6 WATER BUDGET

REGIONAL WATER PLAN • RIO CHAMA WATERSHED

CHAPTER 6

CONTENTS

TABLES

INTRODUCTION

The water budget presented in this section of the Rio Chama Regional Water Plan summarizes information discussed in detail in the **WATER SUPPLY** and **WATER DEMAND** chapters of the Plan, and presents a relative estimate of inflows to and outflows from the region. Essentially the budget examines, in as much detail as data permit, the components of a hydrologic cycle equation that sets inflow for a watershed equal to outflow:

Precipitation = Evapotranspiration + Water Yield ± Change in Storage

Precipitation is the only inflow to the watershed. By definition there are no natural surface flows into a watershed. The Rio Chama watershed is sufficiently large (at 3,157 square miles) and surrounding geology is such that there is no indication of significant ground water flow into the watershed. Trans-basin diversions are made into Heron Reservoir and the Rio Chama by the San Juan-Chama Project, and these are accounted for separately in the water budget.

Evapotranspiration in the equation above means upland evapotranspiration, or evapotranspiration not associated with human uses or with the river and riparian corridor itself. It includes interception on vegetation surfaces, ground surface evaporation, and moisture transpired by vegetation before it leaves the root zone. It is estimated in two ways: subtractively, by taking native evapotranspiration to be the remainder when all quantifiable yield components have been subtracted from estimated precipitation; and additively, by estimating evapotranspiration empirically for each major tributary basin and adding the tributary estimates. Neither evapotranspiration figure can be corroborated by direct measurement, but both methods result in very similar estimates: about 85 percent of total precipitation.

It is also assumed for water budget purposes that there are no changes to water in storage. Changes in surface water storage in the three Rio Chama reservoirs are ignored for two reasons: first, over a long period of time changes in storage (except for evaporation) will cancel out as increases in one period will be offset by decreases in another; and second, almost none of the water stored in Abiquiu, El Vado, or Heron Reservoirs is used in the planning region. Therefore changes in storage affect the region only indirectly. It is assumed that there are no appreciable changes in ground water storage also for two reasons: first, there is no evidence for any ground water storage changes (and very little quantitative ground water information of any kind); and second, ground water uses in the region are very small in comparison to total water uses or to other components in the water budget, suggesting that it is unlikely that significant quantities of water have been withdrawn from storage. Anecdotal evidence exists, however, of locally declining water tables.

Yield includes all water that enters the hydrologic system of the watershed below the root zone where it falls (even if it is evaporated or transpired elsewhere in the system after recharging an aquifer or appearing as surface flow somewhere). Water yield can be examined in more detail.

$$\mathbf{Yield = RO + D_{SW} + D_{GW} + E_{Res} + ET_{Rip} + Q}$$

where

RO = Surface runoff
$\mathbf{D}_{SW}$ = Surface water depletions
$\mathbf{D}_{GW}$ = Ground water depletions
$\mathbf{E}_{Res}$ = Reservoir evaporation
$\mathbf{ET}_{Rip}$ = Riparian evapotranspiration and river surface evaporation
Q = Ground water flow out of watershed

This budget is presented in terms of water yield, including 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, making it especially difficult to reliably separate ground and surface water components of a water budget.

INFLOWS

PRECIPITATION

Precipitation is the only source of water in the watershed, apart from San Juan-Chama Project diversions, that is almost totally used outside the planning region. Precipitation was estimated by producing an isohyetal precipitation map at a scale of 1:250,000 so that it could be overlaid with a United States Geological Survey (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 watershed is shown in Table 6-1 below.

Sufficient data do not exist to permit an estimate of ground water recharge as a fraction of precipitation or yield by tributary basin. The Rio Chama watershed generally is characterized by shallow aquifers overlying varying bedrock geology. Streams typically go from gaining to losing and sometimes back again more than once over their length. A given stream reach may well be gaining (in

TABLE 6-1: 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**

other words, its flow is increased by ground water discharges into the stream) during comparatively wet years or times of year, and be losing flow to ground water in dryer conditions. In general, there is a close hydraulic connection between the streams and shallow aquifers in the Rio Chama watershed so water flows from one system to the other depending on the relative elevation or hydraulic head of stream channels and water tables. For these reasons, along with a lack of water level and stream flow data, quantification of stream-aquifer interactions has been impossible.

