply to the middle Rio Grande Valley for municipal, domestic, and industrial uses. The project is also authorized to provide supplemental irrigation water and incidental recreation, fish, and wildlife benefits. The San Juan-Chama Project was authorized by Congress in 1962 and is legally a part of the Colorado River Storage Project (Bureau of Reclamation, web site).

The City of Albuquerque is the largest purchaser of water from this project, contracting for almost half the deliverable water: 48,200 acre-feet per year. For this water the City pays over a million dollars a year in fees and operating expenses. The MRGCD purchases the second largest amount at 20,900 acre-feet per year followed by smaller municipalities such as Santa Fe, Taos, and Española. The water is released from reservoir storage on the Rio Chama and diverted and consumed by MRGCD water users within the Conservancy District. (Bureau of Reclamation web site). San Juan waters are also credited against depletions created in the Rio Grande by Pojoaque unit diversions. Heron Reservoir functions as a water bank, with water stored by the federal government on behalf of San Juan - Chama Project contractors (listed in Table 4-21). Once released from Heron Reservoir, water becomes the property of the contractor.

Even though the San Juan-Chama Project has a commitment to deliver up to 96,200 acre-feet of water each year, not all the contracted water is necessarily called for or

TABLE 4-21: 1999 SAN JUAN - CHAMA PROJECT WATER ALLOCATIONS

Contractors: Municipal, domestic, and industrial supplies	Acre-ft/yr allocated (before evaportive losses)
City of Albuquerque	48,200
Jicarilla Apache tribe	6,500
City and County of Santa Fe	5,605
County of Los Alamos	1,200
City of Española	1,000
Town of Belen	500
Village of Los Lunas	400
Village of Taos	400
Town of Bernalillo	400
Town of Red River	60
Twining Water & Sanitation District	15
San Juan Pueblo	2,000
Irrigation supplies	
Middle Rio Grande Conservancy District	20,900
Pojoaque Valley Irrigation District	1,030
Other uses	
Corps of Engineers - Cochiti Reservoir recreation pool	5,000
Total contracted allocations	93,210
Uncontracted supplies reserved for Taos area (including Taos Pueblo)	2,990
Total allocations	96,200

Source: Bureau of Reclamation, web site actually delivered in any given year. Particularly in the early years of the project, water was not always used and the long-term average delivery of water through the Azotea Tunnel into Willow Creek through water year 2000 was 92,740 acre-feet per year (USGS, 2001). Channel conveyance losses (both above Heron Reservoir on Willow Creek and below Heron Reservoir on the Rio Chama and on the Rio Grande to Otowi) have averaged approximately 1,423 acre-feet per year as calculated by the U.S. Bureau of Reclamation pursuant to the accounting rules of the San Juan-Chama Project specified by the Rio Grande Compact Commission. Similarly, the accounting of reservoir evaporation attributable to San Juan-Chama Project storage has averaged 23,382 acre-feet per year through 2000 (Kevin Flanigan, New Mexico Interstate Stream Commission, personal communication, 20 March 2003). In addition, calculated average depletions of project water above Otowi Gage have been 1,361 acre-feet per year (Flanigan, personal communication, 20 March 2003) and this must be added to the Otowi flow estimate to account for all San Juan-Chama project water (in other words, some depletions of Rio Grande water above Otowi have been offset by adding flow to the Rio Chama so that there will be no net effect at the Otowi gage).

Subtracting the estimated Project reservoir evaporation and conveyance loss depletions of 24,805 acre-feet per year from the average Azotea Tunnel delivery of 92,740 acre-feet per year suggests that about 67,935 acre-feet per year of water should flow past the Chamita gage and into the Rio Grande. However, official accounting of San Juan-Chama water flowing past Otowi gage averages approximately 60,640 acre-feet per year for the period from 1971-2000, so there is an apparent discrepancy of almost 6,000 acre-feet per year. This could result from inherent limits to the accuracy of stream gaging and reservoir stage calculations; from accounting procedures that are not completely compatible or consistent over time; from error in reservoir evaporation estimates (the largest depletion component); and/or from the existence of an appreciable quantity of water in storage in Rio Chama Reservoirs at any given time (372,053 acre-feet at the end of 2000, for example).

Reservoir Evaporation

Reservoir evaporation, along with other water uses, is calculated by the Bureau of Reclamation and the Corps of Engineers for the three reservoirs in the region, and is reported in the State Engineer's summary of water uses in New Mexico, published every five years. Evaporation calculation methods are described above, and reported reservoir evaporation figures for the last five reports are shown in Table 4-22 below, and shows total reservoir evaporation including losses of both San Juan-Chama Project and native water combined. The average of these five reported values is 29,962 acre-feet per year.

TABLE 4-22: RESERVOIR EVAPORATION

Year	Reported evaporation (acre-ft/yr)
1980	45,312
1985	26,512
1990	22,862
1995	29,592
2000	25,535
Average	29,962

The majority of the total reservoir evaporation in Rio Chama reservoirs can be attributed to the storage of San Juan-Chama Project water, since for the most part native water is only stored in El Vado Reservoir, while all Heron storage and most Abiquiu storage is actually Project water. The Bureau of Reclamation calculates the long-term average evaporation loss from San Juan-Chama Project water to be 23,382 acre-feet per year (Flanigan, personal communication, 20 March 2003).

To put this quantity in perspective, it nearly equals all consumptive uses within the planning region combined, and is well over twice the entire annual water consumption of the City of Santa Fe.

Historical Reservoir Storage

Graphs of total water in storage for the three reservoirs are included in Appendix B. Graphs for Abiquiu and El Vado Reservoirs also include the fraction of total storage made up by San Juan-Chama Project water (all Heron Reservoir storage is San Juan-Chama water; it is not allowed by statute to store native Rio Chama tributary flows).

The graph for Heron Reservoir shows a regular annual pattern of drawdowns from approximately 400,000 acre-feet (virtually full capacity), since contractors are obligated to take delivery of their allocations during each year, without carry-over storage. The reservoir as a whole normally maintains a reserve of over 300,000 acre-feet to enable delivery of the entire contracted 96,200 acre-feet per year even if net inflows are less than that. Actual annual inflows from the San Juan watershed are highly variable, ranging from only 6,311 acre-feet in 2002 or 19,393 acre-feet in 1997 to 164,129 acre-feet in 1979 (Flanigan, personal communication, 20 Mar. 2003).

Both El Vado and Abiquiu total storage peaked in the wet year of 1987, although El Vado has nearly reached its capacity of 196,000 acre-feet several years since then, while Abiquiu is limited by its storage easement to 183,000 acre-feet except for flood control. Both reservoirs had also dropped to their lowest levels in decades by the end of 2000.

GROUND WATER SUPPLY

This section of the Regional Water Plan describes the ground water supplies in the Rio Chama watershed, based on existing information. It summarizes:

- geologic conditions as they relate to ground water resources;
- characteristics of aquifer systems;
- available information for recharge assessment; and
- recommendations for further studies to better manage ground water resources.

It has not been possible to quantify the total available ground water supply, because data are far too limited. Neither is it possible to firmly quantify ground water recharge, for similar reasons. Recommendations are made to address this data gap so that future work may be conducted to characterize recharge and to complete a more confidently quantifiable ground water budget.

The Rio Chama watershed is geologically complex and has been divided, for purposes of this study, into three distinct geologic provinces (following Bingler, 1968). This, the **GROUND WATER SUPPLY** section of the Water Plan is organized into three subsections.

The **Geologic Structure** subsection discusses the overall geology for the region, and includes cross sections of selected geologic units and aquifer systems. The **Hydrogeology** subsection discusses aquifer characteristics such as depths to water, saturated thickness, specific yield, storage, and transmissivity, wherever information is available. The **Aquifer Recharge and Yield** subsection presents available information on these topics.

To date there have been no large-scale quantitative ground water investigations within the Rio Chama watershed. This has been an especially challenging research effort as few aquifer studies have been conducted within the study area. There are few wells with consistent ground water level data over time, and the well log information is spotty or entirely absent for a great deal of the Region.

Technical information derives largely from published reports of the New Mexico Bureau of Mines and Mineral Resources (NMBMM), New Mexico OSE, and USGS. Numerous consultant reports provided ground water information on specific areas within the watershed. Some information on hydrologic characteristics of aquifer systems has been extracted from studies conducted outside the watershed on the same or similar aquifer systems. A number of reports provide qualitative descriptions of the ground water in selected areas within the watershed. Well logs have been examined in all areas of the region for which they are available, and as much information as possible has been extracted from them.

GEOLOGIC STRUCTURE

The northern boundary of the watershed is just north of the Colorado-New Mexico border, above the town of Chama, in the volcanic South San Juan Mountains. The western boundary of the watershed is the Gallina-Archuleta Arch (on the other side of this steep rim lies the San Juan Basin). The eastern boundary is the steep faulted blocks of the Tusas Mountains (which is a visual expression of the Brazos Uplift). The southern boundary of the watershed is the confluence of the Rio Chama with the Rio Grande, just north of Española. The Rio Chama watershed contains approximately 3,157 square miles (RCAA, 1997).

The geologic deposits found in the Rio Chama watershed span over one billion years. The oldest deposits were laid down in the Precambrian time, and due to erosion and mountain-building processes, these Precambrian rocks are exposed in both the eastern and western parts of the study area. Following the Precambrian, during the Paleozoic Era, New Mexico was part of a supercontinent called Pangea that stretched from pole to pole. For part of this time, the supercontinent tilted down to the west and the sea invaded, depositing a succession of marine sedimentary rocks in parts of what is now the Rio Chama watershed. Following the Paleozoic Era, during the early part of the Mesozoic Era, the sea regressed and continental sediments were laid down throughout the study area as river, floodplain, and alluvial fan deposits. Late in the Mesozoic, the sea transgressed again (from the east) and both marine and continental deposits were laid down throughout the study area.

During the end of the Mesozoic Era and beginning of Cenozoic Era (Late Cretaceous to Early Tertiary Periods), the North American Plate moved west and collided with the East Pacific Plate. As a result, vertical deformation of the crust formed the Rocky Mountains, as seen most dramatically in the Brazos and Sangre de Cristo Mountains. The region was raised approximately 5,000 to 7,000 feet, pushing the older rocks high above their former surface surroundings. This mountain building event, referred to as the Laramide Orogeny, consisted of two major pulses in the study area. The initial pulse began with the development of the north-northeast trending Brazos-Sangre de Cristo uplift. The second phase of the orogeny consisted of the right lateral shift of the Colorado Plateau relative to the North American continent, creating uplifts and associated basins (the Chama and Española Basins are in the study area). As a result of this tectonic activity, the area was exposed to folding and faulting. The Brazos fault zone is a major west trending transverse structure in the north-central portion of the watershed. The northern part of the watershed is characterized by numerous northwest-trending fault and fold zones that transect the nearly flat floor of the basin (Muehlberger, 1967).

Bingler (1968) divided this study area into distinct geologic provinces: the Española Basin; the Chama Basin; and the Cystalline and Volcanic provinces, as illustrated in the accompanying geologic map (Figure 4-5). The Española Basin deposits are marked by a thick, faulted accumulation of basin-fill sandstone, siltstone, and conglomerate, which are slightly consolidated (compacted). The deposits were primarily formed during the Tertiary Period and are typically characterized by the Santa Fe Group. The Chama Basin province comprises the north-central and north-western part of the watershed. Rocks are largely shale, sandstone, and limestone from the Cretaceous, Jurassic, and Triassic Periods. The crystalline and volcanic province makes up primarily the eastern parts of the watershed and a small portion of the southwestern part of the watershed - the Tusas and Jemez mountains. The crystalline rocks are granite, gneiss, and quartz-rich metamorphic rocks, primarily Precambrian deposits. These crystalline deposits are overlain by volcanic and volcanic sedimentary rocks of Tertiary Period, which are similar to volcanic deposits in the Española Basin province.

Following is a summary of the primary geologic features found in the watershed from most recent to oldest (Table 4-23). The following pages contain Figure 4-5, which is a geologic map of the region, and Figures 4-6 through 4-9, which are geologic cross sections through various areas in the Rio Chama watershed. Locations of the cross-sections are shown on the geologic map.

PAGES 4-33 TO 4-43

						Approximate Maximum Thickness of Stratigraphic Units (ft)										
						Chama Basin Province						Crystalline & Volcanic Province				Espanola Basin Province
						Local area						Local area				
ERA	PERIOD	EPOCH	Rock Units		Lithology	Lower Chama	Chama	Cebolla	Gallina	Jarosa	French Mesa	Brazos	Tierra Amarilla	Las Tablas	La Madera	Espanola Basin
Cenozoic	Quaternary		Alluvium		Stream deposits and recent terrace gravels	U	U	U	30	25	40	U	50	U	U	U
			Landslide debris		Talus breccia, incised by recent drainage	U	U	U	50	50	40	U	100	U	U	U
			Terrace gravel		Coarse gravel deposits	U	U	U	30	NP	5	U	40	U	U	U
			Bandelier Tuff		Non-welded to densely welded ash flow	NP	NP	NP	NP	600	NP	NP	NP	NP	NP	NP
	Tertiary	Miocene and Pliocene	Basalt - Sierra Negra, Cisneros, Dorado		Dikes and flows of olivine basalt	90	NP	50	NP	NP	NP	NP	50	130	NP	U
			Tesuque Formation		Sands, silts, clays, slightly consolidated	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	1400
			Los Pinos Formation		Tuffaceous sandstone with volcanic conglomerate, flows of basalt and rhyolite	670	NP	1200	NP	NP	NP	NP	NP	2300	300	U
			Abiquiu Tuff		Thin parallel beds of tuff, ash and fanglomerate, slightly indurated	1350	NP	NP	20	110	NP	NP	NP	NP		1500
			Conejos Quartz Latite		Andesite flow breccia. Lower tuffaceous sandstone & conglomerate	NP	500	NP	NP	NP	NP	NP	NP	600		NP
			Ritito		Conglomerate with pebbles and boulders, poorly indurated	NP	NP	1000	NP	NP	NP	NP	NP	400		200
		Eocene	El Rito Formation		Sandstone with volcanic gravel	400	NP	60	NP	NP	NP	100	NP	NP		U
			Blanco Basin Formation		Conglomerate, sandstone, and siltstone	NP	300		NP	NP	NP	300	NP	NP	NP	NP
Mesozoic	Cretaceous		Lewis shale		Shale, calcareous, fissile, parallel bedded	NP	600	1000	NP	NP	2000	600	250	NP	NP	NP
			Mesaverde Group		Sandstone, and siltstone, and shale	NP	263	135	NP	NP	600	260	180	NP	NP	NP
			Mancos Shale	Upper Mancos Undifferentiated	Calcareous, finely-bedded, highly fissile shale	NP	1100	1100	300	NP	2000	1100	1200	NP	NP	NP
				Carlile, Niobrara, & other Members	Fissile, thin-bedded, calcareous shale & siltstone	1650	434	500		NP		400	715	NP	NP	NP
				Greenhorn Member	Thin-bedded limestone and calcareous shale	25	20	30		NP		20	60	NP	NP	NP
				Graneros Member	Calcareous shale with thin sandstone beds	100	120	100		NP		120	150	NP	NP	NP
			Dakota Formation		Massive, cross bedded sandstone with shale	380	390	225	110	NP	140	400	325	NP	NP	NP
	Jurassic		Morrison Formation	Brushy Basin Member	Mudstone, indurated claystones with thin sandstone lenses	275	25	400	900	900	670	90	375	NP	NP	NP
				Lower Member	Thin-bedded sandstone, siltstone, and mudstone	400								NP	NP	NP
			San Rafael Group	Todilto Formation	Thin-bedded limestone overlain locally by massive gypsum	60	NP	NP	130	NP	100	NP	NP	NP	NP	NP
				Entrada Formation	Massive, cross bedded, fine grained sandstone	200	250	200	300	NP	250	231			NP	NP
	Triassic		Chinle Formation	Upper Shale Member	Interbedded mudstone, siltstone, and sandstone	450	500	450	600	200	600	420	NP	NP	NP	NP
				Lower Sandstone Member	Coarse-grained, conglomeratic sandstone	250			250	360	220	70		NP	NP	NP
Paleozoic	Permian		Cutler Formation		Alternating cross-bedded purple arkosic sandstone and mudstone	1500	NP	NP	NP	NP	700	NP	NP	NP	NP	NP
			Yeso Formation		Even bedded, fine-grained sandstone	NP	NP	NP	150	80	NP	NP	NP	NP	NP	NP
			Abo Formation		Mudstone and lenticular sandstone	NP	NP	NP	2900	950	NP	NP	NP	NP	NP	NP
	Pennsylvanian		Madera Formation		Limestone, arkose, and shale	NP	NP	NP	1550	700	NP	NP	NP	NP	NP	NP
Pre-camb.			Maquinta, Burned Mt, Kiawa Mt, Moppin, and other members		Quartzite, schist, gneiss, granite, and greenstone	NP	5000	10000	1550	2000	NP	5000	NP	18000	12000	U

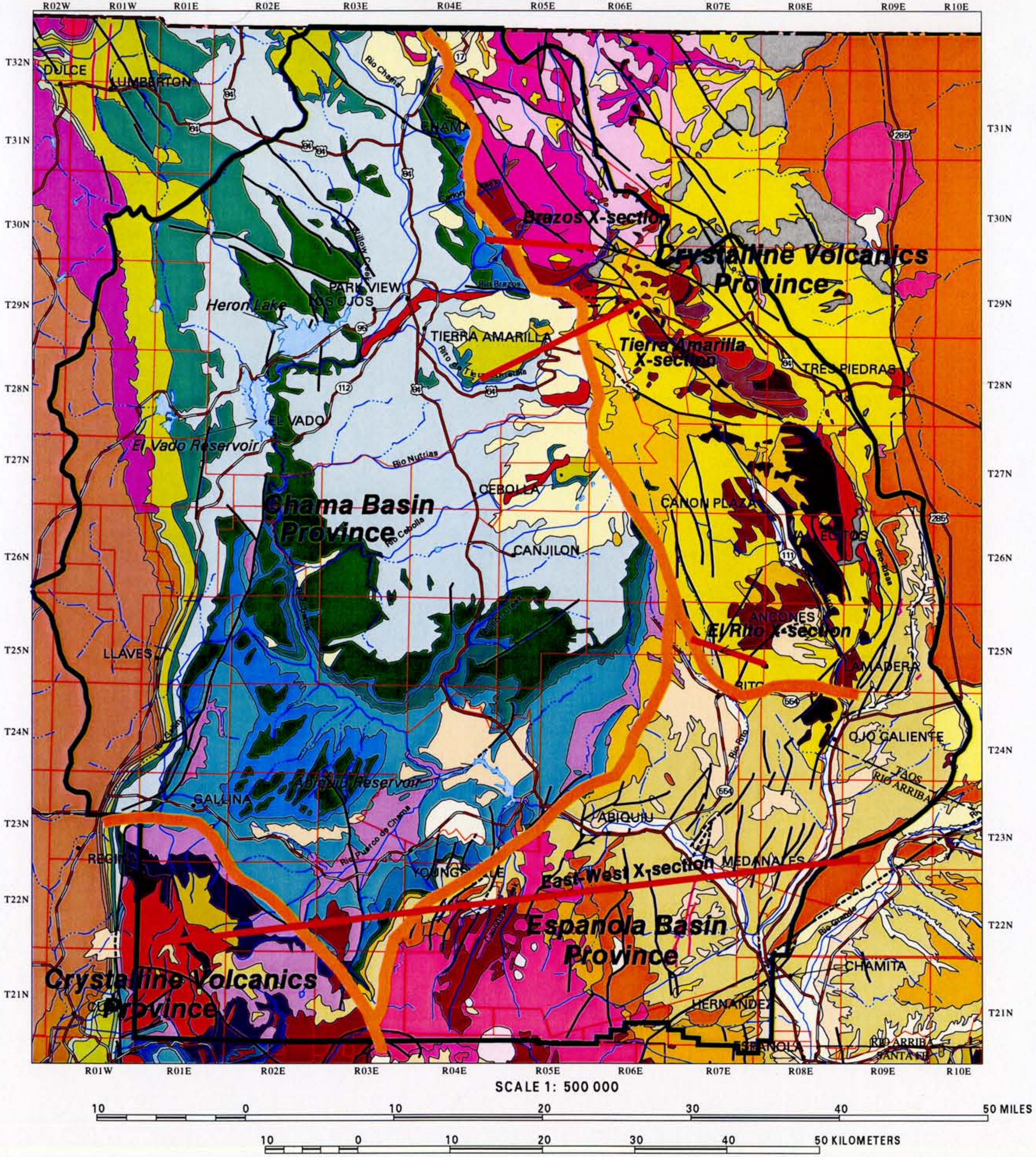
Summary of exposed stratigraphic units in the Rio Chama watershed (after Smith et. al., 1961; Muehlberger, 1967; Muehlberger, 1968; Landis, E. R. and Dane, C. H., 1967; Doney, H. H., 1968, Barker, F., 1958; Bingler, E. C., 1965; Kelley, V. C., 1978; Woodward, L. A. et. al., 1976; Woodward, L. A., and Timmer, R. S., 1979; and Crouse, D. L., et. al., 1992)

Note: U = unknown, NP = not present

TABLE 4-23: PRIMARY GEOLOGIC UNITS IN THE RIO CHAMA WATERSHED

Rio Chama Water Planning Region

Surface Geology Map



Explanation

- State Line
- County Line
- Perennial Stream/River
- Intermittent Stream
- Interstate
- U.S. Highway
- State Highway
- Township/Range
- Planning Region
- Contact
- Fault
- Dashed Fault
- Dotted Fault
- Ti Dikes
- Geologic Province Boundary
- X-Section

■ Qa
■ Qb
■ Qe
■ Ql
■ Qp
■ Qbt
■ Qr
■ QTs
■ QTsf
■ Qe/Tnb
■ Qp/QTs
■ Thb
■ Ti

■ Tlp
■ Tlrp
■ Tlv
■ Tn
■ Tnb
■ Tnr
■ Tnv
■ Toa
■ Tps
■ Tsf
■ Tsj
■ Tui
■ Turp

■ Tv
■ TKa
■ Kd
■ Kkf
■ Kls
■ Km
■ Kmv
■ Kpc
■ Kpl
■ J
■ Jm
■ Jsr
■ TRc

■ Pa
■ Pct
■ Py
■ IPm
■ M
■ Yp
■ YXp
■ X
■ Xp
■ Xms
■ Xmo
■ Xm

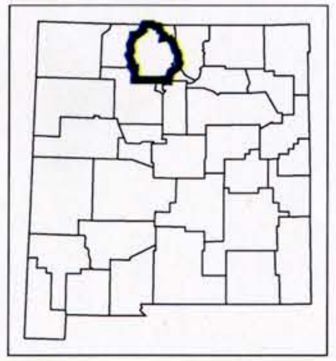
Produced by New Mexico Water Resources Research Institute, January 2001

Base map prepared by the U.S. Geological Survey

Compiled from digital data provided by the New Mexico Resource Geographic Information System Program (RGIS). Original base maps digitized from 1:500,000 mylar sheets and 100,000 paper maps for New Mexico. These data meets National Mapping Accuracy Standards for 1:500,000 and 1:100,000 scale maps. Surface geology provided by Green and Jones 1997, open-file report 97-52. Boundary of the Rio Chama Water Planning Region is based on county lines and OSE boundaries.

