Availability and variability of surface-water resources in Taos County, New Mexico--An assessment for regional planning

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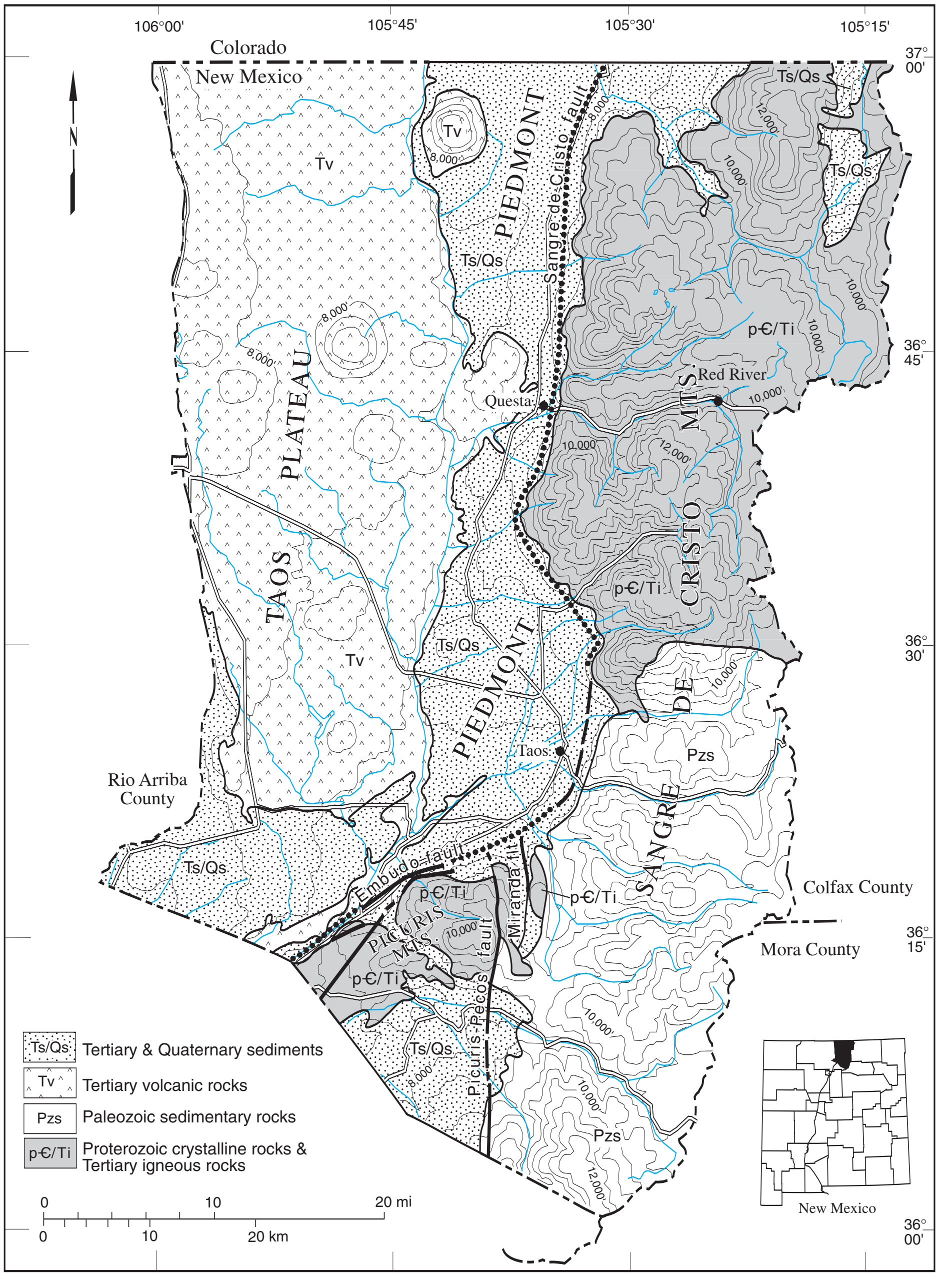

FIGURE 1—General geology and physiographic features of Taos County (modified from Anderson and Jones, 1994).