RECHARGE

Although ground water recharge is not accounted for separately from surface runoff, it is considered as a process that involves some fraction of total watershed yield. Five approaches to estimating recharge over the Rio Chama watershed as a whole were evaluated in the **WATER SUPPLY** chapter, suggesting a range of recharge values from approximately 120,000 acre-feet per year to 325,000 acre-feet per year. The most quantitative approach to estimating ground water recharge that seems reasonable given the situation in the Rio Chama is that taken by Waltemeyer and Kernodle (1992) for the San Juan Basin, to estimate overall recharge for a large semi-arid watershed. This approach is discussed in detail in the ***Aquifer Recharge*** discussion in the **WATER SUPPLY** chapter. Waltemeyer and Kernodle assumed that recharge was primarily correlated with winter precipitation and developed a regression equation for recharge as a function of winter precipitation:

$$\mathbf{R = 0.486\ P_W^{0.76}}$$

where,

R = recharge (cfs)
$\mathbf{P}_W$ = winter precipitation (cfs)

It is important to note that much of the water that initially recharges ground water will discharge as base flow in streams, spring flow, or evapotranspiration elsewhere in the basin. In fact, it seems likely that the same water cycles between ground and surface water multiple times before it leaves the watershed. It should not be assumed that anything like 124,000 acre-feet per year is actually added over the long term to ground water systems within the watershed. Most of the gross recharge must leave the watershed as baseflow in the Rio Chama and therefore makes up part of the flow recorded at the Chamita gage.

The calculation is shown below:

Total precipitation (acre-ft/yr)	3,265,398
Winter precipitation (P_W) = .5 x (Total precip.) (acre-ft/yr)	1,632,699
Winter precipitation (cfs) = .00138 (acre-ft/yr)	2,253
Recharge (cfs) = 0.486 x (2253 0.76)	171.7
Recharge (acre-ft/yr) = 724.46 x 171.7 (cfs)	**124,390**

SAN JUAN–CHAMA PROJECT DIVERSIONS

The San Juan-Chama Project diverts water 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 6-2. 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 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.

It should be noted that 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 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 1,424 acre-feet per year as accounted 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-

TABLE 6-2: 1999 SAN JUAN-CHAMA PROJECT WATER ALLOCATIONS

Contractors: Municipal, domestic, and industrial supplies	Acre-ft/yr allocated
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

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. In effect, some diminished flows in the Rio Grande have been offset by adding flow to the Rio Chama.

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, resulting in an apparent discrepancy of over 7,000 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).

In the water budget the total trans-basin average diversion of 92,700 acre-feet per year is used in the inflow column, and the estimated average added flow at Chamita of 67,900 (calculated as described above) is used in the outflow column, recognizing that the total amount of San Juan-Chama water added to the Rio Chama effectively declines as the water makes its way downstream and becomes subject to conveyance and reservoir evaporation losses. In any case, San Juan-Chama water is accounted for separately from native Chama flows, and is included in water budget calculations as a separate line item identified as such.

OUTFLOWS

UPLAND EVAPOTRANSPIRATION

Native or upland evapotranspiration is by far the greatest outflow of water in the watershed (as it is everywhere in non-humid climates). Estimates of average evapotranspiration in different states in the United States range from 40 percent of total precipitation in the Northwest and Northeast to up to 100 percent of total precipitation in the Southwest (Hanson, 1991). Unfortunately, it is very difficult to measure evapotranspiration, and no direct measurements have been reported in the Rio Chama watershed. Two different methods are used in this study to estimate upland evapotranspiration. The first method uses available information to derive feasible evapotranspiration estimates for the tributary watersheds, and sums these values to estimate evapotranspiration for the entire watershed. The second method derives evapotranspiration for the entire watershed as the difference between total average precipitation and total water yield.

Some studies have been made of evapotranspiration in geographically, ecologically, and topographically similar areas to parts of the planning region. A summary of results from these studies is presented below in Table 6-3.

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 (Crawford, personal communication, 2002). However, no measurements of leaf area index or any of the other principal vari-

TABLE 6-3: 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*

ables affecting evapotranspiration have been reported in the Rio Chama watershed.