Horizontal accuracy: At the scale of 1:500,000 at least 90 percent of the points tested are within 1/30th inch (0.0333 inch), or within 423 ground meters, of their true location.

Projection: Universal Transverse Mercator, Zone 13, Units meters, NAD83.



Explanation

⬜ Qa –Alluvium; upper and middle Quaternary
🟥 Qb –Basalt and andesite flows and locally vent deposits
🟨 Qe –Eolian deposits
🟨 Ql –Landslide deposits and colluvium
🟧 Qp –Piedmont alluvial deposits: upper and middle Quaternary
🟫 Qbt –Bandelier Tuff; Jemez Mountains area
⬜ Qr –Silicic volcanic rocks
🟧 QTs –Upper Santa Fe Group
🟨 QTsf –Santa Fe Group, undivided. Basin fill of Rio Grande rift region
🟨 Qe/Tnb –Eolian deposits over basalt and andesite flows
🟧 Qp/QTs –Piedmont alluvial deposits over Upper Sante Fe Group
⬛ Thb –Hinsdale Basalt
🟥 Ti –Tertiary intrusive rocks
🟨 Tlp –Los Pinos Formation of Lower Santa Fe Group
🟪 Tlrp –Lower Oligocene ryolitic pyroclastic rocks (ash–flow tuffs)
🟥 Tlv –Lower Oligocene and Eocene volcanic rocks, undifferentiated; intermediate composition
🟧 Tnb –Basalt and andesite flows; Neogene. Includes flows interbedded with Santa Fe and Gila Groups
🟥 Tnr –Silicic to intermediate volcanic rocks; mainly quartz latite and rhyolite Neogene
🟪 Tnv –Neogene volcanic rocks
🟫 Toa –Ojo Alamo Formation
🟧 Tps –Paleogene sedimentary units
🟨 Tsf –Lower and Middle Santa Fe Group
🟫 Tsj –San Jose Formation
🟥 Tui –Miocene to Oligocene silicic to intermediate intrusive rocks; dikes, stocks, plugs, and diatremes
🟪 Turp –Upper Oligocene rhyolitic pyroclastic rocks (ash–flow tuffs)
🟥 Tv –Middle Tertiary volcanic rocks, undifferentiated
🟪 TKa –Animas Formation
⬛ Kd –Dakota Sandstone
🟩 Kkf –Kirtland and Fruitland Formations; coal–bearing
🟩 Kls –Lewis Shale; marine shale and mudstone
🟦 Km –Mancos Shale; divided into Upper and Lower parts by Gallup Sandstone
🟩 Kmv –Mesaverde Formation–Interbedded, olive–gray shale and massive lenticular sandstone
🟩 Kpc –Pictured Cliffs Sandstone; prominent cliff–forming marine sandstone
🟩 Kpl –Point Lookout Sandstone; regressive marine sandstone
🟦 J –Jurassic rocks
🟦 Jm –Morrison Formation and upper San Rafael Group
🟩 Jsr –San Rafeal Group
🟦 TRc –Chinle Group
🟦 Pa –Abo Formation; red beds, arkosic at base, finer and more mature above
🟪 Pct –Cutler Formation
🟦 Py –Yeso Formation–Gypsum and tan, pale–red to white sandstone
⬛ IPm –Madera Formation (Limestone, or Group)
⬛ M –Mississippian rocks, undivided
⬛ Yp –Middle Proterozoic plutonic rocks (younger than 1600 Ma)
🟨 YXp –Middle and Lower Proterozoic plutonic rocks, undivided
🟨 X –Lower Proterozoic rocks, undivided
🟥 Xms –Lower Proterozoic metasedimentary rocks (1650 – 1700 Ma)
🟫 Xmo –Lower Proterozoic metamorphic rocks, dominantly mafic
🟥 Xp –Lower Proterozoic plutonic rocks (oldr than 1600 Ma)
⬛ Xm –Lower Proterozoic metamorphic rocks, dominatly felsic volcanic, volcaniclast

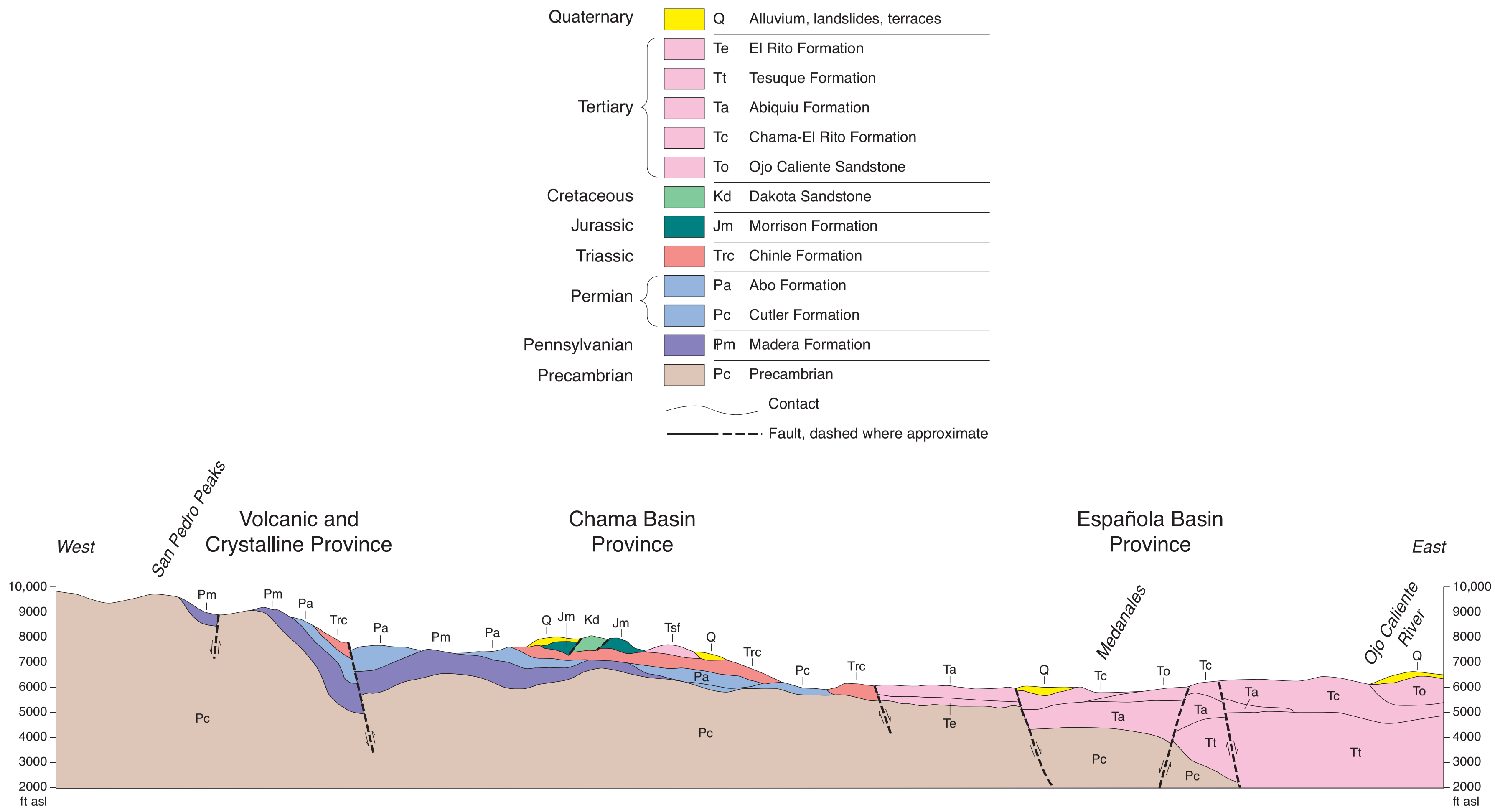


FIGURE 4-6: EAST-WEST CROSS SECTION

Approximate East-West Geologic Cross Section of the Southern Portion of the Rio Chama Watershed
(based on geologic maps and cross sections from: Kelley, V.C., 1978, Manley, 1982; Woodward et al., 1979; and Woodward et al., 1976)

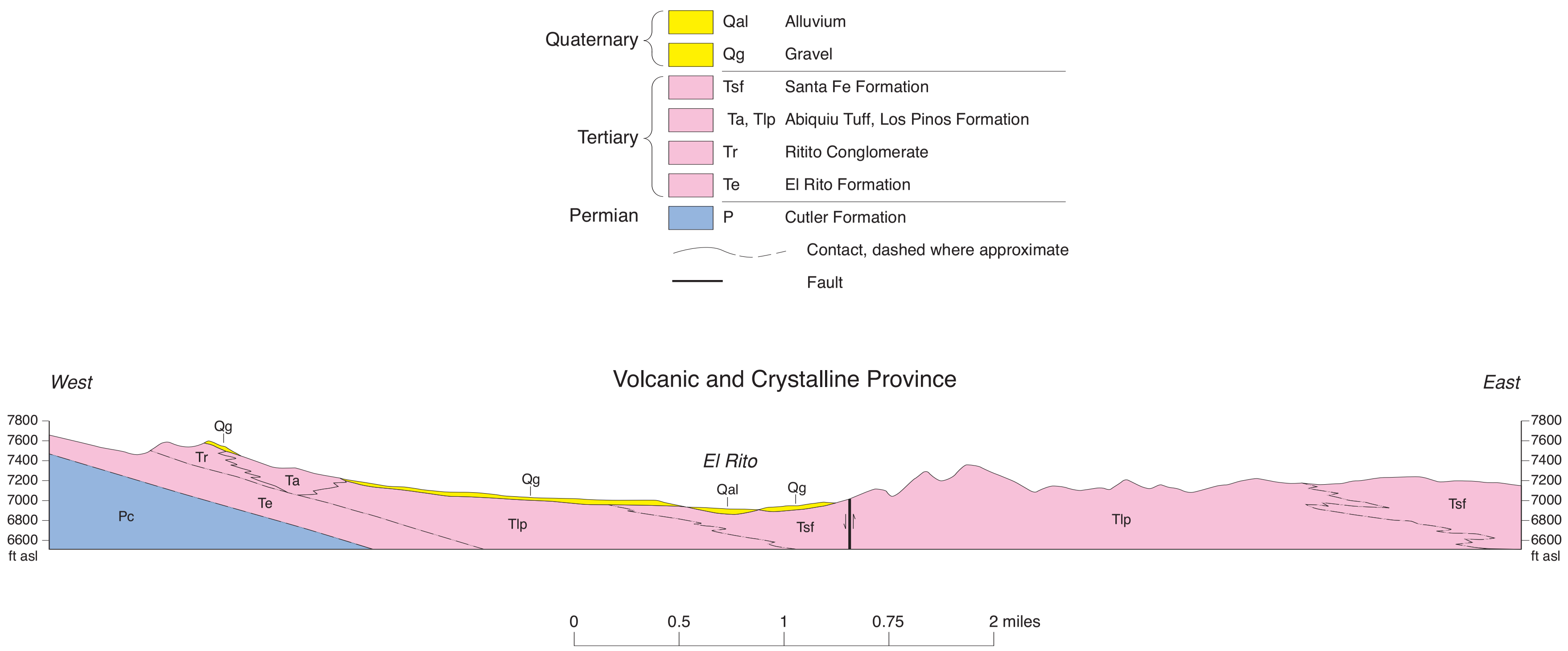


FIGURE 4-7: EL RITO CROSS SECTION

Geologic Cross Section near El Rito (from Bingler, E. C., 1968)

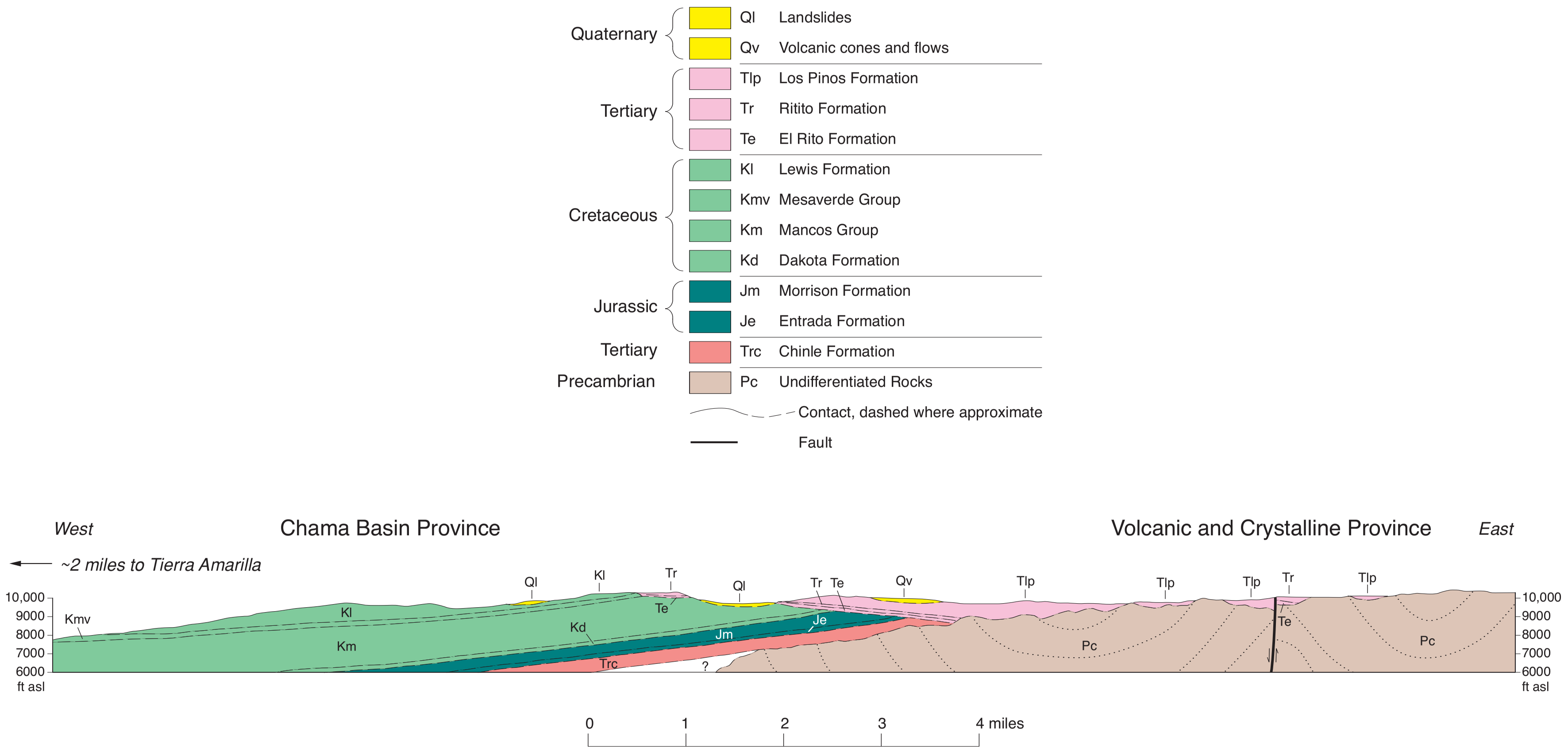


FIGURE 4-8: TIERRA AMARILLA CROSS SECTION

Geologic Cross Section near Tierra Amarilla (from Doney, H. H., 1968)

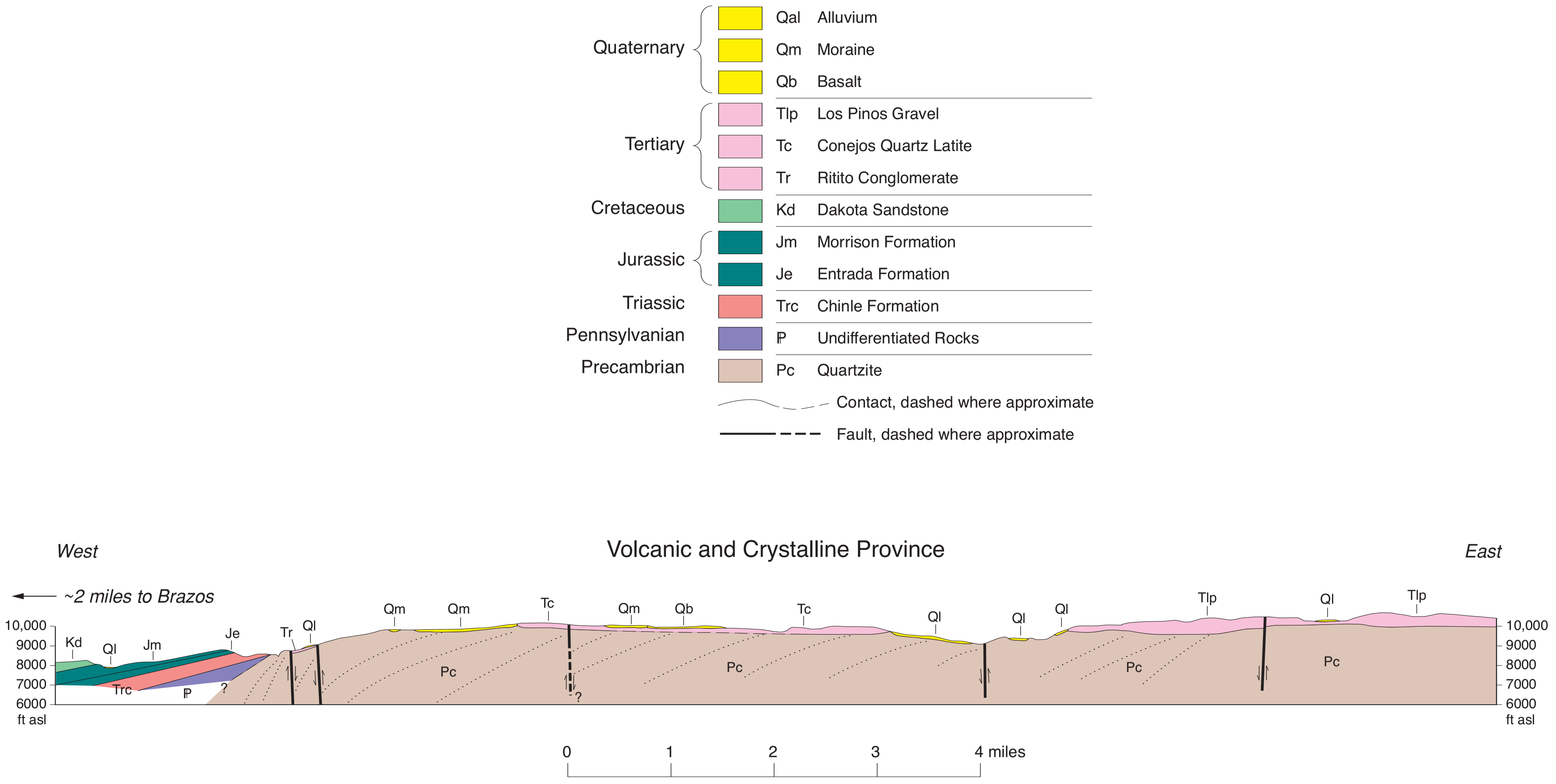


FIGURE 4-9: BRAZOS CROSS SECTION

Geologic Cross Section near Brazos Peak (from Muehlberger, W. R., 1968)

GEOLOGIC UNIT DESCRIPTIONS

Quaternary Period

Broad areas along the Chama River, many of the larger tributary valleys, and some of the higher mesas in the Rio Chama watershed are covered by terrace gravels and alluvium (deposited by running water on broad slopes, aprons, or valleys). Terrace deposits are composed of well-rounded cobbles and pebbles of granite, gneiss, schist, quartzite and metarhyolite mostly originating from the Brazos and San Pedro Mountains. The gravels are commonly in a matrix of silt and sand and the original deposits are often slumped and reworked. Gravels are found capping ridges up to 600 feet above modern drainage levels and well above terrace deposits from glacial events (Muehlberger, 1967). The alluvium is represented as layers of unconsolidated sands, silts, and cobbles in the low plains and the canyons of the Rio Chama and its tributaries (Smith et al., 1961). In our region these deposits are generally shallow, seldom exceeding 100 feet in thickness.

Tertiary Period

Tertiary rocks in the Rio Chama watershed are coarse conglomerate, fine to coarse-grained sedimentary deposits, and extrusive volcanic rocks that represent widespread erosion and deposition related to Late Cretaceous orogeny and widespread volcanism (Bingler, 1968).