Abstract

Surface-water withdrawals supply over 93% of Taos County water requirements, and an accurate inventory of this important resource is a crucial first step in developing a regional water plan. Summary statistics of existing streamflow data for the Taos region and simple time-trend analysis are used to define the average annual surface-water supply, to describe its geographic and temporal variation, and to predict its future variability. The surface-water system is described and inventoried by drainage basin. Historic streamflow data from all gage stations in Taos County, and adjacent localities in Colorado and Rio Arriba County, with more than 10 yrs of record are compiled through the end of water year (September) 1994. The discharge data are evaluated for standard statistical parameters, including mean, median, minimum, maximum, and 10th, 25th, 75th, and 90th percentiles. Estimates of surface-water yields for "average," "wet," and "dry" years are developed separately by reach of stream, by drainage basin, and for Taos County based on median, $P_{.75}$, and $P_{.25}$ discharges. An estimated 238,000 acre-ft of surface water originates from the major basins

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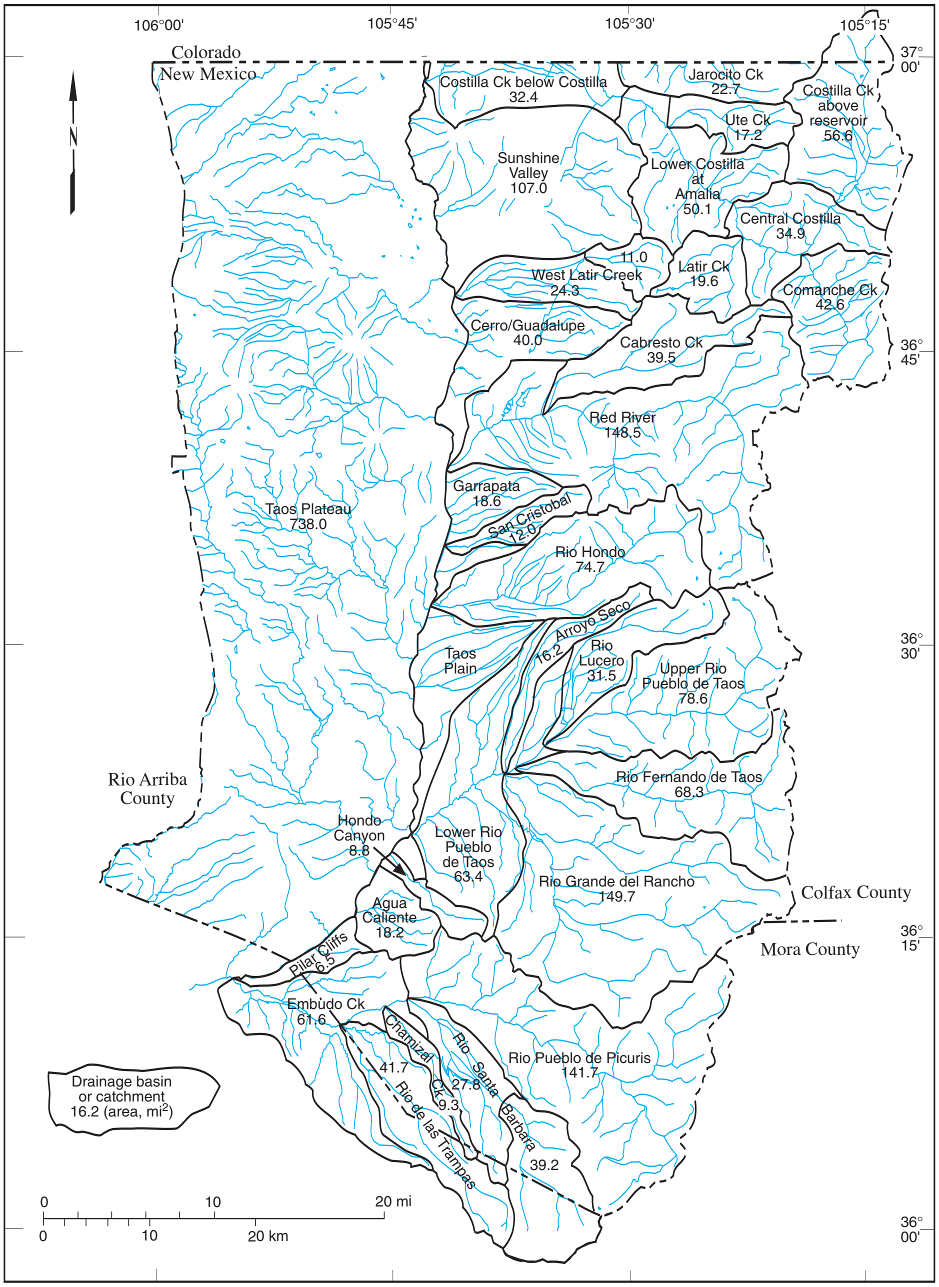