Table 6-4 below summarizes the results of a compilation of information including evapotranspiration rates (from Table 6-3), available precipitation (from Table 6-1), predominant vegetation type (from field visits and Bureau of Land Management 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 6-4 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 may in fact be greater than zero, but it is likely to be quite small (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 cal-

TABLE 6-4: ESTIMATED PRECIPITATION AND EVAPOTRANSPIRATION

Watershed	Area (Sq. mi.)	Est. ET (in.)	Total precip. (acre-ft/yr)	Total ET (acre-ft/yr)	Potential 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**

culated using the isohyetal map overlay system described previously. 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.

Two caveats must be observed regarding this table:

1) The values in the table are not based on direct measurements: total upland evapotranspiration in the Rio Chama watershed is ***not*** likely to be exactly 2,828,419 acre-feet per year, even though that is the number resulting from spreadsheet calculations. 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 seems to be approximately 2,800,000 acre-feet a year on average**, with an unknown range of error.

2) The principal value of the table is to estimate an overall upland evapotranspiration rate for the watershed as a whole. It is not primarily intended to predict yield in any individual tributary. The unknown but significant uncertainty pertaining to the overall watershed estimates may be proportionally greater for any individual tributary calculation.

The total upland evapotranspiration rate presented in Table 6-4 does tend to corroborate the result when quantifiable watershed yield is subtracted from total precipitation, which is the second method of estimating upland evapotranspiration (and is shown in the water budget summary in Table 6-12). Both methods give a result somewhat over 2,800,000 acre-feet per year, and lend confidence that this may be a reasonable estimate. Similarly, the total estimated yield of approximately 437,000 acre-feet per year presented in Table 6-4 is fairly close to the sum of yield components shown in Table 6-12 and discussed in the estimates of individual tributary yields below.

TRIBUTARY YIELDS

It was not possible to reliably quantify watershed yields by tributary basin. Rather, this water budget focuses on the Rio Chama watershed as a whole. However, potential yields for individual tributaries in Table 6-4 can be compared with the results predicted by the equation developed for the Taos plateau by Hearne and Dewey (1988), and with observed flows when available, as summarized below in Table 6-5. The Hearne and Dewey Taos plateau regression equation can be stated as:

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

where,

Q = mean annual water yield (acre-feet per year)
A = watershed area (square miles)
P = mean winter precipitation (inches)
S = slope of the tributary (feet of rise to miles of run)

A regression curve for winter precipitation fraction was 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 is not particularly strong ($R^2 = 0.59$). Because of this relatively poor correlation and uncertainty in the data, the equation was calculated using an estimate of winter precipitation fraction as predicted by the regression line; then values were calculated again by adding and subtracting the standard error for a 95 percent confidence interval to 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 6-5 on the next page, along with observed streamflow data wherever it was available. Values among these sources sometimes diverge significantly.

The Hearne and Dewey equation using uncorrected Rio Chama winter precipitation fractions (the middle "predicted yield" column in Table 6-5), over estimates total watershed yield, as compared to the sum of observed streamflow, surface water depletions, ground water depletions,

TABLE 6-5: RANGE OF PREDICTED TRIBUTARY FLOWS, HEARNE AND DEWEY METHOD

Watershed	**Predicted Water Yield** (all figures in acre-feet per year)			**Observed Flow** (if available) (acre-ft/yr)
	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 Creek	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)***
Horse Lake etc.	23,587	33,765	46,372	
Willow Creek	8,914	12,760	17,524	
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)***
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**	***406,200***

**Note: Values in the table 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.*

ground water outflow, reservoir and river evaporation, and riparian evapotranspiration (summarized below in Table 6-12). At the same time, it seems to underestimate 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 high-altitude tributaries using the 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-altitude tributaries the correlation is reasonably good. 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.

RIPARIAN EVAPOTRANSPIRATION AND RIVER SURFACE EVAPORATION

Riparian evapotranspiration was estimated by multiplying river length by width and multiplying the resulting area by evapotranspiration rate. River length was considered to be 633,279 feet (119.94 mi.), a figure provided by the New Mexico Water Resources Research Institute GIS system. For riparian evapotranspiration, river length was multiplied by an average riparian area width of 100 feet. Riparian evapotranspiration was taken to be 1.5 times the alfalfa or pasture Evapotranspiration rate (OSE internal memorandum, 25 July 2000). Note that this earlier memorandum has been superseded by a more recent memorandum (OSE internal memorandum, 26 August 2002). An average of the alfalfa crop irrigation requirement at Española (36.2 inches per year, again per OSE internal memorandum) and the pasture crop irrigation requirement in the upper Chama area (about 11 inches per year, from hydrographic surveys) is 23.6 inches, or 1.97 feet per year. 1.5 times the average crop evapotranspiration rate would be 2.95 feet per year, so total annual riparian evapotranspiration is estimated as:

Riparian ET = (633,279 x 100/43,560) acres x 2.95 feet per year
= 1453.8 acres x 2.95 feet per year
= **4,289 acre-feet per year**

River surface evaporation was calculated similarly, assuming an average river width of 40 feet and an evaporation rate equal to the average of the pan evaporation at Abiquiu, El Vado, and Heron reservoirs multiplied by a river evaporation correction factor of 0.6 (OSE memo, 25 July 2002):

River surface evaporation
= (633,279 x 40/43,560) acres x 4.2 feet per year x 0.6
= **1465 acre-feet per year**

LAKE EVAPORATION

The combined surface area of Stinking, Horse, Thompson, Boulder, and Enborn Lakes was estimated at approximately 1680 acres from the USGS 1:250,000 Aztec, NM map. Lake evaporation was assumed to be approximately equal to the El Vado Reservoir pan evaporation rate of 3.97 feet per year multiplied by a lake evaporation coefficient of 0.7. Estimated lake evaporation is:

Lake evaporation = 1680 acres x 3.97 feet x 0.7
= **4,669 acre-feet per year**

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. Reported reservoir evaporation figures for the last five reports are shown in Table 6-6, 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**. The reported values include both wet and dry years, so the average seems a reasonable figure to use for water budget purposes.

TABLE 6-6: 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 New Mexico Interstate Stream Commission estimates the long-term average evaporation loss from San Juan-Chama Project water to be 23,382 acre-feet per year, and other conveyance losses to be 1,424 acre-feet per year (Flanigan, personal communication, 20 March 2003), for a total loss of 24,805 acre-feet per year. Subtracting 24,805 acre-feet of San Juan-Chama evaporation from a total estimate of 29,962 acre-feet leaves an estimated annual 5,157 acre-feet of native reservoir evaporation.

SURFACE WATER DEPLETIONS

Surface water irrigation use is estimated by the Office of the State Engineer by multiplying estimated total surface-water-irrigated acreage by an estimated composite crop irrigation requirement. The figures shown are for *depletion*: total diversions are estimated at 55,000 to 90,000 acre-feet per year, with the difference appearing as return flow. As with reservoir evaporation, reported totals for the past five reports (plus a supplemental report for 1994) are summarized in Table 6-7 below. The average of these reported figures, **24,255 acre-feet per year**, has been used in the water budget.

Surface water depletions for uses other than irrigation have been compiled from figures reported by the OSE for the Rio Arriba County for 2000 (Wilson et al., 2003). They have been adjusted for the planning region and are summarized in Table 6-8 below.

TABLE 6-7: SURFACE WATER IRRIGATION DEPLETIONS

YEAR	Reported Depletion *(acre-ft.yr)*	SOURCE
1980	33,090	Sorensen, 1982
1985	25,931	Wilson, 1986 (withdrawal *w/d ratio for 1980)
1990	19,269	Wilson, 1992 (project withdrawal * .30)
1994	20,925	Wilson and Lucero, 1998 (farm withdrawal * .50)
1995	18,462	Wilson and Lucero, 1997
1999	27,854	Wilson et al., 2003
AVERAGE	**24,255**	

Surface water depletions for the public water supply systems (there are two of them, in Chama and Lumberton) were derived according to the OSE estimates (71 percent of water diverted for the Chama system is depleted, and 50 percent of water diverted for the Lumberton system is depleted) (Wilson et al., 2002). Livestock and commercial depletions were estimated by multiplying Rio Arriba County values from the OSE report by 0.56, the percentage of county land area comprised by Rio Chama planning region.

TABLE 6-8: NON-IRRIGATION SURFACE WATER DEPLETIONS

CATEGORY	Reported depletion *(acre-ft/yr)*
Public water supply	**124.0**
Self-supplied domestic	**0.0**
Self supplied livestock	**93.6**
Self-supplied commercial	**38.1**
Self-supplied industrial	**0.0**
Self-supplied mining	**0.0**
REGION TOTAL	**255.7**

SURFACE WATER OUTFLOW

The USGS streamflow gage near Chamita effectively measures surface flow out of the Rio Chama watershed, since it is located just upstream of the confluence of the Rio Chama with the Rio Grande. Since 1972 San Juan-Chama Project flows averaging about 67,900 acre-feet per year have been added to streamflow at the Chamita gage because 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 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.