Santa Fe Group: The Santa Fe Group is predominantly fluvial, deformed, slightly consolidated sedimentary rocks. It is divided into two formations. The uppermost is the Chamita Formation, that consists of white to pinkish tuffaceous beds comprised of moderately coarse sand and gravelly layers with white tuff layers (Galusha and Blick, 1971). These deposits are included with the Tesuque Formation in parts of the study area. The lower and more ubiquitous formation is the Tesuque Formation, which is further divided into five members in descending age: Ojo Caliente Sandstone; Chama-El Rito Formation; Pojoaque Member; Skull Ridge Member; and Nambe Member. These deposits are primarily fine-to-coarse-grained, slightly consolidated, sands and silts with clay beds. The deposits also include conglomeratic sandstones and volcanic ash beds. Colors range from tan to gray to pink. The Abiquiu Tuff is a stream-laid deposit of silty tuff, micaceous and tuffaceous sandstone, and volcanic conglomerate consisting of well-bedded, fine-grained material. The lower part of the deposit is gray to grayish-pink conglomerate. The upper part is similar to Los Pinos Formation, except finer grained and grayish white (Bingler, 1968). The Abiquiu Tuff is included as part of the Santa Fe Group.

Los Pinos Formation represents a sand and gravel apron and includes nearly all of the volcanic and volcanic clastic rocks in the Tusas Mountains. Rock types include tuffaceous graywacke, sandstone, siltstone, pebble-to-boulder conglomerate, basaltic-to-rhyolitic flow rocks, and breccia. The color is light gray to grayish tan (Bingler, 1968).

The Ritito Formation is slightly unconsolidated to unconsolidated conglomerate, which is primarily found in the eastern part of the watershed area. The conglomerate consists of rounded to angular pebble-to boulder size clasts of Precambrian rock types. The deposits are typically gray to brownish gray (Bingler, 1968).

Pre-Santa Fe Group: The El Rito Formation was deposited as fluvial torrential streams during the uplift of the Brazos Mountains to the north and east (Smith et al., 1961). The formation includes breccia, boulder-to-cobble conglomerate, and well-consolidated medium-grained sandstone. The deposits range from brick-red to pale orange to pink to yellowish-gray in color. The clasts are gray to bluish-gray color (Bingler, 1968).

The Blanco Basin Formation is a partially consolidated coarse-grained arkosic conglomerate interbedded with arkosic sandstone and siltstone (Muehlberger, 1967). The matrix ranges in color from reddish purple to light gray and clasts are typically pink granite, schist, or gneiss (Bingler, 1968).

Cretaceous Period

The Lewis Shale unit is fissile not well-consolidated, parallel-bedded shale containing calcareous concretions (Muehlberger, 1967). It is dark-gray to light olive-gray calcareous shale, its basal part contains thin beds of sandstone lithologically similar to the underlying Mesaverde Group.

The Mesaverde Group is composed primarily of fine-grained massive to thick bedded, cliff forming sandstones. They are yellow to light gray in color (Muehlberger, 1967).

The Mancos Shale consists of light to dark gray calcareous shale of marine origin. The unit consists of four members (in descending order): Upper shale member (unnamed); Carlile and Niobrara shale members; Greenhorn limestone member; and Graneros sandstone and shale member (Smith et al., 1961; and Doney, 1968). The upper shale consists of calcareous, soft, platy, fissile shale with sandstone and limestone interbeds. The Carlile and Niobrara shale members are olive-gray to very dark gray or black shale. The Greenhorn limestone member is composed of interbedded calcareous shale and limestone. The Graneros shale member is a sequence of thin-bedded, dark gray to black sandy shale.

The Dakota Formation is mainly fine-to-coarse-grained, pale orange-white, conglomeratic, chert-bearing, quartz sandstone with interbeds of gray, carbonaceous, silty shale (Doney, 1968). The formation is subdivided into three units: a marine upper sandstone unit; a fluvial middle shale unit; and a fluvial lower sandstone unit. The upper sandstone unit is typically pale orange to white, massive, and fine-grained. The middle shale unit is carbonaceous. The lower sandstone unit is a conglomeratic sandstone with local lenses of variegated greenish and reddish claystone and shale.

The Burro Canyon Formation underlies the Dakota Sandstone (and was formerly mapped as part of the Dakota). This formation is composed of pale orange to white, very fine-to coarse-grained, locally congomeratic sandstone in thick beds. The unit includes little shale and the sandstone is cemented with silica (Shomaker, 1979).

Jurassic Period

Jurassic deposits are described as almost entirely nonmarine. The Morrison Formation is the uppermost Jurassic unit and consists of sandstone, mudstone, and minor limestone and consists of two members. The upper member is the Brushy Basin Member and consists of rocks of brightly-banded shales, thin limestones, conglomerates, and sandstones. The lower member consists of gray to cream-colored sandstones and siltsontes interbedded with red or green mudstones. The bulk of the lower member consists of alternating sequence of pale brown, chocolate, or deep purple mudstones and white to pale gray siltstones (Smith et al., 1961).

The Todilto Formation crops out in a narrow continuous belt. The upper member of the Todilto Formation consists of massive gypsum with shaly partings. The lower member consists of dark colored, fissile calcareous shales grading upward into thinly bedded limestone to massive gray limestone (Smith et al., 1961).

The Entrada Sandstone Formation consists of aeolian (wind blown) fine to medium grained subarkose to lithic arkose. Cross-bedding is present throughout. The color is generally tan or white, but red outcrops are present in the basin (Smith et al., 1961).

Triassic Period

Triassic strata exposed in the Rio Chama watershed are of non-marine, primarily fluvial origin (Lucas and Hunt, 1992). The Chinle Formation in the watershed has been reported by Smith (1961) to consist of two members; an upper shale member; and a lower sandstone member. The upper shale member probably represents the Petrified Forest and Rock Point members (described as distinct members in the San Juan Basin). This member consists of interbedded and intertonguing red, chocolate, purple and variegated mudstones, siltstones, and sandstones (Smith et al., 1961). The lower sandstone member is thought to represent the Agua Zarca, Salitral, and Poleo (described as distinct members in the San Juan Basin). The lower sandstone member crops out at Ghost Ranch and consists of white gray quartzose to micaceous sandstone which weathers buff to brown. The unit ranges from massive beds, coarse-grained, to slabby medium to fine-grained. Lucas and Hunt (1992) later identified the Moenkopi Formation to underlie the Chinle in parts of the Rio Chama watershed. They describe the Moenkopi Formation as a sequence of fluvial strata dominated by grayish red and grayish orange siltstone and trough-crossbedded sandstone intercalated with some intraformational conglomerate.

Permian Period

Permian deposits exposed in the Chama basin include the Cutler, Yeso, and Abo Formations. The Cutler consists of cyclic alternation of cross-bedded arkosic sandstone, which are locally conglomerates, and mudstones. The sandstones tend to form small cliffs and the thicker, less competent mudstone units form slopes (Smith et al., 1961). The Yeso Formation is tan-brown to orange even-bedded, fine-grained to very fine-grained sandstone. The Abo Formation is reddish-brown mudstone and lenticular sandstone, arkose with minor conglomerate, and minor limestone (Woodward et al., 1976).

Pennsylvanian Period

Pennsylvanian deposits consist of a thin-bedded sequence of alternating limestone, arkosic limestone, shale, and quartz sandstone. Two major lithologic subdivisions are the basal Sandia Formation and the upper Madera Formation. The sediments are found along the western edge of the watershed and rest nonconformably on the Precambrian rocks (Woodward et al., 1976).

Precambrian

Precambrian rocks are primarily found in the east (along the crest of the Tusas Mountains from Ojo Caliente northwestward) and west (south of Gallina). The major rock types include quartzite, schist, gneiss, and granite (Muehlberger, 1968). The quartzite is medium-to-coarse-grained blue-gray to grayish white. Two primary schists are a quartz-muscovite-biotite schist is fine grained equigranular, quartz rich schist that is gray to yellow gray and speckled with small flakes of biotite. The hornblende-chlorite schist includes a greenschist, which is fine-grained dark green rock. The gneiss rocks are pink to reddish orange to yellowish brown, schistose, fine-to medium-grained. Other gneiss rocks are gray and foliated. The granite is often pink to reddish orange, massive to faintly foliated (Bingler, 1968).

HYDROGEOLOGY

Aquifer characteristics include hydraulic conductivity, specific storage (for confined systems), specific yield (for unconfined systems), and transmissivity. The discussion below is based on tests that were actually conducted outside the region, but in the same (or similar) aquifer systems as those found within the Rio Chama watershed. They are presented here to indicate approximate values, and it should be noted that these characteristics vary spatially within any aquifer system. For example, a well in one area may intersect a sandy unit that transmits water readily, but this sandy unit may not be extensive and therefore may not be present a short distance away. Water-bearing units in most aquifers are neither homogeneous nor continuous. Hydraulic conductivity is the capacity of permeable geologic media to transmit a fluid, and is a property of the media and the fluid flowing through them. Assuming the fluid is water, hydraulic conductivity will vary (orders of magnitude) depending on the size, shape, interconnectedness, and volume of spaces within the media. Typically, gravel and sand have higher hydraulic conductivities than silts and clays. Hydraulic conductivity is expressed in the same terms as velocity (distance per unit of time), and is typically reported as ft/sec or ft/day.

Specific storage is the volume of water released from or taken into storage in a confined system, per unit volume of the porous medium, in response to a unit change in hydraulic head. The release from storage in confined aquifers represents the secondary effects of water expansion and aquifer compaction caused by changes in fluid pressure. Storativity values are dimensionless and typically range from 0.005 to 0.00005 (0.5% to 0.005%). Large head changes over extensive areas are required to produce substantial water yields from confined aquifers.

Specific yield for an unconfined aquifer is the volume of water that may be released from storage, per unit surface area of aquifer, per unit decline in the water table. The specific yields of unconfined aquifers are much higher than the storativity values for confined aquifers. Specific yield values are dimensionless and typically range from 0.01 to 0.30 (1% to 30%). The higher values represent a greater release of water from storage due to an actual dewatering of the soil pores.

Transmissivity refers to the ability of the aquifer to transmit water. It is essentially the hydraulic conductivity computed over the entire saturated thickness of the aquifer. The transmissivity of the material varies widely, depending on the permeability of the material, amount of recharge area, lithology, thickness of the material, and gradient of the stream valley. Transmissivity has dimensions of squared distance per time, and is typically reported as ft^2/day. Transmissivities greater than 1,000 ft^2/day represent good aquifers for water well exploration.

A discussion follows of the aquifer systems within the three separate geologic provinces. It should be noted that aquifer systems that predominate in one geologic province may also be found in places in the other provinces.

Quaternary System Aquifers

All the drainages of any appreciable size within the watershed, in all three provinces, contain some quantity of alluvial valley fill. However, the depth and extent of the alluvium tends to be quite limited in most of the region, and thus the storage capacity of the stream-valley alluvium will be small, and the alluvium may dry up in droughts. Water contained in the alluvium can be discharged to underlying formations, to surface streams and to the air. In general the development of large supplies of ground water by means of wells in alluvium is not feasible for the reasons stated above. The highest transmissivities can be expected in the river valleys where coarse sand and gravel predominate. Transmissivity values for alluvial material in San Juan Basin (west of the study area) range from 1,000 ft^2/day to 40,000 ft^2/day (Stone et al., 1983).

Chama Basin Province Aquifers

The main aquifers in the northern, central, and western parts of the watershed are from deeper strata within Mesozoic deposits of the Colorado Plateau. These deposits are primarily composed of moderately to well-consolidated sedimentary rocks that vary greatly in thickness, lithology, and hydraulic characteristics. The discussion below summarizes six principal water-yielding units within the Rio Chama watershed: the Mesaverde, Dakota, Mancos, Morrison, Entrada, and Chinle aquifer systems.

Mesaverde Aquifer

The Mesaverde aquifer comprises water-yielding units in the Cretaceous Mesaverde Group and is at or near land surface in the northern and western parts of the watershed. The Mesaverde unit ranges from approximately 135 to 600 feet thick. The aquifer is typically found in confined conditions due to its fine-grained makeup and its position above a thick confining unit (Mancos Shale) which serves as a barrier to downward ground water flow (USGS, 1995).

Water generally recharges the Mesaverde aquifer in upland areas that receive relatively more precipitation, typically the flanks of the mountains. Ground water discharges from the aquifer directly to streams, springs, and seeps, by upward movement through fractures in confining layers and into overlying aquifers. Stone, et al. (1983) report transmissivity values within different formations of the Mesaverde aquifer (in the San Juan Basin) to range from 2 ft2/day to 240 ft2/day.

Mancos Aquifer

The Mancos aquifer system comprises water-yielding units in the medium-to-coarse grained sandy layers of the Mancos Shale. The unit exceeds 1,000 feet thickness in parts of the watershed area. The aquifer is found in confined conditions due to the fine-grained nature of the shale. The thick layers of the Mancos Shale serve as a confining layers to those units it contacts. There are scattered springs in the Mancos Shale in the central portion of the watershed area, and there are also many small perched water tables that are present as lakes in landslide depressions throughout the Mancos ourcrop. In general, the Mancos Shale is not a highly productive aquifer. Transmissivity estimates for the formation are not available, but wells thought to draw water from the Mancos aquifer in the vicinity of Tierra Amarilla yield up to approximately 20 gpm.

Dakota Aquifer

The Dakota aquifer system comprises water-yielding units in the Cretaceous Dakota Sandstone and Burro Canyon Formations. This aquifer is at or near land surface in the north and central part of the watershed. The Dakota unit ranges from 110 to 400 feet thick. The aquifer is typically found in confined conditions and is overlain by a thick confining unit (Mancos Shale) and underlain by the Morrison and Chinle confining units that restrict vertical flow.

The coarse-grained sandstone beds of the Dakota Sandstone Formation have good permeablilites and several springs emerging from this formation have been mapped in the Chama Basin of the watershed. In some areas of the basin, artesian conditions are common. Potable water from the Dakota Sandstone is available in some places at depths of less than 500 feet except on those mesas where dissection by erosion has prevented appreciable storage (Smith et al., 1961). Transmissivity values of the Dakota sandstone (in the San Juan Basin) range from approximately 40 ft^2/day to 105 ft^2/day (Stone et al., 1983).

Morrison Aquifer

The Morrison Formation underlies the Dakota aquifer and includes an upper, non-water-yielding fine-grained unit called the Brushy Basin Member, which forms the Morrison confining unit. This member mainly consists of relatively impermeable siltstone, mudstone, and claystone. The middle and lower parts of the Morrison Formation consist of interbedded fine to medium sandstone, siltstone, and mudstone. This sequence is called the Morrison aquifer, although only the coarser-grained strata generally can be expected to yield water. The Morrison Formation is as thick as 900 feet in areas within the watershed. Transmissivity values of the Morrison Formation (in the San Juan Basin) are as high as 500 ft^2/day (Stone et al., 1983).

Entrada Aquifer

The Entrada Sandstone generally is very fine to fine sandstone. Above Ghost Ranch, several springs flow from the base of the Entrada sandstone in Arroyo del Yeso. The Entrada sandstone is well sorted and has good permeablility, however it crops out as steep cliffs over most of the watershed area and thus has limited recharge. The aquifer is typically found in confined conditions and is underlain by a thick confining unit (Chinle shale member) which serves as a barrier to vertical ground water flow. Transmissivity values of the Entrada Sandstone (in the San Juan Basin) are as high as 350 ft^2/day (Stone et al., 1983).

Chinle Aquifer

The upper shale member of the Chinle Formation is generally considered a confining layer. However, the lower sandstone member of the Chinle Formation locally contains as much as 200 feet of coarse-grained, permeable sandstone and serves as an aquifer (Smith et al., 1961). In some areas faults have controlled the drainage pattern and the ground water distribution. A favorable area for ground water accumulation in this lower sandstone member of the Chinle is in Arroyo Seco to the west of Ghost Ranch and to the northeast of Echo Amphitheater. Here, the sandstone unit is buried by approximately 200 feet of Upper Chinle Shale Member. Smith (1961) reports that reasonable amounts of ground water up to 50 gallons per minute (gpm) could be drawn from depths of less than 300 feet in these areas. Transmissivity values of the Petrified Forest Member of the Chinle Formation (in the San Juan Basin) are greater than 100 ft^2/day (Stone et al., 1983).

Española Basin Province Aquifers

The main aquifers in the central and south part of the watershed are from aquifers of sedimentary origin, primarily of the Santa Fe Group. The Santa Fe Group was deposited in a series of grabens and fault structures during Miocene and early Pliocene time in the Tertiary Period. The beds of the Santa Fe Group are more than 3,700 feet thick in some areas in the Española Basin (Galusha and Blick, 1971), and probably as thick as 1,500 feet in the study area. In general these Tertiary deposits are coarse grained with many boulder and pebble layers and typically good water-bearing aquifers. This aquifer, represented by Santa Fe Group deposits, is influenced by recharge from precipitation and snowmelt, surface runoff, depletion by shallow ground water evaporation and transpiration, pumping from wells, and discharges from springs (Coone and Kelly, 1984).

The Tesuque Formation has a moderate permeability, but because it is areally extensive, is thick in some areas, and has a relatively large recharge potential, it is considered an important aquifer (Spiegel and Baldwin, 1963). Ground water which occurs in sands and gravels of the Tesuque Formation is usually, but not always, found under water table (unconfined) conditions. In the Santa Fe area, the Tesuque Formation is a better aquifer than the underlying older rocks and yields sufficient water for ordinary domestic use. However the more clay rich zones do not yield sufficient water.

Hearn (1985) assessed the Tesuque Formation aquifer characteristics from deposits just outside of the Rio Chama watershed. Based on aquifer tests conducted in the Los Alamos Canyon, San Ildefonso, Pojoaque, and Nambe areas, the hydraulic conductivity of several units within the Tesuque Formation range from 0.5 to 2 ft/day. The transmissivity values, based on these aquifer tests conducted just outside the study area, ranged from 335 ft^2/day to 2,100 ft^2/day.

Water is stored in the Tesuque Formation in both confined and unconfined conditions. In the case of confined conditions, specific storage is approximately 2×10^{-6} (0.002%) per foot (Hearne, 1985). This represents a storativity value which is on the low end of the typical range for confined aquifers. No aquifer tests of the Tesuque aquifer system have been conducted within or just outside the study area to determine the specific yield. However, Hearn estimated the specific yield (storage under unconfined conditions) based on knowledge of materials comprising the formation. The materials are poorly sorted and generally contain considerable clay and silt. For materials similar to the Tesuque Formation, the aquifer system is expected to have an average specific yield of about 0.1 to 0.2 (10% to 20%) (Hearn, 1985). This represents a storativity value which is on the high end of the typical range for unconfined aquifers.

Crystalline and Volcanic Province Aquifers

This region is primarily comprised of Precambrian crystalline rocks overlain by Tertiary volcanic and sedimentary deposits. A sequence of Tertiary age deposits covers up to 60 percent of the province, and approximately half of the Tertiary section is composed of volcanic conglomerate. Poorly consolidated conglomerate of sandstone intertongues with the volcanic conglomerate. Basalt and silicic pyroclastics are also present. The average thickness of the Tertiary deposits over the Precambrian rock is 300 feet (Bingler, 1965). No aquifer studies have been conducted on these Tertiary deposits, however, based on the above discussion of the Santa Fe Group deposits, these Tertiary volcanics and sediments may also be expected to have an average specific yield of about 10 percent to 20 percent.

Precambrian rocks underlie these Tertiary deposits, and are exposed above ground surface in the higher mountains such as Ortega Mountains and La Madera Mountain (Bingler, 1965). Some ground water is available from fractures in these hard rocks, but they are more important for their control of the movement of ground water in overlying, more permeable Tertiary rocks. The Precambrian rocks have a relatively small volume of primary pore space to store or transmit water. However ground water may be contained in openings caused by weathering or in openings caused by structural deformation of the rocks such as faults and joints. The bedrock may serve as sources of springs and surface stream flow. If a well in crystalline rocks does not encounter open fractures or weathered zones below the water table, it may produce little or no water. Wells in valleys are likely to be more successful than the wells on ridges, as valleys are often coincident with fault zones, where as ridges are generally formed of more massive rocks. In general the productivity of wells in crystalline rock is highly variable, difficult to predict, and not infrequently very low.

Observation Wells and Water Level Monitoring

A search was made for community wells with any recorded water level measurements over time, and for monitoring wells or piezometers in the Rio Chama watershed. The purpose of this search was to see if water level data was available over some time period to evaluate changes in water levels due to wet and dry years, or trends in regional water levels over longer periods of time. Unfortunately, relatively little such information seems to exist.

USGS Observation Wells

The USGS maintains a database on monitoring wells as part of the USGS Observation Well Program. USGS personnel (Robert Gold and Roy Cruz) supplied provisional ground water data from this database including information on water level measurements of wells dating back to 1958 (for some wells). A total of 144 monitoring wells in the database are located within or adjacent to the Rio Chama watershed. Unfortunately, however, for most of these wells only one or two water level measurements have ever been recorded. Only one well within the region, and five nearby but just southeast of the region boundary, have been monitored systematically over time so that hydrographs are available. The one well within the region is located on the western edge of the study area in T25 and R1W, near Llaves. The five nearby wells are located in T21N and R8E, near Española. Figure 4-10 shows the location of these six wells and a hydrograph for each well. Three deeper wells (water level below 60 feet) do not show much variation with time. Of the three shallower wells, one well had drop in water level of approximately 12 feet from 1975 to 1988.