GROUND WATER DEPLETIONS

Ground water use in the region is small in relation to other water budget components and to ground water use in most other regions. Ground water depletions have been compiled from figures reported by the OSE for the Rio Arriba County for 2000 (Wilson et al., 2002). These figures are adjusted for the planning region and are summarized in Table 6-9.

TABLE 6-9: GROUND WATER DEPLETIONS

CATEGORY	Reported depletion (acre-ft/yr)
Public water supply	**400.0**
Self-supplied domestic	**807.0**
Irrigated agriculture	**659.5**
Self supplied livestock	**99.4**
Self-supplied commercial	**106.4**
Self-supplied industrial	**73.5**
Self-supplied mining	**7.0**
Power generation	**0.0**
REGION TOTAL	**2,152.8**

Public water supply depletions were compiled from OSE reported totals for Rio Chama public and commercial systems (where available). There are many public supply systems in the region that were not included in the OSE inventory. For those systems, depletions were calculated using the same method used by the OSE (Wilson et al, 2002). Water withdrawal (W) was calculated as: W = Pop x GPCD/892.74. Gallons per capita per day, (GPCD), was assumed to be 80, as recommended in the OSE report. The OSE estimates that 50 percent of public supply water withdrawn is depleted (Wilson et al, 2002).

Self-supplied domestic withdrawal was estimated using the equation for withdrawal shown above. Population was estimated as the difference of population served by MDWCAs and the total population in the watershed (14,690 – 5954 = 9006). Self-supplied domestic depletions are assumed to be equal to withdrawals, as in the OSE reports (Wilson et al, 2002).

Total groundwater withdrawal for irrigated agriculture was taken from OSE (Wilson et al, 2002). Depletion amounts not calculated for the Rio Chama watershed in the OSE reports were estimated to be the same percentage of withdrawal amounts used for Rio Arriba county (as supplied by the OSE) (Wilson et al., 2002).

DOMESTIC, COMMUNITY, AND COMMERCIAL WATER USE

It is often a matter of interest what fraction of total water depletions in the region is comprised of private well pumping, community water system uses, and commercial or industrial uses. Table 6-10 itemizes these uses, whether the source of the water is originally ground or surface water. Residential and commercial water use of 1,556 acre-feet per year (as compared to about 24,250 acre-feet per year of irrigation depletions) accounts for only 5.8 percent of total intentional water depletions (not counting reservoir evaporation or river/riparian evapotranspiration). Figures from this table are not included as such in the water budget in Table 6-12, since they are already counted in the surface and ground water depletions itemized in Tables 6-8 and 6-9 above. Ground water sources provide almost 90 percent of all domestic and commercial water used.

TABLE 6-10: DOMESTIC, COMMUNITY, AND COMMERCIAL DEPLETIONS

CATEGORY	Reported depletion *(acre-ft/yr)*		
	Ground water	Surface water	Total
Public water supply	400.0	124.0	524.0
Self-supplied domestic	807.0	0	807.0
Self-supplied commercial	106.4	38.1	144.5
Self-supplied industrial	73.5	0	73.5
Self-supplied mining	7.0	0	7.0
REGION TOTAL	**1393.9**	**162.1**	**1556.0**

GROUND WATER OUTFLOW

The boundary of the Rio Chama watershed and planning region, determined by surface topography, is somewhat arbitrary in terms of ground water flows. Geologically, the Española Basin extends from the Jemez y Sangre planning region into the lower end of the Rio Chama watershed, so that the boundary between the two planning regions divides the Española Basin. Outflow takes place at the southern end of the Rio Chama watershed, in Española Basin Tertiary deposits. Ground water outflow into the Jemez y Sangre part of the Española Basin can be computed using Darcy's Law:

$$\mathbf{Q} = -\mathbf{KIBW}$$

where,

Q = ground water flow out of the watershed
K = hydraulic conductivity
I = hydraulic gradient
B = saturated thickness
W = width of aquifer through which water flows

Hydraulic conductivity in the Tertiary Santa Fe Group deposits was estimated to be 0.5 ft/day, based on aquifer tests conducted on several units in the Tesuque Formation just outside the study area (Hearne, 1985). Saturated thickness was assumed to be 1000 feet (Duke Engineering, 2000). These are the same values for hydraulic conductivity and saturated thickness used in the water budget for the Jemez y Sangre planning region. The Jemez y Sangre Regional Water Plan Report (Duke Engineering, 2000) includes a map showing estimated water level contours within the Rio Chama watershed. The hydraulic gradient, length, and width over which this extends were measured from the Duke Engineering map. Table 6-11 shows the values used to calculate the discharge of ground water out of the watershed.

Discharge is calculated as follows:

$$\mathbf{Q = (0.5\ {}^{ft}\!/_{day})(0.0139)(1000\ ft)(63{,}360\ ft)(0.000023\ {}^{acre}\!/_{ft^2})(365\ {}^{day}\!/_{year}) = 3{,}697\ {}^{acre\text{ - }ft}\!/_{year}}$$

Discharge, or calculated subsurface outflow, is **3,697 acre-ft/yr.**

TABLE 6-11: INPUT VARIABLES FOR CALCULATING GROUND WATER DISCHARGE

Aquifer	Hydraulic conductivity (ft/day)	Change in water level (ft)	Change in length (ft)	Hydraulic gradient	Saturated thickness (ft)	Width (ft)
Santa Fe Group	0.5	6800 - 5700	79,200	0.0139	1000	63,360

SUMMARY WATER BUDGET

The budget components presented above are summarized in Table 6-12. All quantities are rounded to emphasize that they represent ranges of values with unknown margins of uncertainty rather than precisely known quantities. Upland evapotranspiration in Table 6-12 is estimated simply as the remainder after total yield and San Juan-Chama deliveries are subtracted from total inflow. However, the resulting estimate of 2,846,850 acre-feet per year is quite close to the independent estimate of 2,828,400 acre-feet per year derived as shown in Table 6-4 previously.

San Juan-Chama Project outflows are estimated by subtracting average reservoir evaporation attributable to Project storage (23,400 acre-feet per year) and estimated conveyance losses (1400 acre-feet per year) from the average Project inflows at the Azotea tunnel of 92,700 acre-feet per year, for an estimated average outflow of 67,900 acre-feet per year.

TABLE 6-12: LONG-TERM AVERAGE WATER BUDGET

INFLOW *Acre-ft./yr*		**OUTFLOW** *Acre-ft./yr*	
Precipitation	3,265,000	Reservoir evaporation - native water	5,150
Ground water inflow	0	Other lake evaporation	4,700
Native surface water inflow	0	River surface evaporation	1,450
San Juan – Chama diversions	92,700	Riparian evapotranspiration	4,300
		Change in reservoir storage	0
		Change in ground water storage	0
		Ground water depletions	2,150
		Ground water flow out of basin	3,700
		Surface water depletions	24,500
		Chamita flow (surface outflow)	372,200
		Total native watershed yield	**418,150**
		San Juan - Chama deliveries	**67,900**
		San Juan - Chama evaporation & losses	**24,800**
		Upland evapotranspiration	**2,846,850**
TOTAL INFLOW	**3,357,700**	**TOTAL OUTFLOW**	**3,357,700**

EFFECTS OF DROUGHT

The Rio Chama watershed, like most of the Southwest, experienced a significant drought in water year 2002. The water budget presented in Table 6-13 incorporates estimates of how a drought such as that of 2002 may affect inflow and outflow in the watershed.

Data for water year 2002 were not generally available at the time of writing. River discharge at the Chamita gage from 1990 was used since that was also a dry year (lowest previous discharge at Chamita since 1971, for instance), and 1990 figures were also used for San Juan-Chama diversions, evaporation, and deliveries. It was assumed that reservoir evaporation of native water, along with river and lake losses, remained the same. This drought-year water budget is intended as an example of a serious but not atypical condition in the watershed, rather than a detailed accounting for any particular year.