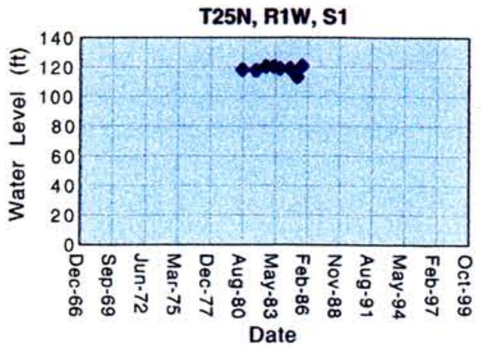
Mutual Domestic Water Users Association Wells

The MDWUA community wells are not monitored for water levels, and therefore there is no available data to evaluate changes in water levels due to wet and dry years and or withdrawals and returns, and impacts on nearby surface water bodies. As part of this study, we talked with the supervisors of several of the community water systems. Information regarding water supplies and ground water resources, based on these personal communications, is presented in the Community water resources section below.

AQUIFER RECHARGE AND YIELDS

Recharge to aquifer systems is a complex phenomenon that is very difficult to measure, and no actual measurements have been reported in the Rio Chama watershed. In addition to aquifer recharge from natural precipitation, recharge can occur as incidental recharge from water that seeps into the ground after various human uses; and artificial recharge by constructed or managed projects designed to put water in the aquifer. There are no artificial recharge projects in the watershed at present. The inciden-

Rio Chama Water Planning Region Hydrographs



Explanation

- State Line
- County Line
- Perennial Stream/River
- Intermittent Stream
- Interstate
- U.S. Highway
- State Highway
- Township/Range
- Planning Region

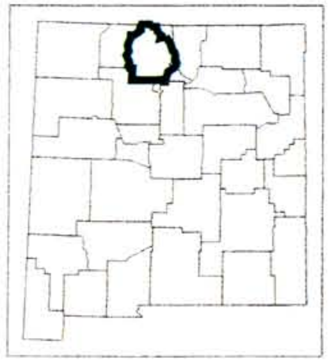
Produced by New Mexico Water Resources Research Institute, January 2001

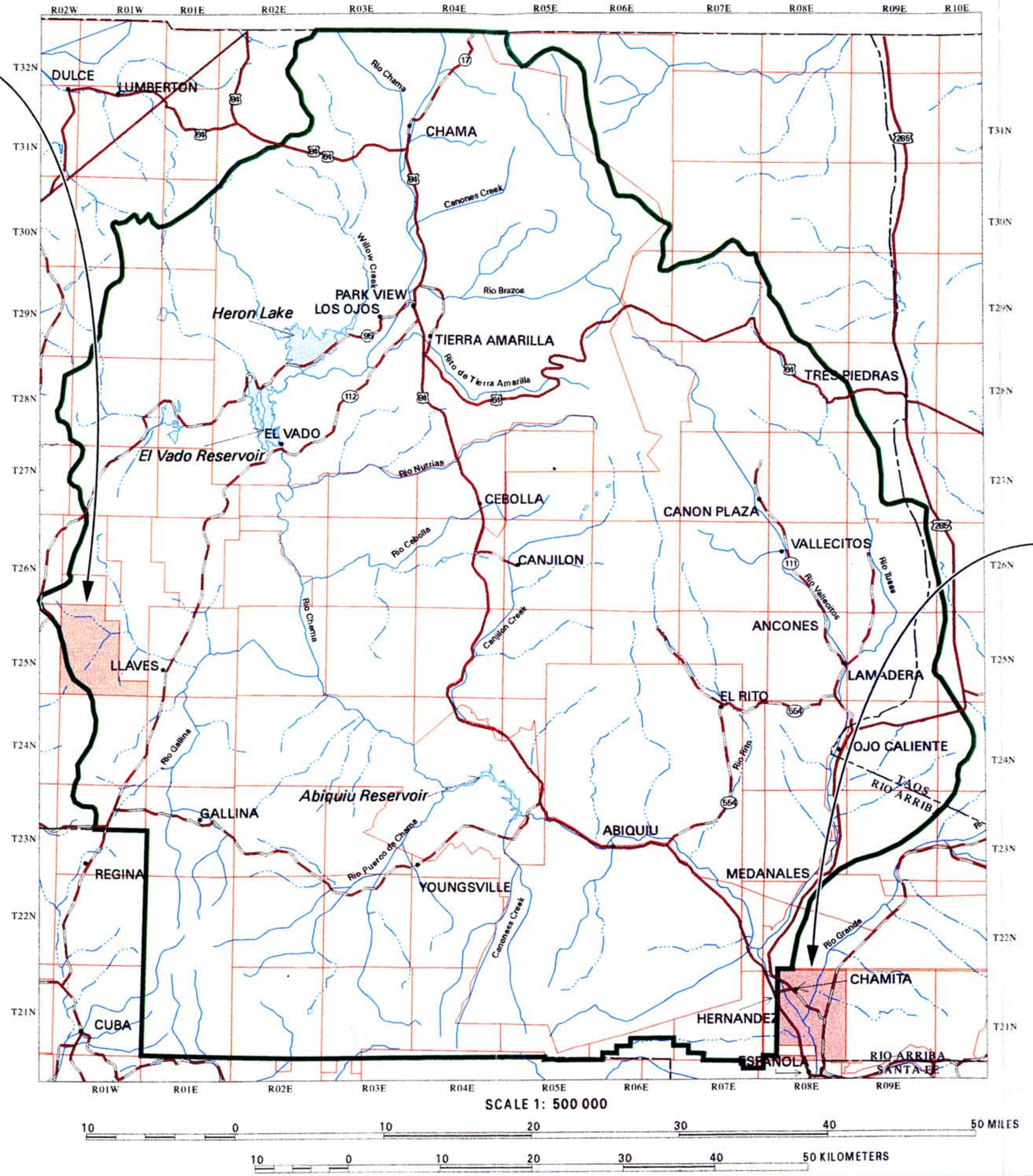
Base map prepared by the U.S. Geological Survey

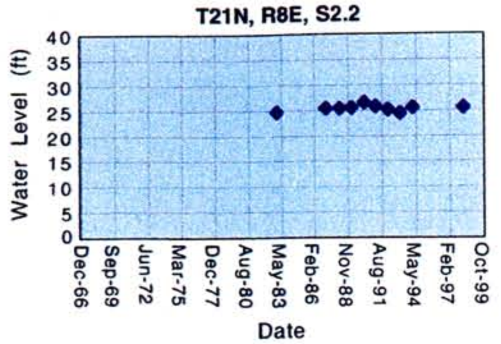
Compiled from digital data provided by the New Mexico Resource Geographic Information System Program (RGIS). Original base maps digitized from 1:500,000 mylar sheets and 100,000 paper maps for New Mexico. These data meets National Mapping Accuracy Standards for 1:500,000 and 1:100,000 scale maps. Shaded relief provided by RGIS and is based on 1:250,000 Digital Elevation Models (DEMs) created by the U.S. Geological Survey. Boundary of the Rio Chama Water Planning Region is based on New Mexico county boundaries, and surface drainage divides. The cadastral accuracy of the county boundaries where verified by the use of 1:100,000 Public LandSurvey System (PLSS) from RGIS.

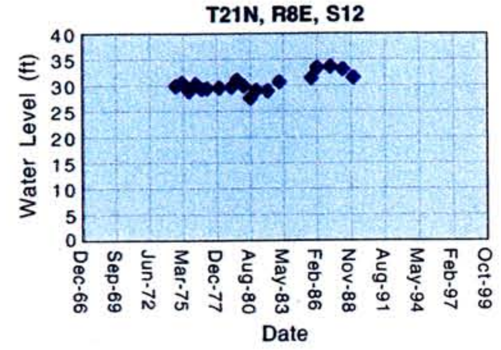
Horizontal accuracy: At the scale of 1:500,000 at least 90 percent of the points tested are within 1/30th inch (0.033 inch), or within 423 ground meters, of their true location.

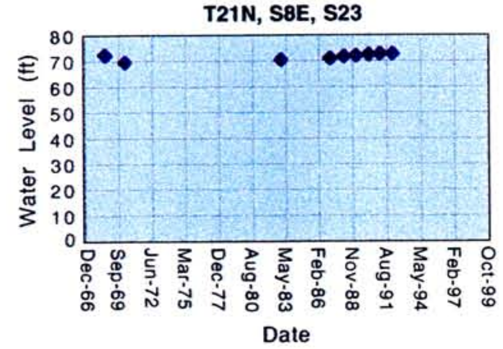
Projection: Universal Transverse Mercator, Zone 13. Units meters, NAD83.

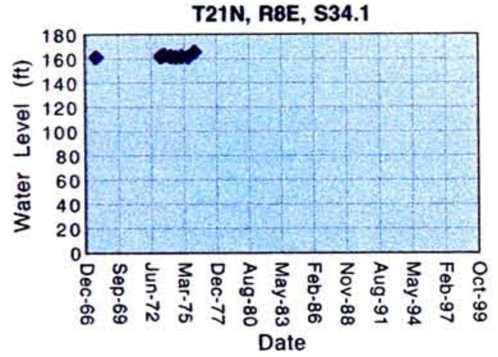


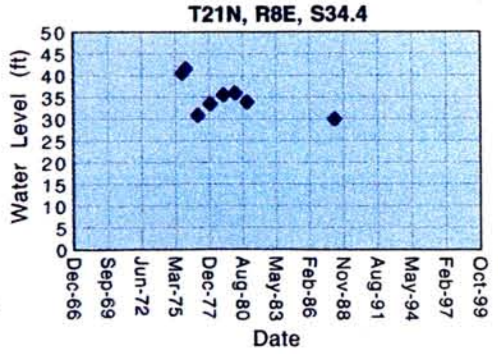












tal or return-flow recharge mechanism that is important in our region is seepage below the root zone in irrigated fields, which may be a significant source of local aquifer recharge. Most of the visible streamflow in the Rio Chama and its tributaries probably soaked into the ground near where it fell as snow or rain and spent some time as recharge to a shallow aquifer before emerging as baseflow in a stream, so any attempt to quantify recharge depends a great deal on its definition.

Natural Recharge

Natural recharge is percolation of surface water resulting from precipitation and snowmelt that penetrates the subsurface and is not intercepted by evaporation or transpiration. Percolating water moves at highly variable rates through the unsaturated zone to the saturated zone, and may re-emerge as spring discharge or base flow of a stream. Recharge can be thought of as either areal (also called diffuse or direct), or concentrated (Gee and Hillel, 1988).

Areal recharge results from percolation of water below the active root zone of local vegetation that takes place over a wide area, not confined to concentrations of water such as stream or arroyo channels or areas of ponding. An example would be a significant snowfall that melted into the ground while most vegetation was dormant and thus did not all evaporate or become transpired. This kind of situation is infrequent in lower areas, and may not contribute a large fraction of total aquifer recharge in our arid climate. Gee and Hillel (1987) and Stephens (1994) suggest that areal recharge in semi-arid regions occurs primarily during certain times of the year. It is typically episodic, occurring in short and sometimes unpredictable events, and may be confined to certain areas. Stephens (1994) found that recharge was much greater in sandy soils as compared to silts or clays. Deep percolation can occur preferentially during snowmelt primarily because the soil moisture content is high and infiltration gradual at times when evapotranspiration is low. Areal recharge can be continuous and spatially distributed throughout the entire vadose zone, or it may be concentrated through distinct pathways that cut preferentially through the vadose zone. Gee and Hillel (1987) believe that spatially concentrated recharge through preferred pathways constitutes the principal mode of areal recharge in semi-arid areas. Stephens (1994) suggests that continuous and spatially distributed recharge constitutes the principal mode of areal recharge when there is no ponding or significant plant uptake, such as would occur in the winter months.

Moisture flux through the vadose zone is extremely difficult to measure directly, but estimates exist of areal recharge rates, which are not surprisingly rather small: Spiegel and Baldwin (1963) estimated direct recharge in the Santa Fe area at 0.5 to 0.7 inches per year. McAda and Wasiolek (1988) proposed rates that ranged from 0.5 inches per year for the Ancha Formation near Arroyo Hondo to 0.05 inches per year for the Tesuque Formation above La Bajada in the Santa Fe area. Wilson (1978) suggested an average areal recharge rate of 0.28 inches per year for the Santa Fe Group in the Santa Fe area. Hearne (1985) in his evaluation of groundwater resources in the Tesuque aquifer system near Pojoaque did not consider areal recharge to be a significant mechanism. Anderholm (1994) suggested that areal recharge occurs primarily within sandy arroyos, if it occurs at all - which might better be described as a kind of seepage infiltration from stream beds, discussed further below. Kearns and Hendrickx (1988) studied the variability of areal recharge rates by different soil types and vegetation and precipitation distribution in southern New Mexico. They found that areal recharge had maximum values of 1.6 inches per year for a condition with bare sand (2 meters depth) and 0.18 inches per year for a condition with grass with loam soil (6 meters depth). Mean values for these same conditions were 0.42 inches per year and 0.02 inches per year, respectively. It should be noted that this study took place near Las Cruces, an area significantly drier and warmer than anywhere in the planning region, and characterized by quite different soils and vegetation.

Conceptually, it seems clear that the great majority of precipitation that falls in the lower elevations of our region will either evaporate directly from the land surface or be transpired by plants. Even though in reality some areal recharge undoubtedly occurs in our region, it would be conservative for planning purposes to assume that areal recharge does not account for an appreciable fraction of total recharge.

Concentrated recharge can occur as seepage beneath the bed of streams or arroyos. Stream and arroyo bed material tends to have much greater hydraulic conductivity than surrounding non-alluvial material (Lewis and Nimmo, 1998); and obviously there will tend to be a disproportionate availability of water in watercourses, so there will be much more infiltration of water into the subsurface along streams and arroyos than in upland areas. However, streams can be either losing streams, where water seeps from the stream into the subsurface; or gaining streams, where water from the subsurface discharges into the stream. In at least some reaches the Rio Chama is in fact a gaining stream, where ground water contributes to stream flow (Wells, 2000); and this may well be true for reaches of other tributary streams. This exchange of water between surface streams and subsurface aquifers is difficult to quantify. Duke Engineering (2000) took the approach of estimating the net stream gains and losses in the Espanola Basin (south of the study area) as the balance remaining from comparison of other water budget components. It seems likely to be inconclusive at best to attempt to isolate losing stream reaches in the Chama watershed, estimate rates of recharge from each one, and attempt to deal with issues of potential double-counting, where recharge to ground water in one area becomes discharge from ground water elsewhere in the region.

Mountain front recharge is a regionally important kind of concentrated recharge thought by some investigators to be particularly important in northern New Mexico (Anderholm, 1994; Wasiolek, 1995). Anderholm (1994) defines mountain-front recharge as "…the sum of mountain-stream-channel recharge and subsurface flow [into large valley-fill basins] from the mountains". Mountain-front recharge occurs across the interface, or boundary, between uplifted crystalline mountain blocks and the alluvial or sedimentary basin aquifer system. Flow into valley fill sediments occurs as either seepage from streams that drain the mountains or subsurface inflow of water from the fractured bedrock to the basin-fill sediments. A number of studies have proposed quantifications of mountain-front recharge in New Mexico (for instance Duke Engineering, 2000; Anderholm, 1998; and Wasiolek, 1995).

The Rio Chama watershed is too complex geologically for any one type of recharge mechanism to obviously predominate. There are probably parts of the northern and perhaps western boundaries of the Española basin (in the southern part of the Rio Chama watershed) where mountain-front recharge is a significant phenomenon. Certainly seepage from streambeds occurs in many places throughout the basin; and some degree of areal recharge probably occurs also. However, it seems very likely that, for instance, infiltration that originally entered the subsurface through fractures in crystalline rock may emerge as flow from a spring, become surface flow in a tributary stream, and perhaps recharge an aquifer in a different part of the region as seepage from the stream bed. For this reason, even though there are published methods to estimate seepage from streambeds, or mountain-front recharge, or even areal recharge, it would be an extremely complex undertaking of dubious accuracy to attempt to estimate recharge based on specific local contributions of each mechanism. Adequate data do not exist to support such an effort with any reasonable expectation of accuracy. It is possible to suggest an order-of-magnitude level of total ground water recharge within the region as a whole, based on work in similar hydrogeological settings (see the Water budget recharge studies section below). It must be emphasized, however, that this is a very imprecise and perhaps inaccurate number, and it should not be used for purposes of attempting to define sustainable basin-wide ground water use levels, as discussed in Wasiolek (1995) and Bredehoeft et al (1982).

Recharge Estimation Methods

There are several methods for deriving subsurface natural recharge that could be applied to any of the primary mechanisms discussed above. No one method is used solely throughout New Mexico or throughout the semiarid southwestern states. A good summary and discussion of various methods can be found in Water Resources Research Center (1980), but three principal kinds of approach are summarized below:

- Chemical and isotope analysis – Sources and amount of recharge can be evaluated by comparing the chemistry of water from rainwater, springs, surface water, and shallow and deep ground water;

- Theoretical ground water modeling – A model can be constructed to determine the amount of water that needs to enter a regional basin aquifer to maintain hydraulic heads or water levels in the aquifer. A simplified approach would be to estimate ground water discharges from a basin assumed to be in equilibrium, and deduce that total recharge from all sources must equal discharges to maintain the equilibrium; and

- Water budget – Recharge is calculated based on known or estimated values of precipitation, evaporation and streamflow runoff.

Chemical and isotope approaches are based on the premise that various sources of recharge water have unique chemical signatures from chemicals dissolved in the water, or isotopes of hydrogen or oxygen in the water molecules, that can be used to estimate the amount of recharge and the movement of the ground water (see Stone, 1992, for example). The stable isotope method uses seasonal variations in hydrogen and oxygen isotope concentrations in rainwater and compares this to seasonal variation of concentrations in ground water at different locations. Unfortunately, the seasonal variations are very small, and variations from one location to the other are often larger than the seasonal variations. This can lead to high statistical uncertainty of results. The chloride method looks at the ratio of chloride concentrations in precipitation as compared to those in soil water. This method assumes that all chloride comes from precipitation (not from human activities or geologic media) and that chloride is not reactive in unsaturated zone. However, no data have been collected in our region that would enable either method to be used.

The ground water modeling approach uses water level data and information on hydrologic properties to calculate the amount of recharge that has theoretically occurred. Site specific data is required for parameters such as transmissivity, hydraulic gradient, and saturated thickness. If site specific data is not available estimates must be made which may result in substantial errors. Ground water models are also sensitive to the accuracy of representations of boundaries to the aquifer system being modeled, which would pose problems in our region. The boundary between the Rio Chama and the Jemez y Sangre planning regions cuts across the Española basin, requiring either an artificial boundary to the system or a unified modeling effort. In addition, the geologic characteristics of the boundaries between the Española Basin, Chama Basin, and Crystalline and Volcanic geologic provinces within our region are not nearly as well explored as the basin boundaries in most of the mountain-front recharge studies.

The water budget method uses climatic and hydrologic data and calculates recharge based on an equation which simply expresses the fate of all precipitation:

P = ET + RO + R

where,

P = precipitation
ET = evapotranspiration
RO = runoff or stream discharge
R = recharge to the ground water system

In other words, all the water that falls must either evaporate (or transpire), run off as surface water, or recharge ground water. There is no place else for it to go. The same equation can be restated as:

R = P – RO – ET

Estimated values for precipitation were made for the Rio Chama watershed, as explained above. Runoff can be calculated reasonably accurately by adding the estimated irrigation depletion for the region to the annual average flow past the Chamita gage. However, ET data has not been directly measured or calculated for the Rio Chama watershed and the uncertainty in ET estimates is probably greater than the total recharge amount. Runoff at the Chamita gage (plus calculated depletions) could be used in the budget equation, but much of that runoff has been shallow-aquifer recharge at some point, has quite possibly cycled between recharge and streamflow repeatedly as it traveled through the watershed, and therefore cannot be reliably distinguished from recharge. This is precisely the dilemma that has led to consideration of watershed yield as an aggregate quantity rather than to attempt to separate recharge and surface flow in this water resource assessment.

An approach has, however, been developed to estimate “potential recharge” for an area not dissimilar geographically to the Rio Chama. Waltemeyer and Kernodle (1992) developed regression equations for winter precipitation and snowpack loss as related to altitude for the San Juan River basin. They also developed an equation for potential recharge based on total winter precipitation, assuming that the fraction of summer precipitation that ultimately became recharge was negligible. In this equation all the water content in melting snow at the end of the winter becomes "potential recharge". The conceptual model is that all springtime snowmelt becomes recharge, but no summer precipitation does. While in reality some melting snow is undoubtedly transpired and some rainfall (at least from stream channels) escapes evapotranspiration and becomes recharge, the summer recharge contribution would tend to offset early-season transpiration of snowmelt, so the overall model is reasonably descriptive of conditions in the Southwest. The San Juan watershed is considerably larger (19,400 square miles) than that of the Rio Chama, but it seems close enough in overall geography to justify using the Waltemeyer and Kernodle equation in our region. Their equation is:

$\mathbf{R} = 0.486\, \mathbf{P}_w^{0.76}$

where,

$\mathbf{R}$ = potential recharge, in cubic feet per second, and
$\mathbf{P}_w$ = mean annual winter precipitation for the basin, in cubic feet per second

Based on data in Kunkel (1984), from the weather stations in the Rio Chama watershed and generally covering a period from the 1930's to the 1980's, the overall average fraction of precipitation that falls from October through April on the weather stations in question is 47 percent. The values for the stations range from 57 percent at Chama to 36 percent at Abiquiu Dam. Clearly the fraction of winter precipitation goes up with altitude. It seems reasonable to assume an overall October to April precipitation fraction for our region of about 50 percent.

Using the estimate of total annual precipitation given above and assuming 50% of it to be winter precipitation, Pw would be approximately 3,265,398 x 0.5 = 1,632,699 acre feet per year. 1,632,699 acre-feet per year x 0.00138 = 2253.1 cubic feet per second. Using this value in the Waltemeyer and Kernodle equation gives:

$\mathbf{R} = 0.486\,(2253.1)^{0.76}$

$\mathbf{R} = 0.486\,(353.3) = 171.7$ cfs

171.7 cubic feet per second x 724.46 = 124,390 acre-feet per year of potential recharge for the 3,157 square mile Rio Chama watershed. This would equate to approximately: 124,390 acre-feet per year x 12 in. per ft. / 2,020,480 acres = 0.74 inches per year potential recharge, averaged over the entire watershed.