Precipitation for 2002 in the Chama watershed was about 50 percent of normal, based on National Weather Service data for the Chama, Ghost Ranch, Canjilon Ranger Station, and Alcalde weather stations; suggesting overall precipitation inflow of approximately 1,632,500 acre-feet. San Juan-Chama diversions for 1990 were about 76,000 acre-feet, evaporation was estimated to be about 24,700 acre-feet, and deliveries must then have been about 51,300 acre-feet. Changes in storage were still assumed to be zero for budget purposes. It was also assumed that ground water depletions and outflow were unchanged from the average conditions illustrated in Table 6-12. Values reported by the OSE for 1990, a drought year, were used for surface water depletions. Lake and river evaporation were assumed to remain unchanged. Upland evapotranspiration is estimated, as in Table 6-12, by subtracting total yield and San Juan-Chama deliveries from inflows.

TABLE 6-13: DROUGHT-YEAR WATER BUDGET

INFLOW *Acre-ft./yr*		**OUTFLOW** *Acre-ft./yr*	
Precipitation	1,632,500	Reservoir evaporation - native water	5,000
Ground water inflow	0	Other lake evaporation	4,700
Native surface water inflow	0	River surface evaporation	1,500
San Juan - Chama diversions	76,000	Riparian evapotranspiration	4,300
		Change in reservoir storage	0
		Change in ground water storage	0
		Ground water depletions	2,100
		Ground water flow out of basin	3,700
		Surface water depletions	19,300
		Chamita flow (surface outflow)	177,500
		Total native watershed yield	**218,100**
		San Juan-Chama deliveries	**51,300**
		San Juan-Chama reservoir evaporation	**24,700**
		Upland evapotranspiration	**1,414,400**
TOTAL INFLOW	**1,708,500**	**TOTAL OUTFLOW**	**1,708,500**

Clearly, precipitation varies dramatically. Upland evapotranspiration has to vary with it, although the actual variation in evapotranspiration may not be as great as that indicated above since soil moisture in storage can be used by plants to somewhat buffer the effects of a reduction in precipitation. Surface streamflows also vary dramatically, of course. Streamflow is much more sensitive to winter precipitation than to total annual precipitation and therefore can vary much more than annual precipitation. The flow at Chamita in 1990, for instance, ranks 16th lowest in the 76 (discontinuous) years on record from 1913 to 2000 in terms of total flow – but after 1972 an average of about 67,900 acre-feet annually have been added to Chamita flows by San Juan-Chama deliveries, and about 51,300 acre-feet were added in 1990. If 51,300 acre-feet are subtracted from the measured flows of 177,494 acre-feet, the remaining 126,194 acre-feet are the second-lowest native flows ever recorded (lowest was about 115,700 acre-feet in 1934, as reported in the USGS flow-duration analysis performed for this water plan). Native flows in 2002 were probably even lower, however.

It is important to note that although 1990 Native flows were about 23 percent of average, total precipitation in water year 1990 (October 1989 through September 1990) was 110 percent to 120 percent of normal in the region (Western Regional Climate Center web site, monthly total precipitation tables for Chama and El Rito). This is another illustration of the importance of winter precipitation in higher elevations as opposed to total precipitation throughout the watershed.

Although the water yield is lower in drought years than in non-drought years, there has been enough water available (at least so far) for human consumptive uses. Irrigation shortages and problems for community water systems do occur, but variations in flow out of the region are greater than the reported variations in water use within the region.

CONCLUSION

The water budget summarized in this part of the Rio Chama Regional Water Plan presents the most reliable information that exists at present, but the numerical values presented all depend on assumptions and estimates to varying degrees. The investment required to measure tributary flows, irrigation diversions and return flows, and representative ground water levels, for instance, would be repaid handsomely in accurate data about water supply and use in the region.

The 85 percent or so of total precipitation that appears to leave the watershed as upland evapotranspiration might be considered an appealing target for increases in water yield, and indeed some potential may exist there. Caution is appropriate, however, in assuming that any substantial fraction of that water can be made available for consumptive uses. Little is known about the ecological or other effects of large-scale manipulations of watersheds to increase yields, and the costs would likely be considerable, especially in view of long-term maintenance requirements to ensure continuing additional yields, if they materialize. Other obvious concerns include dangers from erosion or flash flooding, and potential ecological consequences of focusing on water production too exclusively. On the other hand, if water can in effect be stored in the soil and shallow aquifers of upland watersheds, net yields for human use may be greater than those for an equivalent amount of water stored in open reservoirs, where evaporation losses already nearly equal all other consumptive uses in the planning region combined.

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