In addition to these calculation methods, there are various subsurface recharge studies by other investigators involving basin aquifers in northern New Mexico and southern Colorado. Three studies (Huntley, 1979; Duke Engineering, 2000; and Wasiolek, 1995) indicated that recharge accounts for between 3.5 percent and 14 percent of the total precipitation. The rates are not directly comparable, however, since the studies yielding higher fractions focused only on the mountain areas that contributed recharge to lower-elevation basins, while the 3.5% estimate considers both basin and mountain areas.

Huntley (1979) investigated mountain-front recharge to the aquifer of the northern San Luis Valley in Colorado, and estimated that 14 percent of the total mountain area precipitation contributed to mountain-front recharge or ground water flow to the basin. This valley, bounded on the east by the Sangre de Cristo Mountains, is filled with sediments that have been correlated with the Santa Fe Group deposits found in New Mexico.

Wasiolek (1995) studied the recharge to the Tesuque aquifer system from selected drainage basins along the western side of the Sangre de Cristo Mountains near Santa Fe. The 90-square mile study area is located in the Española Basin south of the Rio Chama watershed study area. Wasiolek estimated that 12.6 percent of total precipitation in the mountain-front study area contributed to basin recharge.

Duke Engineering (2000) conducted a water supply study for the Jemez Y Sangres water planning region, which encompasses approximately 1,892 square miles in the Española Basin (just south of the Rio Chama watershed study area). The area is bounded on the east by the Sangre de Cristo Mountains and on the west by the Jemez Mountains. Basin fill is primarily composed of sediments from the Santa Fe Group. Values from the Duke Engineering study indicate that in that study area total calculated recharge divided by total area suggest that approximately 3.5 percent of the total, entire-area precipitation contributed to recharge. We took this approach because the Duke study included streambed recharge throughout the study area, rather than isolating mountain-front recharge only.

These studies show a considerable spread in calculated recharge to precipitation ratios. The Huntley and Wasiolek studies evaluated only mountain-front recharge, and the area in which the total precipitation was estimated (the mountain block terrain) was small relative to basin area. Thus it is not surprising that recharge as a fraction of total precipitation would be greater in these studies than in ones that include a greater percentage of low-elevation, low-precipitation basin area in evaluating recharge. In contrast, our calculations using the Duke Engineering data considered total precipitation since calculated recharge in that study included both mountain-front recharge (over the mountain blocks) and stream loss recharge (over most of the basin). This approach seems more descriptive of the situation in the Rio Chama watershed since most of the region is more mountainous than basin. The Waltemeyer and Kernodle approach is also based on total basin area rather than looking only at mountain-front recharge.

Another cause for differences in the calculated recharge to precipitation ratios may be the methods used for computing ET: Duke Engineering used ET values derived from the Thornthwaite formula, and Wasiolek used ET values derived using a method described by Troendle and Leaf. These methods may lead to different ET values, which in turn will result in differences in calculated recharge. Other reasons for discrepancies in calculated recharge ratios include different designations of mountain-front boundaries or differing geologic and aquifer conditions.

The Rio Chama watershed is similar to the basins investigated in the studies mentioned above in that much of it is mountainous and part of the watershed is comprised of sediments of the Santa Fe Group. However the Rio Chama watershed is more complex in that it is underlain by many aquifers, which are geologically distinct. With the above precautions in mind, and for purposes of order-of-magnitude estimates only, we have presented Table 4-24 to show the range of recharge estimates suggested by the calculation methods described.

The Waltemeyer and Kernodle calculations and the estimate based on Duke Engineering data use the Table 4-15 estimate of 3,265,000 acre-feet per year of total precipitation across the Chama watershed because they explicitly consider both basin and mountain areas. The Wasiolek and Huntley estimates of recharge fraction were based on mountain-area precipitation, so it seems more realistic to apply those percentages to the figure of 2,324,000 acre-feet per year that is the estimated total volume of precipitation that falls in the higher parts of the watershed that get over 16 inches of precipitation per year.

While these figures vary by a factor of more than 3, they do suggest a range of likely recharge values for the Rio Chama watershed. For planning purposes it would be conservative to give more weight to the smaller values rather than the larger. These estimates can be compared with those mentioned earlier by McAda and Wasiolek (1988), Wilson (1978) and Spiegel and Baldwin (1963) proposing areal recharge rates ranging from 0.7 inches per year to 0.05 inches per year in the Santa Fe area.

TABLE 4-24: SUMMARY OF RECHARGE ESTIMATES

Method	Estimated recharge, in./y	Estimated recharge, af/y
Waltemeyer and Kernodle	0.74	124,000
Duke Engineering	0.67	113,000
Wasiolek	1.74	293,000
Huntley	1.93	325,000

It cannot be overemphasized, however, that much of the visible streamflow in our region has at one time been some kind of subsurface recharge, so that nothing like 113,000 to 325,000 acre-feet per year is added to long-term ground water storage in the watershed. Most of our recharge re-emerges as streamflow after a fairly short residence time in the subsurface.

Artificial Recharge

There is no artificial recharge or managed projects designed to put water into aquifers within the Rio Chama watershed. It might be said that the reservoirs constructed for surface water storage contribute to a sort of artificial recharge in their immediate vicinity, but it is very unlikely that they have significant effects regionally.

Incidental Recharge (return flow)

Incidental recharge includes return flow or water that seeps into the ground after various human uses, including domestic uses and irrigation. Return flow from ground water usage in the Rio Chama watershed is estimated at about 1,000 acre-ft per year, based on data in Wilson and Lucero (1997). This is almost entirely seepage from septic tank leach fields. While it is more than half of all the ground water pumped for domestic use, it is also contaminated with microbiological pathogens and nitrates (at a minimum) and can easily degrade ground water supplies where it becomes an appreciable source of recharge. See the Water quality section below for further discussion of this issue.

Taken over the region as a whole, recharge from surface water irrigation is a far greater quantity than that from domestic ground water consumption, although there may be local areas where domestic return flows predominate. About 75,000 acre-feet per year is diverted for irrigation use in the Rio Chama valley per year, and about 45,000 acre-feet of that total is estimated to be return flows (Wilson et al, 2002). Accurate data do not exist to enable apportioning the return flows between direct returns of tailwater to the streams from which it was diverted, and seepage to ground water - but clearly if even a small fraction of the total return flow recharges local aquifers, that recharge is considerably greater than all ground water diversions in the region, which total less than 3,000 acre-feet per year (Wilson et al, 2002).

Sustainable Yields

Aquifer recharge, even if it were precisely known, does not define the volume of water that can safely be pumped from an aquifer. It is incorrect to assume that if ground water use does not exceed recharge, ground water conditions will remain constant. In predevelopment equilibrium conditions (before human intervention changed the natural flow system by groundwater pumping, irrigation, and so on) the ground water hydrologic system could be described as simply: *recharge (water entering) = discharge (water leaving)*. From this conceptual model it might be tempting to assume that if ground water use does not exceed total recharge, ground water conditions will remain constant – but this is not the case. Ground water systems of any finite size (such as the Rio Chama watershed) will continue to have outflow into other systems, and water will continue to be removed from storage if it is not replenished by continuing recharge. Recharge to ground water aquifers supports not only subsurface flow, it also supports baseflow to the Rio Chama and other streams, springs, and lakes; natural vegetation; and sometimes agriculture - as well as maintaining ground water levels within reach of wells.

Dunne and Leopold (1978) define safe aquifer yield as "…the annual draft of water that can be withdrawn without producing some undesirable result." With this in mind, it is apparent that what really defines the acceptable amount of water that can be removed from the ground water system is not the gross amount of recharge, but the fraction of recharge we are willing to divert from all the hydrologic functions mentioned above. To put it another way, sustainable yield can be thought of as the use of groundwater in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences (Alley et al., 1999).

Bredehoeft, Papadopulos, and Cooper (1982) point out that a water budget establishing aquifer recharge and ensuring that pumping does not exceed discharge will not ensure sustainable ground waster use, because steady-state aquifer conditions will only be achieved when either recharge is increased to equal pumping or previously-occurring discharges are diverted to the pumping. In our region, much of the existing ground water discharge that would be re-directed is baseflow to existing streams including the Rio Chama, and therefore pumping equal to any appreciable fraction of recharge will have the effect of diminishing streamflows. They quote C.V. Theis (1940) on this issue: *"Under natural conditions… previous to development by wells, aquifers are in a state of approximate dynamic equilibrium. Discharge by wells is thus a new discharge superimposed upon a previously stable system, and it must be balanced by an increase in the recharge of the aquifer, or by a decrease in the old natural discharge, or by loss of storage in the aquifer, or by a combination of these."* It is important to realize that any decrease in water stored in an aquifer results in a lowering of the water table (or potentiometric surface if the aquifer is artesian).

Quantitative information on ground water level changes with time is provided by six USGS monitor wells, five of which are unfortunately located just outside of the study area. One of these shallow wells (in the Española Basin) showed a noted drop in water level of approximately 12 feet from 1975 to 1988 (no data was reported after 1988). This is a significant decrease in water level, but it is impossible to determine its cause with certainty.

Qualitative information was derived by assessing MDWUA resources, based on personal communications with water system supervisors (see the **Community Water Resources** section of this chapter). None of these systems are systematically monitored for water levels. The majority of these community water systems (68%) have difficulty at times producing enough water to meet demands, and there are reported problems of water shortages during dry periods. It does appear that in these locations recharge may not supply enough water to support desired ground water diversions. In addition, it is entirely possible that with continued pumping, the storage of ground water may be severely impacted and water levels may decline.

Based on qualitative assessment of available information, there are no significant ground water resources or aquifer systems that can support large volumes of withdrawals in the Rio Chama watershed. Some – but not all – alluvial and Mesozoic aquifer systems clearly display short-term impacts, and may sustain long-term declines in water levels as well. Tertiary aquifer systems (mostly in the Española Basin) tend to have fewer problems with water shortages and more reliable yields.

Ground water is not necessarily a renewable resource, since water can be removed from aquifer storage much faster than it is recharged. In addition, ground water availability may well fluctuate from year to year. The starting point for any attempt to define and achieve sustainable ground water use is to monitor water levels at appropriate locations, beginning perhaps with the most vulnerable communities but ideally throughout the planning region. This is the most basic kind of data needed for any further refinements in ground water management and planning for sustainable water use.

WATER QUALITY

Information on water quality in the Rio Chama planning region has been developed from data supplied by the New Mexico Environment Department (NMED), the U.S. EPA web site (Surf Your Watershed), the Rio de Chama Acequias Association, and the USGS. Data included are data for private wells, public water systems, and surface water tributaries to the Rio Chama.

SURFACE WATER QUALITY AND CONTAMINATION

New Mexico Water Quality Standards

Surface water quality in the Rio Chama watershed is generally considered good, at least from the standpoint of chemical contamination. EPA's "Index of Watershed Indicators" score for the Rio Chama is 3, or mid-range on a scale of 1 to 5. This score indicates some observed water quality problems, but good overall resiliency in the watershed and relatively low vulnerability to environmental stress (EPA "surf your watershed" web site). There is some concern about metals levels in some reaches (primarily aluminum), which may come from mining activities and/or natural sources, but acutely toxic levels have not been observed. Water quality parameters related to watershed and streamside conditions, such as turbidity, excessive or inappropriately silty stream bottom deposits, excessive temperature, inadequate dissolved oxygen, or excessive total organic carbon, are much more common and indeed affect some part of the majority of the Rio Chama system (NMED Surface Water Quality Bureau web site). (SWQB)

It is important to note that advisories suggesting maximum amounts of fish considered safe to eat, varying by size of fish and class of human consumer (pregnant women should eat least) have been issued by the New Mexico Environment Department. The latest information and advisory levels are available at the NMED Surface Water Quality Bureau web site. The fish advisories so far apply only to the reservoirs, not to the Rio Chama itself. The source of the mercury is considered likely to be atmospheric deposition resulting originally from mercury contained in coal burned in power plants.

Under the provisions of the Federal Clean Water Act and the New Mexico Water Quality Act, streams and water bodies in the state have been assigned "designated uses", which are the uses that the water bodies can be expected to support in the absence of pollution or other adverse human impacts. Numerical standards for pollutants or parameters of concern are developed to measure the ability of water bodies to support these designated uses. Periodically the Surveillance and Standards Section of the NMED Surface Water Quality Bureau samples streams and lakes in New Mexico to determine if these standards are being met, and an annual report is prepared as required under Section 303 (d) of the Clean Water Act to list all water bodies in New Mexico that fail to fully support their designated uses. Table 4-25 below summarizes the designated uses for streams and reservoirs in the

TABLE 4-25: STATE OF NM DESIGNATED USES AND IMPAIRED WATER BODIES

Stream reach or water body	Designated Uses	Impaired reach(es)	Pollutant
Rio Chama - Rio Grande to Abiquiu Reservoir	IRR, LW, WH, CWF, WWF, SC	Chama to Abiquiu Dam	Metals
Rio Chama - Abiquiu to El Vado Reservoirs	IRR, LW, WH, CWF, WWF, SC		
Rio Chama - El Vado Reservoir to state line	DWS, FC, HQCWF, IRR, LW, WH, SC	Chama above Rio Brazos	Temperature
El Vado and Heron Reservoirs	IRR, LW, WH, PC, CWF	Both reservoirs	Fish consumption advisories because of mercury levels
Abiquiu Reservoir	IRR, LW, WH, CWF, WWF, PC	Abiquiu Reservoir	Fish consumption advisories because of mercury levels
Rio Ojo Caliente	IRR, LW, WH, CWF, WWF, SC	Rio Ojo Caliente	Stream bottom deposits (SBD), metals
Rio Tusas	IRR, LW, WH, CWF, WWF, SC	Rio Tusas	SBD
Rio Vallecitos and tributaries	DWS, IRR, HQCWF, LW, WH, SC	Rio Vallecitos	Metals, temp., turbidity, total organic carbon (TOC)
Rio Puerco de Chama	IRR, LW, WH, CWF, WWF, SC	Rio Puerco de Chama	Temperature, coliform, TOC, SBD
		Rito Resumidero, Rito Redondo	SBD, TOC
		Poleo Creek	Turbidity, TOC
		Rito Encino	TOC
		Coyote Creek	SBD, TOC
Rio Gallina	IRR, LW, WH, CWF, WWF, SC	Rio Gallina, Clear Cr., Cecilia Cnyn. Cr.	SBD
Abiquiu Creek	IRR, LW, WH, CWF, WWF, SC	Abiquiu Creek	Nutrients, dissolved oxygen, SBD
El Rito above town of El Rito	DWS, IRR, HQCWF, LW, WH, SC	El Rito above town of El Rito	Nutrients, turbidity
El Rito below town of El Rito	IRR, LW, WH, CWF, WWF, SC	El Rito below town of El Rito	Metals
Rio del Oso	DWS, IRR, HQCWF, LW, WH, SC	Rio del Oso	Turbidity, temperature, TOC
All other perennial Rio Chama tributaries above Abiquiu Dam	DWS, FC, HQCWF, IRR, LW, WH, SC	Rio Chamita	Metals, TOC
		Rito de T. Amarilla	Temperature, turbidity, SBD
		Rio Brazos	Temperature
		Chavez Creek	Tempearture
		Canjilon Creek	Conductivity, temp. turbidity, dissolved oxygen, TOC
		Rio Nutrias	Turbidity
		Rio Cebolla	Conductivity
		Cañones Creek (above Abiquiu Res.)	Turbidity, metals, coliform, TOC, temperature
		Polvadera Creek	SBD, temperature

Key to Designated Uses:

DWS = Domestic Water Supply
PC = Primary (human) contact
SC = Secondary (human) contact
WWF = Warm water fishery
CWF = Cold water fishery
FC = Fish culture
IRR = Irrigation
LW =-Livestock watering
WH = Wildlife habitat
HQCWF = High quality cold water fishery

Chama watershed, and instances where they fail to fully support those uses.

No aquatic threatened or endangered species are identified in the 303(d) list for the Rio Chama and its tributaries.

The full-length 303(d) list as published for the Rio Chama and its tributaries is included in the Appendix.

The nutrients, stream bottom deposits, turbidity, and perhaps some metals problems typically result from sediments washed into streams because of poor ground cover in contributing watershed areas and/or from degraded and eroding stream banks. Elevated temperatures are almost always the result of damaged or removed riparian vegetation. These non-point source problems are by far the most significant surface water pollution issue in the Rio Chama and its tributaries. Sediment loading and resultant turbidity, as well as elevated temperatures that reduce available oxygen, can be toxic to fish and adversely affect aquatic ecology. The factors that most often contribute to this type of stream pollution and degradation are the removal of riparian vegetation, streambank damage and destabilization, erosion from poor road design or maintenance, and poor rangeland condition. These contribute greatly to erosion, sediment transport, and resultant water quality problems.

Agriculture can also be a contributor to stream bottom deposits, when soil erodes from fields into acequias and streams, but apparently does not contribute many nutrients. Nutrient levels along all stretches of the Rio Chama are relatively low. Many tributaries were found to be adversely affected by agriculture in NMED sampling, but it should be noted that agriculture in this sense includes ranching and stock raising, and therefore the effects of rangeland management, ground cover condition, and riparian degradation probably account for the majority of the adverse water quality effects attributed to agriculture.

At this time little direct enforcement action is focused on non-point source pollution such as that affecting the Rio Chama. The EPA and NMED are in the process of developing Total Maximum Daily Load (TMDL) standards for many Rio Chama tributaries, and the TMDLs will include a plan for eventual achievement of standards and designated uses. For the foreseeable future, however, major efforts to improve non-point-source water quality center on grants made through the NMED SWQB Watershed Protection section for projects that demonstrate good ways to reduce the non-point source pollutants entering the stream system.

EPA and NMED records were searched to find how many, if any, facilities within the watershed were listed on various lists of permittees, dischargers, cleanups, or other sites of environmental concern. The results are summarized below.

NPDES permittees
Two NPDES point-source surface water discharge permittees are listed by the NMED SWQB web site in the Rio Chama watershed:

- Chama wastewater treatment plant, NM0027731
- Parkview Fish Hatchery, NM0030139

Leaking underground storage tanks
A total of 30 sites are listed by the NMED Underground Storage Tank Bureau as having leaked within the Chama watershed. The complete list is included in the Appendix, and updates can be found on the NMED Underground Storage Tank Bureau web site.

RCRA hazardous waste facilities
Four sites appear in the EPA RCRA hazardous waste handlers database linked to the EPA "surf your watershed" web site. They are:

- AT&T near La Madera; handler
- El Paso Natural Gas, Ojito P/L (near Lindrith); small quantity generator
- Northern NM Community College, El Rito; exempt small quantity generator
- US Dept. of the Interior, Chama Field Division, Chama; handler

None of these facilities treats, stores, or disposes of hazardous waste and all seem likely to handle or generate very small quantities of legally defined hazardous wastes.

CERCLIS ("superfund") hazardous substance sites
None found.

Toxic Release Inventory (TRI) sites
None found.

San Juan Pueblo Water Quality Standards

The San Juan Pueblo reservation includes the lower few miles of the Rio Chama and its confluence with the Rio Grande. The Pueblo has adopted water quality standards that have the same legal standing under the Clean Water Act as those adopted by the State of New Mexico. The Pueblo has designated uses for the Rio Chama within its boundaries and has promulgated water quality standards for the protection of those uses. The designated uses are:

- Coldwater fishery
- Warmwater fishery
- Primary contact for ceremonial as well as recreational use
- Secondary contact
- Irrigation
- Industrial water supply

Principal promulgated standards specific to the Rio Chama are:

1. **Dissolved oxygen:** minimum 6.0 mg/l.
2. **Fecal coliform:** (testing alternatives and maximum levels described)
3. **Temperature:** maximum 20 degrees Celsius
4. **PH range:** 6.5 - 8.5
5. **Total ammonia:** calculated and specified as a function of pH and temperature
6. **Total residual chlorine:** maximum 0.003 mg/l.
7. **Turbidity:** maximum 25 NTU.
8. **Maximum Contaminant Levels** and maximum numeric criteria for **Toxic Pollutants** as defined in the Clean Water Act are also specified.

There are also general standards regarding (principally) stream bottom deposits; floating soilds, oil, or grease; color, odor, and taste; nuisance conditions; pathogens; radioactive materials; and dissolved solids. In addition, the Pueblo has an anti-degradation standard prohibiting, in general, degradation of existing water quality by other than natural causes.

These standards are potentially enforceable under the Clean Water Act and water entering the Pueblo reservation could be required to meet them. No formal action has been initiated by the Pueblo, but planners and water users in the Region should be aware that water flowing into the Pueblo can be required to meet Pueblo water quality standards.

GROUND WATER QUALITY AND CONTAMINATION

Most of the data pertaining to private wells was obtained from files in the NMED Española Field Office. This office has held a number of "water fairs" since September 1987. In addition, door-to-door and in-office testing were also conducted in order to gather ground water quality data. Water samples are still accepted for testing at the field office and water fairs are held when requested by the public, civic groups or government entities. All available ground water data was obtained from NMED and RCAA water testing. The most recent results were obtained from a joint water fair sponsored by the Rio Chama Acequia Association and NMED's Drinking Water and Ground Water Bureaus on July 12, 2000.

These data gathering methods have resulted in testing of thousands of private wells. Data has been gathered on a substantial percentage of private wells in Rio Arriba County. When this data is combined with the sampling done by community water systems, as required by the Safe Drinking Water Act, we have a pretty good overall idea of the ground water quality in most of the county.

There are a few isolated spots where little testing has been done, either because there are no community water systems or the field office has not conducted water fairs or door-to-door testing. Testing in these areas would be in order to be sure of the ground water quality. NMED's Drinking Water Bureau has the equipment and personnel available to assist the County in this endeavor. NMED's Ground Water Bureau also occasionally becomes involved in cases where there is apparent extensive ground water contamination. They also have the necessary equipment and will gladly assist in gathering data.

NMED became concerned about ground water quality in the late 1980's when the first water fairs began to show the extent of contamination in the Española Valley. Results from these water fairs rather alarmed NMED staff. Previously, it was thought that ground water quality in the Valley was rather good. These water fairs began to prove otherwise. As more water fairs were held, a picture of extensive nitrate contamination in certain areas began to be seen.

The discovery of a large plume in Chamita resulted in the community receiving monies from the legislature to create a water system. Other monies were obtained later and, today Chamita is served by its own water system. The evidence of extensive contamination in the El Guache-Hernandez area has also encouraged residents of these and other communities further north to band together and create their own water systems. Phase I of this project is already complete and many households have already connected to the system.

Testing was also conducted in northern communities but little or no contamination was found. It was decided to concentrate on the more southern areas of the county where contamination had already been found. However, occasional testing was done again in the northern communities.

Nitrates have been of special concern because of its effect on infants. Nitrate contamination above 10 milligrams per liter of water can cause methemoglobinemia or “blue baby syndrome” in infants and small children under about two years of age. An infant will develop this syndrome because the hemoglobin in the blood is unable to transport oxygen molecules. Methemoglobinemia can be fatal.

Septic Systems and Ground Water Quality

Perhaps the major water quality problem in the region is ground water contamination by individual septic systems. There are already thousands of systems in use and, considering the population growth rate in some parts of the region, there will soon be hundreds if not thousands more. Since there are only a few community sewage collection systems, most of the new residences will utilize onsite liquid waste systems for treating their sewage. Most of these systems will consist of a septic tank and a standard drainfield. There are a few evapotranspiration beds, mounds and other alternative systems being used, but not many. Proactive planning could minimize the effect of these additional septic systems on the county’s ground water supplies. Community sewage collection systems could be an important step towards protecting ground water quality and preventing further deterioration.

A critical factor contributing to ground water pollution is the clustering of residences along the river valleys. In many cases, homes are built in the flood plains. In these cases, the liquid waste systems are installed in alluvial or sandy soils with high ground water. This is an extremely bad combination that is conducive to ground water contamination. The septic effluent receives almost no treatment before it reaches the water table. In a worst case scenario, the drainfield is installed directly in the ground water. Since there are many illegal systems it is unknown how many of these systems are in existence but the number is probably high.

In principle, a properly installed and operated septic system can have minimal impact on ground water quality. For this to be the case, however, two important processes must happen: pathogenic microbes must be killed and/or adsorbed onto soil particles, and nitrogen present in effluent must be chemically converted into gaseous nitrogen, before reaching ground water. Unfortunately, conditions in most communities in the planning region severely limit these processes. Since most communities are located in valleys not far from streams, soil is generally sandy alluvium and water tables are high. The sandy soil offers less opportunity for pathogen adsorption per lineal foot of effluent travel than finer soil, and tends to be highly transmissive resulting in rapid effluent movement from leach field to ground water. In addition, the shallow depth to the water table leaves little room for any effluent treatment before reaching ground water. For a septic system to work as it should, effluent needs to travel through a greater depth of coarse, sandy soil than it would need if the soil were finer textured. Rapid transit times to ground water also tend to leave inadequate opportunity for the ammonia in raw sewage to nitrify, or oxidize to nitrate, and then denitrify into nitrogen gas. This can account for elevated levels of nitrate observed in ground water. In addition, anaerobic conditions in soil or ground water reduce rates of denitirification of nitrate to nitrogen gas, and excessive septage discharge frequently causes anaerobic (and chemically reducing) conditions as organic material is metabolized by microbes until available oxygen is used up (Dennis McQuillan, personal communication, March 2002).

Even the best septic systems were not intended to be used in densely populated areas. However, there are many communities in Rio Arriba where residences are highly concentrated and have small lot sizes. To make matters worse, many of the lots have a well and septic system onsite. If the ground water is deep or non potable or if there is one or more impermeable layers between the septic system and the ground water, it might not be a problem but there are very few instances where these conditions occur.

In order to address the septic system problem, a number of entities are now in the process of trying to bring together tribal, municipal, county and state government along with other organizations in an effort to create a region-wide sanitation district. This would simplify the process of asking for funds for water and sewer systems. Since monies for sewer systems are extremely hard to come by, the creation of a large sanitation district would make the probability of obtaining monies more likely.

Chamita has been one of the worst nitrate contamination cases found in Rio Arriba County. Although Chamita now has a community water system and the residents have a safe drinking water source, the contamination problem has not been eliminated and undoubtedly continues to worsen. Testing in progress by NMED and Los Alamos National Laboratory have raised the possibility that natural conditions may have contributed to the nitrate levels observed in the Chamita area (McQuillan, personal communication, March 2002), but the continued use of septic systems can only be contributing to further worsening of conditions. Since the Rio Chama is a gaining stream in that area and is being recharged by the ground water from the direction of Chamita, the contaminated ground water may also affect the surface water quality.

Nitrate contamination found in other areas was also caused by septic systems being installed in sandy or alluvial soils, and possibly made more accessible by improperly constructed wells. In the case of Hernandez–El Guache, the water table was relatively deep but there are septic systems that have been in use for decades.

Well construction can contribute to movement of ground water contamination, as well as failing to protect well owners from possible contamination. A properly constructed modern well should have a clay seal filling the well bore all around the casing just above the screened interval where the water enters the casing, and it should have an additional clay seal at the top of the well bore just below ground surface. These seals are placed to keep any contamination from travelling along the well bore where it penetrates geologic formations that would otherwise restrict contaminant movement, and to keep contamination from entering the well from the surface. Most private wells in the region are not properly sealed, however, leaving an annular space between the soil and the well casing, resulting in a direct channel to the aquifer. Even if there is an impervious layer, septic effluent or other contaminants can travel along the casing directly into previously uncontaminated ground water. It seems probable that the degree of nitrate contamination in Chamita, for example, was exacerbated by many such improperly constructed wells. There is a thick layer of clay underlying Chamita that would be expected to largely prevent septic effluent from reaching the aquifer, except for the openings created in it.

Water Testing Results

Testing results for a number of the wells tested in the county by NMED and the Rio de Chama Acequias Association are included in Appendix 4-9. These are a small portion of the testing results but give some indication of the ground water problems found in the area and also where the problems are. Since, sometimes, only mailing addresses are used, some addresses give a false impression of where the wells are actually located. For example, the Chamita results have a San Juan Pueblo or Española mailing address. But generally, most of the wells are located in the same community as the mailing address.

Many names and results appear more than once because residents were encouraged to either take their water into the field office for retesting, they take their samples to water fairs in other locations, were retest during door-to-door testing. NMED preferred to test water sources multiple times rather than to miss any. Duplications also occur because residents sometimes submitted several samples at once.

In many cases, some information is missing because NMED was mostly concerned with nitrate levels and did not gather all the information in order to process as many samples as possible in that sampling period. This generally occurred when a high nitrate level was followed up with door-to-door sampling. It was standard operating procedure in the Española field office that when a high nitrate level was detected, the whole neighborhood where the high level occurred was canvassed until the outer edges of the contaminant plume were found. Little consideration was given to aesthetic aspects.

Public Water Systems

In general, the public water systems in the Rio Chama Watershed are able to provide their consumers with good drinking water. There are some, however, that have experienced problems in providing good drinking water for decades and some have occasional problems with water quantity or quality. Several systems with infiltration galleries or shallow wells close to a river or stream have struggled to provide sufficient water when the water levels have dropped.

A good indication of how much the quality of water being provided to consumers has improved is the number of waterborne disease investigations conducted. There has been a gradual reduction in waterborne disease investigations in the past two decades. In the seventies and eighties it was expected that there would be several investigations conducted every year. Fortunately, the number has been reduced to the point that many years might go by without a waterborne disease outbreak.

Most of these outbreaks usually occurred in the spring and involved systems using infiltration galleries or shallow wells as their source. Many galleries failed to properly filter the surface water soon after they were constructed. Many times, the filter cloth over some galleries became clogged and were either simply removed or large holes were cut in them to allow the water to pass through. The water entering the gallery was essentially raw water with all its impurities. This became evident when the water coming out of the taps became highly turbid. Most systems did not have the means to properly filter and disinfect the water supply. In cases where the system had proper disinfection facilities and added halogens such as chlorine or iodine to the turbid water, there was the added problem of creating carcinogens called trihalomethanes.

Because of changes to the Safe Drinking Water Act and subsequently to the New Mexico Water Supply Regulations, many systems were tested for surface water characteristics and reclassified as surface water systems. This resulted in them having to meet more stringent requirements. This included proper filtration and disinfection, daily monitoring and reporting of turbidity and disinfectant levels. Certified operators are now also required to operate these systems. The additional requirements and improvements to the water system infrastructure combined with operator training have gradually led to the improvement of most of the water systems. Unfortunately, because some have financial problems or are unable to find a suitable water source, not all the systems are operating at optimum level. Too many systems are paying on multiple loans and are unable to obtain additional monies for further improvements. Some just can’t find a suitable water source.

Training for the system operators has been provided by the New Mexico Environment Department, the N.M. Rural Water Association and the New Mexico Water and Wastewater Association. Technical assistance has also been provided by NMED and the NM Rural Water Association under contract with NMED. The training and technical assistance have resulted in a vast improvement of water system operations.

COMMUNITY WATER RESOURCES

This section provides a more detailed look at the geology and hydrology of local communities in the Rio Chama watershed. The locations of these communities can be seen on the regional map at the beginning of the Water Plan. The communities are essentially the only locations where ground water information exists, in the form of consultant reports, personal communications with supervisors of community water systems, and from actual well logs obtained from the Santa Fe and Albuquerque OSE ground water data files.

Well log information is used to summarize geologic units, water-bearing units, depths to water, thickness of water bearing zones, and well yields. This information pertains to wells that may have been drilled as far back as the 1950s, and it is important to realize that depths to water and well yields may be very different today. However this is the best information available to provide basic geologic and aquifer characteristic information of representative areas within the watershed.

There are approximately 3,000 registered entries in the OSE ground water database. These entries represent well logs, applications to drill wells, declarations, or other submittals. Unfortunately, unusually few of the files actually contain well logs - a total of only 239 actual logs were available. Table 4-26 shows the number of actual well logs obtained in each township and range within the study area.

TABLE 4-26: WELL LOGS BY TOWNSHIP AND RANGE

Range	T21N	T22N	T23N	T24N	T25N	T26N	T27N	T28N	T29N	T30N	Total
R1E	0	0	8	1	2	0	0	0	0	0	11
R2E	0	8	2	1	4	0	1	0	0	0	16
R3E	1	9	3	0	1	0	0	0	0	0	14
R4E	0	1	5	1	4	5	5	0	1	1	23
R5E	0	1	14	1	0	4	0	0	3	0	22
R6E	0	1	13	0	0	0	2	0	0	0	16
R7E	0	22	21	7	10	0	1	0	0	0	61
R8E	0	10	25	7	7	4	1	1	0	0	55
R9E	0	0	0	9	7	0	0	5	0	0	21
Total	1	52	33	27	35	13	10	6	4	1	239

ABIQUIU AND CAÑONES

The communities of Abiquiu and Cañones are located in the lower reaches of the Chama Basin province and the upper end of the Española Basin. Most of the ground water resources are derived from either Quaternary alluvial deposits or Tertiary deposits, typically of the Santa Fe Group. Typically, storage capacity of the alluvial deposits is small because of the limited aerial extent and thickness, and the alluvial aquifer may dry up in dry times of the year. The deeper Tertiary deposits tend to yield sufficient water for ordinary domestic use. The community water system for Abiquiu serves about 400 people. The water source is a spring located about 3.5 miles southwest of the community at Agua Caliente. Water is collected as it exits the hill and is protected by a well-constructed springbox. The present flow of the water system is barely adequate to meet the demands of the community (Martinez, 2000).

The community of Cañones has one municipal well, which is approximately 100 feet deep and likely penetrates the Tertiary deposits. The well serves roughly 165 people. Based on personal communication with the supervisor of the community water system, the well has served the community sufficiently for as long as can be remembered. There have been no reported problems with the system and there is enough water to supply the community, even in times of drought. The nearby community of Barranco has one infiltration gallery, located next to the Barranco ditch that serves approximately 75 people. Until recently the system was classified as a ground water system but was reclassified, based on the results of a particulate test, as a surface water system. This system does not have enough water during drought conditions to meet the community's needs (Martinez, 2000).

Water Quality

Abiquiu and Barranco must filter and disinfect the water from infiltration galleries (Martinez, 2000).

Well Log Information

The private wells in the area draw water from Quaternary alluvium and Tertiary sediments. The wells are an average of 114 feet deep and yield (or yielded) an average of 12 gpm. Table 4-27 (following page) summarizes well log information for twenty-seven wells in the vicinity of Abiquiu and Cañones located in township 23N, ranges 5E and 6E.

CEBOLLA AND CANJILON

The communities of Cebolla and Canjilon are located in the Chama Basin geologic province. The ground water resources in the vicinity of these communities are typically derived from the Quaternary terrace and alluvial deposits and the Cretaceous Mancos Shale. The alluvial deposits are not capable of storing a lot of water because of the limited aerial extent and thickness. The alluvial aquifer,

TABLE 4-27: SUMMARY OF WELL LOGS IN THE VICINITY OF ABIQUIU AND CAÑONES

Geological description				
Geologic unit	**Thickness**	**Well depth (ft)**		**Water-bearing formations**
		Range	**Average**	
Tertiary sediments and Quaternary alluvium	Unknown*	50 to 225	114	Quaternary alluvium; Tertiary sand and gravel layers
Cretaceous Dakota Sandstone (one well near Cañones)	Unknown*	125	NA	Cretaceous sandstone

Aquifer characteristics						
Aquifer	**Depth to water (ft)**		**Water bearing thickness (ft)****		**Well yield (gpm)**	
	Range	**Average**	**Range**	**Average**	**Range**	**Average**
Quaternary & Tertiary sediments	18 to 180	72	1 to 22	13	2 to 25	12
Cretaceous sandstone (1 well)	18	NA	9	NA	1.5	NA

** Wells did not penetrate beneath Tertiary deposits, so thickness of these deposits cannot be determined. The Cretaceous deposits are found on the surface at some locations.*

***Based on water yielding zones from drilling logs.*

especially in the Cebolla area, goes dry during times of droughts. The well yields in the Mancos Shale are typically low, and water is not consistently found in this formation.

Cebolla community water system serves approximately 200 people. The community system is comprised of infiltration galleries, the source of which is surface water. The system has had difficulties dating back at least three decades. A water system installed in 1963 consisted of an infiltration gallery and the original yield was 20 gpm, however problems have been noted with the system (Bohannan Westman Huston Engineers, 1972). The infiltration gallery has a history of drying up, especially when the Rio Cebolla has decreased flow. Another gallery was put online several years ago, which alleviated the water problem for only a short period. The older gallery has since stopped producing water and the community is now drawing water from only one infiltration gallery (Martinez, 2000). The water system does not produce enough water to sufficiently meet the needs of the community.

Due to persistent water problems in the vicinity of Cebolla, various investigations have been conducted to try to locate other possible ground water resources. The alluvium was not considered to be thick enough in most locations to yield adequate supplies of water. The Mancos Shale was not considered to be an adequate water-bearing aquifer in this area, however many of the wells draw water from this aquifer (as shown in the table below). The Dakota Sandstone, Burro Canyon Formation, and Morrison Formation were considered to be the most feasible aquifers in the area. Future exploration of water in the area should include drilling into these formations (Shoemaker, 1979; and Water Futures, 1983).

Canjilon community water system serves approximately 370 people. The community shares its water source with the Canjilon Lakes Campground. The spring next to upper Canjilon Lake has been producing an adequate supply of water to meet the needs of the community (Martinez, 2000).

Water Quality

There have been numerous quality problems with the water from the Cebolla infiltration galleries. The system requires filtration, disinfection, and monitoring (Martinez, 2000).

Well Log Information

The alluvial wells or infiltration galleries have yielded up to 5 gpm. The wells drawing water from the Mancos shale range up to 1200 ft deep and have yielded an average of 10 gpm. Table 4-28 summarizes well log information for 14 wells located in townships 26N & 27N, ranges 4E & 5E.

TABLE 4-28. SUMMARY OF WELL LOGS IN THE VICINITY OF CEBOLLA AND CANJILON

Geological description				
Geologic unit	Thickness	Well depth (ft)		Water-bearing formations
		Range	Average	
Quaternary alluvium	Varied*	6 to 90	20	Sand and gravel layers within Quaternary alluvium
Cretaceous Mancos shale	Unknown*	30 to 1,200	403	Sandy layer

Aquifer characteristics						
Aquifer	Depth to water (ft)		Water bearing thickness (ft)**		Well yield (gpm)	
	Range	Average	Range	Average	Range	Average
Quaternary alluvium	0 to 25	Unknown	1 to 25	Unknown	0 to 5	Unknown
Cretaceous Mancos shale	120 to 1,122	350	36 to 700	121	Seep to 40	10

CHAMA

The community of Chama is located in the Chama Basin geologic province. Historically, it has been difficult to obtain potable ground water in sufficient quantities to provide for domestic or municipal use.

The community water system serves approximately 1600 people. The community system derives water from springs and infiltration galleries, the source of which is surface water. A spring that was used for many years as a water resource in Chama is no longer used because of inadequate flow. An infiltration gallery now serves the entire community's needs, however there have been problems meeting demand, especially in the summer (Martinez, 2000).

Water resources seriously dictate the amount of growth and development that can be sustained in the Chama area. Investigations have been conducted to find sources of water. Results indicate that there is no one reliable source of water. Ground water has been found in thick layers of glacial till (north of Lobato), although from one location to another the yields ranged from only a seep to 30 gpm (Glorieta Geoscience, Inc., 1992). The Dakota Sandstone may serve as a feasible aquifer. A test well (located in T31N, R2E) drilled into the Dakota sandstone indicated transmissivity to be approximately 40 ft2/day and well yields were expected to range from 25 gpm to 175 gpm. The depth of the water-bearing layer in the Dakota sandstone is at a minimum 550 feet (Geohydrology Associates, Inc., 1988).

Water Quality

Chama community water system has had a long history of water quality problems. Two wells were shut down because of water quality, one of them had five times the Maximum Contaminant Level for arsenic and was never used (Martinez, 2000).

A water fair conducted in July 2000 included analyzing water from seven privately owned wells with water derived from the Rio Chama (the actual location of these private wells is not known). Sulfates ranged from 48 mg/L to 76 mg/L (average value was 71 mg/L). Nitrates ranged from 2.3 mg/L to 9.1 mg/L (average value was 5.9). Conductivity ranged from 233 mg/L to 356 mg/L (average value was 286 mg/L). Nitrate values meet the New Mexico ground water standards (10 mg/L) and U.S. Environmental Protection Agency (EPA) drinking water standards (10 mg/L). Sulfate levels are within the New Mexico standards (600 mg/L), however some of the sulfate values exceed the U.S. EPA secondary (aesthetic, taste/odor) standard (250 mg/L).

Water quality for a well drilled in the Dakota Formation was determined to be good (Geohydrology Associates, Inc., 1988).

Water quality for wells penetrating the glacial till in the Chama area exceeded standards for manganese and turbidity set by Rio Arriba County (Glorieta Geoscience, Inc., 1992).

COYOTE AND ARROYO DEL AGUA

The communities of Coyote and Arroyo del Agua are located in the Chama Basin geologic province. Historically, it has been difficult to obtain enough ground water in the vicinity to provide for domestic or municipal use.

The community of Coyote has one well that serves approximately 53 people. The well is approximately 90 feet deep and most likely draws water from the Triassic Chinle Formation. During most of the year the well does not recharge fast enough to meet demand. The water storage tank was also too small to handle demand during peak hours. There were constant complaints from residents about low pressure and, in some cases, lack of water. A recent addition of a new well and storage tank has greatly improved the reliability of the system (Martinez, 2000). In general the system still does not adequately supply enough water to the community.

The community of Arroyo del Agua has one municipal well that serves roughly 60 people. The well is approximately 150 feet deep and most likely draws water from the Triassic Chinle Formation. According to the supervisor of the water system, the water level in the well drops dramatically in the dry weather, typically from August through September. The well does not adequately meet the needs of the community.

Water Quality

Water quality data from wells in the Coyote and Arroyo del Agua are not available. However the quality of water derived from the Chinle Formation is not good in many areas. Generally, the water quality deteriorates with depth, making the water unacceptable for stock or domestic use, except in or near outcrop areas (Stone et al, 1983).

Well Log Information

The private wells in the area draw water from the Triassic Chinle Formation. The average depth of the wells is 219 feet, and the average well yield is (or was) 9 gpm. Table 4-29 summarizes well log information for seventeen wells located in township 22N, ranges 2E and 3E.

TABLE 4-29: SUMMARY OF WELL LOGS: VICINITY OF COYOTE AND ARROYO DEL AGUA

Geological description				
Geologic unit	**Thickness**	**Well depth (ft)**		**Water-bearing formations**
		Range	**Average**	
Triassic Chinle Formation	Unknown*	51 to 440	219	Sandy layers within Chinle Formation

Aquifer characteristics						
Aquifer	**Depth to water (ft)**		**Water bearing thickness (ft)****		**Well yield (gpm)**	
	Range	**Average**	**Range**	**Average**	**Range**	**Average**
Triassic Chinle Formation	15 to 365	150	1 to 60	16	Dry to 56	9

** The wells did not penetrate geologic units beneath the Triassic deposits, and therefore the thickness of these deposits can not be determined.*
***Based on water yielding zones from drilling logs.*

EL RITO

The El Rito area straddles the boundary between the Española Basin and the Volcanic and Crystalline geologic provinces. The ground water in the vicinity is derived from a variety of sources such as shallow collection galleries, hand dug wells, springs, and deeper ground water from Tertiary sediments. The water derived from shallow sources tends to dry up during periods of droughts and many of these water sources are not capable of meeting the water demand. The potentially productive formations in the vicinity are deeply buried and include the Los Pinos and Santa Fe Formations (Geohydrology Associates, Inc., 1979).

The community of El Rito has one well that serves approximately 360 people. The well is approximately 30 feet deep and draws water from alluvial deposits. The community of El Rito Canyon has one well that serves approximately 300 people. The well is about 200 feet deep and likely draws water from the Tertiary sediments. This well was recently drilled and replaced the old infiltration gallery. Based on personal communication with the supervisor of the water system, the well has not been producing enough water to serve the community's needs. The well typically goes dry in the late summer early autumn months. The community's water supply problems date back a long time.

Water resources seriously dictate the amount of growth and development that can be sustained in the El Rito area. Investigations have been conducted to find sources of water. The geologic units exposed in the area included Tertiary Period deposits such as El Rito Formation, Ritito Conglomerate, Abiquiu Tuff, Los Pinos Formation, and Santa Fe Formation, and the Quaternary alluvial deposits. The El Rito Formation was found not to produce much water in the area. The Ritito Conglomerate is limited in areal distribution. The Abiquiu Tuff was not considered to be a potential aquifer in the area. The Los Pinos Formation was determined to be capable of producing large quantities of water because the sediments are interbedded with alluvial deposits and the surface exposures serve as recharge areas. Although the Santa Fe Formation is a major water-bearing formation in the Española Basin, in the vicinity of El Rito these deposits were found to be more fine grained and have less thickness and were therefore not considered a potential aquifer. Quaternary alluvium and glacial deposits were considered viable aquifers (Geohydrology Associates, Inc., 1979).

Studies conducted on a variety of wells in the vicinity of El Rito indicated that ground water resources vary tremendously from one location to another. Below we summarize some of these results that were obtained by Geohydrology Associates, Inc. (1979).

- A 102-foot well believed to penetrate an unusually thick sequence of gravel in the alluvium had a coefficient of transmissivity of 207 ft2/day, specific capacity of 1.8 gpm per foot of drawdown of the well, and estimated yield of 80 gpm.

- A 245-foot well in vicinity of Las Placitas was capable of yielding less that 5 gpm.

- Two test holes were abandoned at depths of 200 feet near the vocational school.

- A 400-foot well was abandoned about six miles south of El Rito. In the same area the well used to supply water at the former CCC camp generally was considered inadequate.

- A 731-foot well penetrated gravel in the upper 40 feet and Los Pinos Formation to the bottom depth. The aquifer had a coefficient of transmissivity of approximately 8 ft2/day with an estimated yield of 15 gpm.

Water Quality

Geohydrology Associates, Inc. (1979) indicated the water from wells they investigated in the El Rito area was potable. The water quality of El Rito and El Rito Canyon community wells is not known. However because of the shallow depth of the El Rito's community well, and because it is down gradient from many residences with septic systems, it is susceptible to contamination (Martinez, 2000).

Well Log Information

Wells in the El Rito area that are located in the Española Basin geologic province (township 24N, range 7E) penetrate the alluvial and Tertiary sediments. The average well depth is 190 feet, and the average well yield is (or was) 9 gpm. Table 4-30 summarizes well log information for the seven wells located there.

Wells in the El Rito area located in the Crystalline and

Volcanic geologic province penetrate the alluvial and Tertiary sediments and the Precambrian bedrock. The average well yield for wells drawing from the alluvial and Tertiary sediments is (or was) 14 gpm. The well yields for wells drawing water from Precambrian bedrock was either 1 gpm or 30 gpm. Table 4-31 summarizes well log information for ten wells located in the Volcanic and Crystalline geologic province in township 25N, range 7E.

EL VADO

El Vado is located in the Chama Basin geologic province. The ground water in the vicinity is derived from deep deposits primarily of the Morrison, Dakota, and Burro

TABLE 4-30: SUMMARY OF WELL LOGS: VICINITY OF EL RITO, ESPAÑOLA BASIN PROVINCE

<table>
<tr><th colspan="7">Geological description</th></tr>
<tr><th rowspan="2">Geologic unit</th><th rowspan="2">Thickness</th><th colspan="2">Well depth (ft)</th><th colspan="3" rowspan="2">Water-bearing formations</th></tr>
<tr><th>Range</th><th>Average</th></tr>
<tr><td>Tertiary sediments and Quaternary alluvium</td><td>Unknown*</td><td>55 to 410</td><td>190</td><td colspan="3">Sand and gravel layers within Tertiary aquifer system and Quaternary alluvium</td></tr>
<tr><th colspan="7">Aquifer characteristics</th></tr>
<tr><th rowspan="2">Aquifer</th><th colspan="2">Depth to water (ft)</th><th colspan="2">Water bearing thickness (ft)**</th><th colspan="2">Well yield (gpm)</th></tr>
<tr><th>Range</th><th>Average</th><th>Range</th><th>Average</th><th>Range</th><th>Average</th></tr>
<tr><td>Tertiary sediments and Quaternary alluvium</td><td>0 to 235</td><td>79</td><td>18 to 270</td><td>91</td><td>0.5 to 40</td><td>15</td></tr>
</table>

** The wells did not penetrate beneath the Tertiary deposits; the thickness of these deposits can not be determined.*

***Based on water yielding zones from drilling logs.*

TABLE 4-31: SUMMARY OF WELL LOGS IN THE VICINITY OF EL RITO, CRYSTALLINE/VOLCANIC PROVINCE

<table>
<tr><th colspan="7">Geological description</th></tr>
<tr><th rowspan="2">Geologic unit</th><th rowspan="2">Thickness</th><th colspan="2">Well depth (ft)</th><th colspan="3" rowspan="2">Water-bearing formations</th></tr>
<tr><th>Range</th><th>Average</th></tr>
<tr><td>Tertiary sediments, Quaternary alluvium, and basalt; Precambrian granite (2 wells)</td><td>Varied*</td><td>42 to 450</td><td>98</td><td colspan="3">Sand and gravel layers within Tertiary aquifers and Quaternary alluvium, fractures in Precambrian rocks</td></tr>
<tr><th colspan="7">Aquifer characteristics</th></tr>
<tr><th rowspan="2">Aquifer</th><th colspan="2">Depth to water (ft)</th><th colspan="2">Water bearing thickness (ft)**</th><th colspan="2">Well yield (gpm)</th></tr>
<tr><th>Range</th><th>Average</th><th>Range</th><th>Average</th><th>Range</th><th>Average</th></tr>
<tr><td>Tertiary sediments, Quaternary alluvium, and basalt</td><td>0 to 73</td><td>14</td><td>1 to 75</td><td>31</td><td>0 to 20</td><td>13</td></tr>
<tr><td>Precambrian granite (2 wells)</td><td>200 to 240</td><td>NA</td><td>30 to 80</td><td>NA</td><td>1 to 30</td><td>NA</td></tr>
</table>

** The wells penetrated Precambrian bedrock beneath the Tertiary deposits at depths ranging from 5 ft to 200 ft. In the majority of the wells, the Precambrian bedrock was not encountered.*

***Based on water yielding zones from drilling logs.*

Canyon Formations. The Mancos Shale was not considered a potential aquifer in the area.

El Vado Lake Resort has one well which is 480 feet deep and serves approximately 90 people. American Ground Water Consultants (1978) conducted an investigation to determine the best ground water source for the El Vado Lake Subdivision. The geologic units in the area include the Morrison Formation, Dakota Sandstone, Burro Canyon Formations, and the Mancos Shale. Wells in the general vicinity that penetrate the Morrison, Dakota, and Burro Canyon Formations showed a transmissivity of about 334 ft2/day and daily flow was calculated to be 1,299 gpm. Depth to water in the area was determined to vary from approximately 5 feet to 300 feet (American Ground Water Consultants, 1978)

Water Quality

American Ground Water Consultants (1978) determined during their investigations that concentrations of sulfates and total dissolved solids exceeded the New Mexico drinking water standards, and it was recommended that water pumped from the aquifers in this area be treated for human consumption.

GALLINA AND CAPULIN

Gallina is located in the Chama Canyon sub-basin and the Chama Basin geologic province. Ground water in the vicinity is primarily derived from the Triassic Chinle Formation deposits. The well yields are typically low, and often times the wells can not produce enough water to meet the community's needs.

The community of Gallina has one well that serves approximately 120 people. The well is approximately 150 feet deep and most likely draws water from the Chinle Formation. In 1985, the Gallina community well pumped at 20 gpm. A pump test was conducted on the community well in 1986 and results indicated a transmissivity value of 12 to 92 ft2/day (Mattingly, B. E., 1988). The well production has since dropped to approximately 5 gpm. This production rate is not enough to meet the needs of the community. The community of Gallina formed a temporary agreement to draw water from the Coronado High School water supply, however this is only an interim solution (Martinez, 2000).

The Capulin community has one well that serves 165 people. The well is approximately 400 feet deep and most likely draws water from the Chinle Formation. In 1986 this well was reported to have produced about 40 gpm from zones at 347 to 356 feet. A pump test indicated a transmissivity value of about 20 ft2/day (Mattingly, B. E., 1988). The system has occasionally experienced water shortages because the well cannot recharge fast enough to meet the demand (Martinez, 2000).

Water resources seriously dictate the amount of growth and development that can be sustained in the vicinity of Gallina and Capulin. Investigations have been conducted to find sources of water. As part of an investigation, five 8-inch diameter wells were drilled to depths of 900 in the vicinity. A surface layer of recently deposited alluvium up to 30 feet thick was underlain by Chinle Formation, which was noted to be up to 850 feet thick in the area. Below this lies the Permian Yeso Sandstone (about 150 feet) and Abo Formation (up to 2900 feet thick). Within the area, ground water exists in porous sediments and in fractures. Due to the heterogeneous nature of the Chinle (and Yeso) Formations and the uncertainty and extent of fracturing, obtaining ground water in the area was considered highly unpredictable (Mattingly, B. E., 1988). The Chinle and Yeso Formations are generally hydrologically tight, with small storage coefficient values, which only occasionally produce enough water for irrigation wells. Results of the investigation suggested that additional pumping (of 100 gpm for example) would have noticeable effects on the water table and possibly on surface water bodies (Mattingly, B. E., 1988).

Water Quality

The Capulin community well has occasionally experienced bacteriological contamination, which is believed to be due to soil bacteria. Continuous disinfection is advisable for this water (Martinez, 2000). The quality of water derived from the Chinle Formation is not good in many areas. Generally, the water quality deteriorates with depth, making the water unacceptable for stock or domestic use, except in or near outcrop areas (Stone et al., 1983).

Well Log Information

Wells in the area penetrate the Chinle Formation. The average well depth is 226 feet and the average well yield is (or was) 14 gpm. Table 4-32 summarizes well log information for ten wells located in township 23N, ranges 1E and 2E.

LA MADERA AND VALLECITOS

La Madera and Vallecitos are located in the Crystalline and Volcanic geologic province. Ground water in the vicinity is primarily derived from the Quaternary alluvium and Tertiary sediments. The well yields are often too low to meet the community's needs.

La Madera community has two wells that serve approximately 40 people. The wells are up to 150 feet deep and most likely draw water from the Tertiary deposits. The wells most likely need expansion to meet future demands (Martinez, 2000).

Vallecitos community has one infiltration gallery that serves 96 people. The system does not produce enough water to satisfactorily meet the needs of the community. Efforts to find another reliable water source have so far been unsuccessful (Martinez, 2000).

Water Quality

The water quality from the La Madera wells is good. This Vallecitos community system has experienced water quality problems (Martinez, 2000).

Well Log Information

The private wells in the area generally draw water from the alluvium and Tertiary sediments. The Precambrian bedrock is often penetrated, however does not produce water in the area. The average well depth is 147 feet and the average well yield is (or was) 18 gpm. Table 4-33 below summarizes well log information for eighteen wells located in townships 25N and 26N, ranges 8E and 9E.

LLAVES

Llaves is located in the Chama Basin geologic province. Llaves does not have a community well. Ground water in the vicinity is primarily derived from Jurassic and Cretaceous deposits. The average depth of wells located in the vicinity is 103 feet, and the average well yield is (or was) 11 gpm. Table 4-34 summarizes well log information for six wells located in township 25N, ranges 1E and 2E.

TABLE 4-32: SUMMARY OF WELL LOGS IN THE VICINITY OF GALLINA AND CAPULIN

Geological description				
Geologic unit	**Thickness**	**Well depth (ft)**		**Water-bearing formations**
		Range	**Average**	
Triassic Chinle Formation	Unknown*	97 to 500	226	Sandy layers within Upper Shale Member of the Chinle Formation

Aquifer characteristics						
Aquifer	**Depth to water (ft)**		**Water bearing thickness (ft)****		**Well yield (gpm)**	
	Range	**Average**	**Range**	**Average**	**Range**	**Average**
Triassic Chinle Formation	22 to 302	150	3 to 112	34	1 to 30	14

** The wells did not penetrate geologic units beneath the Triassic deposits, and therefore the thickness of these deposits can not be determined.*
***Based on water yielding zones from drilling logs.*

TABLE 4-33: SUMMARY OF WELL LOGS, VICINITY OF LA MADERA AND VALLECITOS

Geological description				
Geologic unit	**Thickness**	**Well depth (ft)**		**Water-bearing formations**
		Range	**Average**	
Tertiary sediments, Quaternary alluvium, Precambrian bedrock*	Unknown**	31 to 453	147	Sand and gravel layers within Tertiary aquifers and Quaternary alluvium

Aquifer characteristics						
Aquifer	**Depth to water (ft)**		**Water bearing thickness (ft)*** **		**Well yield (gpm)**	
	Range	**Average**	**Range**	**Average**	**Range**	**Average**
Tertiary sediments, Quaternary alluvium, Precambrian bedrock	4 to 400	84	10 to 65	27	0 to 40	18

* *Wells penetrating the Precambrian bedrock yielded no water*

** *Wells penetrated Precambrian bedrock beneath the Tertiary deposits at depths ranging from 50 ft to 453 ft. In the majority of the wells, the Precambrian bedrock was not encountered.*

*** *Based on water yielding zones from drilling logs*

TABLE 4-34: SUMMARY OF WELL LOGS IN THE VICINITY OF LLAVES

Geological description				
Geologic unit	**Thickness**	**Well depth (ft)**		**Water-bearing formations**
		Range	**Average**	
Cretaceous Dakota Sandstone and Jurassic Morrison Formation	Unknown*	40 to 200	103	Sand and gravel layers within the sandstone and shale formations

Aquifer characteristics						
Aquifer	**Depth to water (ft)**		**Water bearing thickness (ft)****		**Well yield (gpm)**	
	Range	**Average**	**Range**	**Average**	**Range**	**Average**
Cretaceous Dakota Sandstone and Jurassic Morrison Formation	20 to 75	40	5 to 12	10	0.5 to 20	11

* *The wells did not penetrate geologic units beneath the Jurassic or Cretaceous deposits, and therefore the thickness of these deposits can not be determined.*

***Based on water yielding zones from drilling logs.*

MEDANALES

Medanales is located in the Española Basin geologic province. The community does not have a municipal well. Ground water in the vicinity is derived from Quaternary alluvium and Tertiary sediments, primarily of the Santa Fe Group. In general, the alluvial deposits do not store much water because of the limited areal extent and thickness, and the alluvial aquifer may dry up during periods of dry climate. The deeper Tertiary deposits tend to yield sufficient water for ordinary domestic use. Well yields in the general vicinity are on the order of 20 gpm.

Water resources seriously dictate the amount of growth and development that can be sustained in the Medanales area. Some investigations have been conducted to find sources of water, to the east of Medanales and Chile and in fact just outside the boundary of the Rio Chama watershed. However, geohydrologic conditions are similar to those in the vicinity of Medanales and results of these investigations are included in the discussion below. (Douglas Wolf, 1996; Horner, 1990; Wolf Engineering, 1997; and LeMay, 1970).

- An exploratory well was drilled in T22N R8E on the Black Mesa Grant. The geologic units in the vicinity are members of the Santa Fe Group (Ojo Caliente Sandstone Member and Chama-El Rito Member) and recent alluvium. The well penetrated a gravel layer in the alluvium from 16 to 36 feet and contained appreciable water. The transmissivity was calculated to be 157 ft^2/day, and well yields were expected to range from 10 gpm to 40 gpm.

- The Franklin Johnson well, located in T22N R7E and 8E, produced water from the Ojo Caliente Sandstone. This well was noted to have a seep in fine sand at 100-ft depth and produced up to 1.5 gpm at the 180 to 190-ft interval.

- The MFM well penetrated the Ojo Caliente sand to a depth of 40 feet and a gravel bed (producing 30 gpm) which is a tongue of the underlying Chama-El Rito formation interfingering the Ojo Caliente sand and closely connected with the nearby Rio Ojo Caliente. A pump test in September 1990 suggested water in storage in the gravel layer to be approximately 437 acre-feet.

- An exploratory well was drilled in T22N R9E on the Sebastian Martin Grant. The well encountered a gravel layer from 90 feet to 110 feet and contained appreciable water. The alluvium in the area was reported to vary in thickness from 100 feet to 500 feet. The transmissivity was calculated to be 156 ft^2/day and well yields were expected to range from 15 gpm to 40 gpm.

- Five water wells were drilled in T22N and 23N and R7E. The water-bearing units included alluvium and Santa Fe Formation. The alluvium occupied the lower elevations and produced higher yielding wells (ranging from 30 to 50 gpm). Wells penetrating the Santa Fe Formation yielded from "a few" gpm to 30 gpm. The depth of those wells exceeded 300 feet.

Water Quality

A water fair conducted in July 2000 analyzed water from eighteen wells in the Medanales area. Concentrations of sulfates, nitrates, and iron met the New Mexico ground water standards and the U.S. EPA standards. The latest door-to-door and in-office testing of private wells included analyzing water from twenty-five privately owned wells in the Medanales area. One shallow (12-foot) well exceeded the New Mexico ground water standard and the U.S. EPA standard for nitrates.

Well Log Information

Wells in the vicinity draw water from the Quaternary alluvial and Tertiary sediments. The average well depth is 220 feet and the average well yield is (or was) 23 gpm. Table 4-35 summarizes well log information for sixty-eight wells located in townships 22N and 23N, ranges 7E and 8E.

TABLE 4-35: SUMMARY OF WELL LOGS IN THE VICINITY OF MEDANALES

Geological description				
Geologic unit	Thickness	Well depth (ft)		Water-bearing formations
		Range	Average	
Tertiary sediments and Quaternary alluvium	Unknown*	25 to 860	220	Sand/gravel layers within Tertiary and Quaternary alluvium

Aquifer characteristics						
Aquifer	Depth to water (ft)		Water bearing thickness (ft)**		Well yield (gpm)	
	Range	Average	Range	Average	Range	Average
Tertiary sediments and Quaternary alluvium	2 to 450	135	135	20	Dry to 60	23

** The wells did not penetrate beneath the Tertiary deposits, so the thickness of these deposits can not be determined.*

***Based on water yielding zones from drilling logs.*

OJO CALIENTE

Ojo Caliente is located in the Lower Chama sub-basin and the Crystalline and Volcanic geologic province. Ground water in the vicinity is derived primarily from Quaternary alluvial and Tertiary sediments and fractures in the Precambrian bedrock. In general, the storage capacity of the alluvial deposits are small due to limited aerial extent and thickness, and the alluvial aquifer may dry up in droughts. The deeper Tertiary deposits tend to yield sufficient water for ordinary domestic use. Finding water in the Precambrian bedrock is unpredictable. For example, some wells in the area yield up to 50 gpm, while others were abandoned because they are dry.

Ojo Caliente has two community wells that serve 250 people. The wells are approximately 120 feet and likely penetrate the Tertiary sediments. The system has sufficient water to meet the community's needs (Martinez, 2000). South Ojo Caliente community has one water well, approximately 150 feet deep, that serves about 65 residents in the area. Based on personal communication with the supervisor of the water system, the well has served the community sufficiently for as long back as can be remembered.

Water Quality

A water fair conducted in July 2000 analyzed water from one well in Ojo Caliente. Concentrations of sulfates, nitrates, and iron met the New Mexico ground water standards and EPA standards.

Well Log Information

The wells in the area of Ojo Caliente draw water from the Quaternary alluvial and Tertiary sediments and Precambrian bedrock. The average well yield for those wells drawing water from the Quaternary and Tertiary sediments is (or was) 18 gpm, and the average yield for those wells drawing water from the Precambrian bedrock is (or was) 34 gpm. Table 4-36 summarizes well log information for sixteen wells located in township 24N, ranges 8E and 9E.

TIERRA AMARILLA AND BRAZOS

Tierra Amarilla and Brazos are located in the Chama Basin geologic province. The geologic units in the area consist of alluvial deposits underlain by the Mancos Shale, Dakota Sandstone, Morrison Formation, and Precambrian bedrock. In the area, the alluvium serves as an aquifer.

TABLE 4-36: SUMMARY OF WELL LOGS IN THE VICINITY OF OJO CALIENTE

<table>
<tr><th colspan="7">Geological description</th></tr>
<tr><th rowspan="2">Geologic unit</th><th rowspan="2">Thickness</th><th colspan="2">Well depth (ft)</th><th colspan="3" rowspan="2">Water-bearing formations</th></tr>
<tr><th>Range</th><th>Average</th></tr>
<tr><td>Tertiary sediments,
Quaternary alluvium, basalt and Precambrian granite</td><td>Varied*</td><td>50 to 750</td><td>312</td><td colspan="3">Tertiary sand/gravel; Quaternary alluvium, fractures in Precambrian rocks</td></tr>
<tr><th colspan="7">Aquifer characteristics</th></tr>
<tr><th rowspan="2">Aquifer</th><th colspan="2">Depth to water (ft)</th><th colspan="2">Water bearing thickness (ft)**</th><th colspan="2">Well yield (gpm)</th></tr>
<tr><th>Range</th><th>Average</th><th>Range</th><th>Average</th><th>Range</th><th>Average</th></tr>
<tr><td>Tertiary and Quaternary</td><td>3 to 350</td><td>91</td><td>5-200</td><td>33</td><td>1 to 60</td><td>18</td></tr>
<tr><td>Basalt or Precambrian granite</td><td>591 to 698</td><td>666</td><td>40 to 82</td><td>57</td><td>22 to 50</td><td>34</td></tr>
</table>

** Wells penetrated Precambrian bedrock beneath the Tertiary deposits from 591 ft to 698 ft. In most wells, the Precambrian bedrock was not encountered.*

***Based on water yielding zones from drilling logs.*

The thickness of the alluvium does not exceed about 40 feet, and wells drilled into the alluvium often do not produce enough water. The underlying Mancos Shale and Dakota Sandstone do not produce a lot of water in the area. The Morrison Formation is a feasible aquifer. The Precambrian bedrock is an unpredictable aquifer as it is necessary to drill into fracture systems in order to encounter water.

Tierra Amarilla has three community wells that serve just about the entire community, approximately 500 people. This includes the residents, the grade school, the highway department, La Clinica, and one restaurant. The wells range in depth from 70 feet to 110 feet and the well yield is as high as 52 gpm. Based on personal communication with the supervisor of the water system, the wells serve the community sufficiently.

The nearby Brazos community has two wells that serve just about the entire community, approximately 420 people. The wells are as deep as 500 feet. According to the supervisor of the water system, the well yield is as high as 15 gpm. However the yield has dramatically decreased from the previous year, when one well produced about 45 gpm. The community wells have so far produced sufficient water to meet the demand.

Ensenada community has one well that is approximately 140 feet deep and serves roughly 220 people. It does not meet the needs of the community, primarily because of bad water quality (Martinez, 2000). The community well penetrates about 12 feet of the alluvium. The underlying Mancos Shale is considered non water- bearing in the area (Geohydrology Associates, Inc., April 1985c).

Los Ojos community has two wells that serve roughly 190 people. The wells were drilled about five apart and both are approximately 55-ft deep. The system does not always produce enough water to sustain demand, and generally cannot meet the needs of the community (Martinez, 2000).

Plaza Blanca community has one infiltration gallery that serves 43 people. The system provides an adequate supply of water as long as the Rio Brazos has a sufficient flow. This system might be in trouble if drought conditions persist (Martinez, 2000).

Los Brazos community has one shallow well that serves 46 people. The system produces enough water to meet the needs of the community.

Water resources seriously dictate the amount of growth and development that can be sustained in the Tierra Amarilla area. Investigations have been conducted to find sources of water. Below we summarize some of these results that were obtained by many investigators (Geohydrology Associates, Inc., 1985c; Glorieta Geoscience, Inc., 1996: and Geohydrology Associates, Inc., 1985b).

- A well located at Corkins's Lodge penetrates a terrace cut by the Brazos River and is completed to 295 feet in fluvial river deposits, basalt, and reworked volcanic deposits. A pump test was conducted on this well in 1996 and indicated a yield of 20 gpm and transmissivity of less than 1 ft2/day.

- An investigation was conducted in 1985 east of the village of Brazos on the north side of Highway 512. Area water-bearing units are the Morrison Formation, Dakota sandstone, and alluvium. The Morrison Formation is the deepest. Although it does not outcrop, it is present in the subsurface at depths of 100 feet or more. Estimated well yield for wells penetrating Morrison Formation sandstone layers estimated 10 gpm or more. The sandy body is somewhat limited in areal extent and variable. Dakota sandstone in the area is probably not water-bearing, as well records from the area indicate the formation is dry. Water was found to be present in the alluvial deposits at depths of 60 feet or less producing well yields of 5 gpm or more.

Water quality

Ensenada began having trouble with the community well in the mid-nineties when the water quality worsened. The water must go through filtration and disinfection. The community is looking for an alternate source. Plaza Blanca, Los Ojos, and Los Brazos filter and disinfect the water to make it potable (Martinez, 2000).

Well Log Information

The wells in the area of Tierra Amarilla draw water from the Mancos shale and Precambrian bedrock. The average well yield for those wells drawing water from the shale is (or was) 24 gpm, and the yield for the one well drawing water from the Precambrian bedrock is (or was) 10 gpm.

TABLE 4-37: SUMMARY OF WELL LOGS IN THE VICINITY OF TIERRA AMARILLA

Geological description				
Geologic unit	Thickness	Well depth (ft)		Water-bearing formations
		Range	Average	
Mancos shale and Precambrian quartzite	Varied*	100 to 324	175	Sandy layers within Mancos shale and fractures in Precambrian bedrock

Aquifer characteristics						
Aquifer	Depth to water (ft)		Water bearing thickness (ft)**		Well yield (gpm)	
	Range	Average	Range	Average	Range	Average
Mancos shale	25 to 80	68	20 to 35	28	10 to 50	24
Precambrian quartzite (1 well)	284	NA	10	NA	10	NA

** The bottom of the Mancos Shale was encountered at approximately 195 ft at one location.*
***Based on water yielding zones from drilling logs.*

Table 4-37 summarizes well log information for three wells located in township 29N, ranges 4E and 5E.

YOUNGSVILLE

Youngsville is located in the Chama Basin geologic province. Ground water in the vicinity is primarily derived from sandstone beds of the Triassic Chinle Formation and Permian Cutler Formation. Alluvial deposits are also potentially water-bearing.

Youngsville community system has three wells that serve approximately 90 people. Two wells are approximately 150 feet deep, and a third deeper well was recently drilled because the two wells did not produce enough water to meet the demands. According to the supervisor of the water system, the three wells do not adequately serve the community's needs.

An exploratory water well was drilled to total depth of 625 feet in 1983. Analysis of the data indicated a transmissivity of 5 ft2/day (Water Futures, 1983).

Water Quality

Youngsville community wells produce relatively good quality water (Martinez, 2000). Water from the exploratory well penetrating the Chinle and Cutler Formations contained flouride, chloride, and total dissolved solids at levels exceeding the New Mexico Water Quality Control Commission standards (Water Futures, 1983).

Well Log Information

The private wells in the vicinity of Youngsville draw water primarily from the Chinle Formation. The average well depth is 347 feet and the average well yield is (or was) 9 gpm. Table 4-38 summarizes well log information for eight wells located in township 23N, ranges 3E and 4E.

Table 4-39 on the following page summarizes the ground water resources for the twenty-three community water systems in the Rio Chama watershed.

TABLE 4-38: SUMMARY OF WELL LOGS IN THE VICINITY OF YOUNGSVILLE

<table>
<tr><th colspan="7">Geological description</th></tr>
<tr><th rowspan="2">Geologic unit</th><th rowspan="2">Thickness</th><th colspan="2">Well depth (ft)</th><th rowspan="2" colspan="3">Water-bearing formations</th></tr>
<tr><th>Range</th><th>Average</th></tr>
<tr><td>Triassic Chinle and Permian Cutler Formations</td><td>Unknown*</td><td>120 to 560</td><td>347</td><td colspan="3">Sandstone layers in Chinle and Permian Cutler Formations</td></tr>
<tr><th colspan="7">Aquifer characteristics</th></tr>
<tr><th rowspan="2">Aquifer</th><th colspan="2">Depth to water (ft)</th><th colspan="2">Water bearing thickness (ft)**</th><th colspan="2">Well yield (gpm)</th></tr>
<tr><th>Range</th><th>Average</th><th>Range</th><th>Average</th><th>Range</th><th>Average</th></tr>
<tr><td>Triassic Chinle and Permian Cutler Formations</td><td>60 to 460</td><td>188</td><td>3 to 42</td><td>24</td><td>2 to 20</td><td>9</td></tr>
</table>

** The wells did not penetrate geologic units beneath the Chinle and Cutler deposits, and therefore the thickness of these deposits can not be determined.*

***Based on water yielding zones from drilling logs.*

TABLE 4-39: SUMMARY OF WATER RESOURCES FOR COMMUNITY WELLS

Community	Water source	Aquifer	Approx. depth of well (ft)	Sufficient water supply	Quality problems
Abiquiu	spring	alluvium	shallow	no	yes
Arroyo del Agua	well	Chinle Formation	150	no	unknown
Cañones	well	Tertiary sediments	100	sufficient	no
Barranco	Infiltr. gallery	alluvium	shallow	no	yes
Brazos	well	Jurassic or Cretaceous	500	sufficient	no
Cebolla	Infiltr. gallery	alluvium	shallow	no	yes
Canjilon	spring	unknown	unknown	sufficient	no
Capulin	well	Chinle Formation	400	no	no
Chama	Infiltr. gallery	alluvium	shallow	no	yes
Coyote	well	Chinle Formation	90	no	unknown
Ensenada	well	Jurassic or Cretaceous	140	no	yes
El Rito	well	alluvium	30	unknown	unknown
El Rito Canyon	well	Tertiary sediments	200	no	unknown
Gallina	well	Chinle Formation	150	no	unknown
La Madera	well	Tertiary sediments	150	no	no
Los Ojos	well	Jurassic or Cretaceous	55	no	yes
Los Brazos	well	Jurassic or Cretaceous	shallow	sufficient	yes
Ojo Caliente	well	Tertiary sediments	150	sufficient	no
Plaza Blanca	Infiltr. gallery	alluvium	shallow	no	yes
South Ojo Caliente	well	Tertiary sediments	150	sufficient	no
Tierra Amarilla	well	Jurassic or Cretaceous	110	sufficient	no
Vallecitos	Infiltr. gallery	alluvium	shallow	no	yes
Youngsville	well	Chinle Formation	150	no	yes

Note: The infiltration galleries for Barranco, Cebolla, Chama, Plaza Blanca, and Vallecitos may be considered to draw essentially from surface water, depending on their proximity to streams.

WATER SUPPLY SUMMARY

SURFACE WATER SUMMARY

On an annual basis, water available in the Rio Chama watershed is limited by water rights long before being limited by physical availability. It can be seen from Table 4-16 (Total Annual Discharges) and Figure 4-4 (Discharge at Chamita) that total flows in the Rio Chama, even in dry years, are much greater than the approximately 70,000 acre-feet per year diverted (or the 26,000 acre-feet consumptively used) on average for uses within the region (Wilson and Lucero, 1997). Even in the driest year since San Juan-Chama Project diversions (1972), about 100,000 acre-feet of water flowed past the Chamita gage in excess of San Juan-Chama project water. On average over 370,000 acre-feet of native water per year flows out of our region into the Rio Grande. However, native flow rates do affect water availability during the growing season and shortages occur on many Rio Chama tributaries as well as the Chama mainstem.

Water rights within the region are based on acreage of historically irrigated land and computed crop-irrigation requirements. Most of these rights have not been quantified, even though an adjudication suit is proceeding and considerable hydrographic survey work has been done in the region in recent years. It seems likely, however, that rights to Rio Chama flows in excess of approximate current diversion rates would be claimed by parties downstream on the Rio Grande, and in fact a water rights application to "surplus" wet-year flows in the Rio Chama has been filed by the City of Albuquerque (Wells, 2001, personal communication).

Water supplies available within the region are quite large compared to current or even future domestic, industrial, and municipal uses. However, they are constrained (sometimes severely) in some areas for agricultural uses by historical supply problems related to natural flow patterns. Agricultural water availability could be increased by storage facilities, but there are challenges in limited appropriate sites, water rights and Rio Grande Compact issues, and expense. Any further storage in reservoirs would further decrease the total amount of water available in the watershed, even though it could improve the timing of its availability. Effective water supplies could also be increased in some cases by investment in water delivery systems and increases in on-farm irrigation efficiency, but this poses many economic issues that are beyond the scope of the current study.

Even looking at the relatively small water needs of existing communities, there are many instances of water shortage because water supplies are very unevenly distributed within the region, and ground water is often quite severely limited, as discussed below. Engineering, community sentiment, and water rights constraints affect possible transfers of water from surface (irrigation) uses to community uses even though this can be done and many community systems are in need of additional domestic water supplies.

LIMITATIONS IMPOSED BY THE RIO GRANDE COMPACT

Our water supply is limited by the terms of the Rio Grande Compact, quite independently of the physical availability of water. Even though we deplete less than ten percent of the water flowing through the Rio Chama hydrologic system, there are significant legal and institutional impediments that stand in the way of expanding the available water supply beyond the total amount we use now.

The Compact constraint that influences the entire water rights system within which we must work is New Mexico's legal obligation to deliver a certain quantity of water to Texas, as measured at Elephant Butte Reservoir. This quantity is calculated based on the adjusted annual flow at Otowi Gage, and if the required quantity is not delivered, New Mexico's water management options are severely restricted until the water debt is paid off. This means that a substantial part of the 372,200 acre-feet per year that flows from the Rio Chama into the Rio Grande on average is “owed” to Texas, and is not available for use in our region or even in New Mexico above Elephant Butte Reservoir. In addition, of course, some of that flow out of the region is “owed” to downstream rights holders within New Mexico.

One of the chief ways in which New Mexico's options are limited is when water levels in Elephant Butte and Caballo Reservoirs become too low triggering the storage restrictions of Article VII of the Compact. Under those restrictions no additional water can be stored in any reservoir built after 1929. All three reservoirs on the Rio Chama were built after 1929, so if New Mexico has fallen behind on its Rio Grande Compact deliveries, no water can be added to El Vado, Abiquiu, or any other reservoir that might be built on the Rio Chama or its tributaries. No new native water could be stored in Heron Reservoir either, but San Juan-Chama water diverted from the San Juan basin is not subject to Rio Grande compact storage limitations.

Since New Mexico's water obligation to Texas is calculated based on the flow past Otowi Gage each year, the State Engineer does not allow water rights transfers to move a point of diversion past Otowi Gage: depletions that now take place above Otowi must continue above Otowi, and similarly, diversions below Otowi have to stay below. In addition, any substantial change in net depletions of water above Otowi Gage could inadvertently increase New Mexico's calculated delivery obligation to Texas and/or cause protests by other Compact signatories.

GROUND WATER SUMMARY

The Rio Chama watershed consists of numerous complex heterogeneous geologic and hydrologic systems. The watershed includes three major geologic provinces each containing distinct aquifer systems that may be interconnected to an extent now unknown.

The Española Basin province, in the southern portion of the watershed, consists of Tertiary Period sediments, primarily of the Santa Fe Group. These deposits are moderately permeable, transmit a fair amount of water, and have a relatively large recharge potential. These aquifer systems are likely the most productive systems in the watershed.

The Chama Basin province, in the north-central and northwestern parts of the watershed, consists primarily of the Mancos, Dakota, Morrison, and Chinle aquifer systems. These aquifer systems produce water in some locations and are dry in other locations. Generally, the deposits have low to moderate permeability and transmissivity, and only the coarser-grained strata in these formations yield water. These aquifer systems in general do not yield large quantities of water and often have associated water quality problems.

The Crystalline and Volcanic province, in the eastern parts and a small portion of the southwest watershed, includes Tertiary deposits and Precambrian bedrock. The Tertiary deposits are similar to those of the Espanola Basin in their hydrologic properties, however they are typically not as deep. The Precambrian bedrock is not considered an important aquifer because unless open fractures are penetrated, little or no water will be obtained.

Alluvial deposits are present over broad areas along the Chama River, tributary valleys, and some high mesas. The alluvial aquifers are highly permeable and transmit large amounts of water. However, these alluvial deposits do not typically provide sufficient water resources because of the small areal extent and thickness. These systems typically go dry during dry times of the year.

Based on a qualitative assessment, there appear to be no significant ground water resources that can support large volumes of withdrawals in the Rio Chama watershed. A number of the alluvial aquifer systems and Mesozoic aquifer systems in the Chama Basin province have experienced noticeable water shortages. The Tertiary aquifer systems (primarily in the Española Basin) tend to have the most productive aquifer systems.

Accurate estimates of watershed recharge are not currently possible due to lack of key hydrologic data. However, using data from other studies conducted on nearby basins (evaluating the contribution of recharge from precipitation) watershed-wide recharge estimates may range from 113,000 acre-ft per year to 325,000 acre-ft per year. These are order-of-magnitude estimates and emphatically do not reflect the amount of water that can safely be pumped from the watershed or any other kind of estimate of sustainable ground water yield. Sustainable yield is not adequately quantifiable given the data now available. Additional investigation, beginning with systematic monitoring of water levels throughout the Region, will be necessary for any reasonable quantification of sustainable yield.

COMMUNITY WATER RESOURCES SUMMARY

The majority of the community water systems in the Rio Chama watershed (68%) do not always produce enough water to meet the demands of their communities. Most of these water systems (73%) are located in the north-central and western portions of the watershed (within the Chama

Basin geologic province). Twenty percent of the troubled community water systems are located in the eastern portion of the watershed (within the Crystalline and Volcanic geologic province). The southern part of the watershed (within the Española Basin geologic province) tends to have the least amount of ground water resource problems (accounting for 7% of the troubled community systems).

A closer look at the aquifer systems reveals more trends in ground water resources. The majority of the water systems (47%) that do not yield enough water to meet the community's needs draw water from Mesozoic deposits of the Chama Basin geologic province (including the Chinle, Morrison, Dakota, and Mancos Shale units). In general, these deposits are hydrologically tight, have small storage coefficient values, and have low transmissivity values.

Alluvial aquifers account for 40% of those community water systems that have problems producing sufficient water. In general it is not feasible to yield large supplies of ground water by means of wells in alluvium because of the small areal extent and thickness and the small storage capacity of the alluvial material.

The Tertiary sediment aquifer systems, in general, are the highest yielding systems. Thirteen percent of the community water wells that have problems yielding sufficient ground water, draw water from the Tertiary sediments (in both the Española Basin and Crystalline and Volcanic geologic provinces). The Tertiary sediments vary in their aquifer characteristics. Those deposits that are coarse grained and permeable typically are good water-bearing aquifers, but finer-grained, tighter, and/or thinner deposits may not be nearly as productive.

Some recommendations for improving community water supplies are summarized in the **Recommendations** section below. More detail on these and other recommendations is provided in the **PLANNING ALTERNATIVES** chapter.

RECOMMENDATIONS

Communities, residents of the planning region as a whole, and Rio Arriba County need to take a long-term approach and develop appropriate water management strategies in order to ensure sustainable future water supplies . Several important steps can be taken by entities within the planning region, including particularly Rio Arriba County, to safeguard our water. These and other ways to provide water for the future are discussed in more detail in the **PLANNING ALTERNATIVES** chapter.

Water systems need to know how much water is being pumped from aquifers and distributed to water users. Water saved in community systems, while small compared to irrigation uses, is still extremely valuable, especially in times of shortage. Water systems should consider performing water audits, if possible, including procedures such as:

- Inventory available water rights, and explore ways to acquire additional rights if they will be needed in the foreseeable future
- Assemble, or begin collecting, pumping records for community wells
- Install and/or make sure of accuracy of meters on community wells
- Consider installing meters at individual connections
- Perform leak tests on the system as a whole (by comparing meter records for water pumped as compared to the total of water delivered through meters at individual connections, if possible); or on specific sections of distribution piping using listening equipment or other technology
- Systematically measure water levels in wells, so that trends in water table elevation over time can be observed

Even before an audit is performed, some of these techniques for water conservation may benefit communities here just as elsewhere:

- Leak testing and repair on water system piping as well as on individual household plumbing, including evaporative coolers
- Low-flow shower heads, toilets, and faucets
- Low water use appliances, especially front-loading clothes washers
- Gray water use in households where domestic water is used for landscape watering

This information would enable water system operators to have a much better idea how much water is being used, how stressed the relevant aquifer(s) may be, whether leaks exist in the system, whether opportunities exist for system repair or more efficient use of an aquifer, and so on. This kind of quantitative information would be a great help in identifying systems with the most pressing needs, quantifying shortages if present, and prioritizing opportunities for improvement, both within each system and among systems around the region.

- Collect additional water level information. In addition to monitoring water levels in community wells, selected (already existing) USGS monitor wells should be monitored. This data is essential to characterize water table changes over time. It is important to select wells that penetrate different aquifers and penetrate different depths. The county should work with USGS to obtain access to the selected wells. It might be worth installing piezometers at selected locations throughout the Region, if existing wells do not collect data from important areas. The water level measurements should be collected according to a regular schedule in order to obtain consistent and useable data. This information is the foundation for any program of sustainable water management in the region, and would not necessarily be too expensive.

- Conduct aquifer studies, which will help to evaluate effects of ground water pumping on the aquifers' long-term capacity to yield water to wells. Aquifer studies will provide data on the various aquifers such as average hydraulic conductivity, transmissivity, storage, and yield.

- Information provided by steps like those mentioned above should be organized and used as a County- or Region-wide hydrologic database that can be used to help address community water needs, support community and natural resource planning efforts, and ideally to support an ongoing process of water management where the County can be a full participant along with State and Federal water management agencies.
- Rio Arriba County should provide a hydrologist, or other single person or entity whose responsibility is to coordinate community water issues, including support for acequias and MDWCAs. Such a person or entity could help coordinate among communities, assist with funding requests, and help collect information.

- In some cases it may be beneficial to consolidate and develop larger water districts, as has been done with the Agua Sana water system. This option would have to be evaluated on a case-by-case basis, depending on water supplies, population density, and engineering constraints like elevation or expense of installing piping or additional wells.

  * Rio Arriba County should purchase or otherwise acquire water rights that could be banked among water users within the region to assist with times of water shortage. In addition, the County should help coordinate and perhaps provide administrative assistance for water sharing or water banking agreements among water users, and consider funding assistance for water infrastructure by issuing bonds and helping to coordinate or leverage other funding opportunities.

- In conjunction with ongoing County planning efforts aimed at conserving agricultural land and traditional community structures, the County should play an active role in enforcing state subdivision regulations, which require thorough hydrologic analysis to verify the existence of adequate water supplies prior to new development.

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