FIGURE 2—Drainage basins, subbasins, and catchments in Taos County.

each year. Total surface discharge for the county is expected to vary from about 189,000 acre-ft in a dry year to as much as 340,000 acre-ft in a typical wet year. The largest stream discharges are during the peak snow-melt months of May and June. The combined spring and summer periods (April through October), which correspond to the irrigation season, contribute from 70% to 90% of annual stream discharges. In most years surface-water supply is sufficient to meet the agricultural demand throughout the irrigation season. Estimates of minimum annual baseflow, varying from 1% to 37% of annual discharge, are derived from minimum monthly discharges during the low-flow winter months of December through February. Long-term, decadal-scale variability of streamflow is evaluated using 80 yrs of stream discharge data from the Rio Grande station at Embudo. Time-trend analysis of these historic data indicates that long intervals of severe dry conditions can persist for up to 30 yrs, wherein annual stream discharge may remain at 64% of the predicted average.

Introduction

Water in the arid Southwest is a fragile and finite resource that planners, water-resource managers, hydrologists, and engineers are striving to inventory, quantify, and manage for future use. Since 1987, the State of New Mexico has endeavored to protect and preserve its water supply through regional water planning, an effort directed by the New Mexico Interstate Stream Commission. The approach to regional water planning is based on an assessment of both available supply and future demand. A critical first step in the planning process is to inventory the quantity and quality of surface water and ground water in the planning region. This paper presents an evaluation of the availability and variability of surface-water resources in Taos County, completed as part of a surface-water assessment for regional planning purposes. Existing streamflow and climatic data for the Taos region are evaluated and interpreted to define the average annual surface-water supply, to describe its geographic and seasonal variation, and to assess its future variability.

Other workers have completed various analyses of streamflow data from Taos County that include summary statistics (Waltemeyer, 1989), flow-duration analyses (Reiland and Haynes, 1963; Reiland, 1980; Waltemeyer, 1989), flow-frequency

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analyses using a log-Pearson Type III probability distribution (Reiland and Haynes, 1963; Waltemeyer, 1986, 1989, 1996), and complex regional analysis using multiple regression techniques relating stream discharge to basin and climatic characteristics (Waltemeyer, 1986, 1996; Hearne and Dewey, 1988). One previous study (Reiland, 1980) extended records to a standard base period of October 1930 through September 1973 to support a flow-duration analysis. The present work defines the availability and variability of stream discharge in the county using summary statistics of existing data and simple time-trend analysis.

Summary of drainage basins and streamflow data

Over 93% of water withdrawals in Taos County in 1990 originated from surface-water sources (Wilson and Lucero, 1997). Surface water flows through 11 perennial streams and rivers that originate in the Sangre de Cristo and Picuris Mountains and discharge into the Rio Grande. These physiographic features and the general geology of Taos County are shown in Fig. 1. The perennial streams and rivers occupy large to intermediate drainage basins on the west face of the Sangre de Cristo Mountains. The drainage basins, subbasins, and watersheds are illustrated in Fig. 2. Basin and watershed statistics, including basin area, elevation range, and number of active or discontinued U.S. Geological Survey (USGS) stream gage stations, are summarized in Table 1. Basin and watershed areas were calculated at 1:100,000 scale using GIS ARC/INFO GRID software and reflect areas of the entire basin (or subbasin) above the tributary confluence or above another point of interest such as a current or historic stream gage.

TABLE 1—Drainage basins of Taos County.

Basin or catchment Subbasin	Area[1] (mi^2)	Elevation range (ft)	Gage stations[2]
Costilla Creek above Costilla	221	12,870–7,900	5A, 2D
Costilla Creek above reservoir	56.6	12,870–9,400	3A
Comanche Creek	42.6	11,220–8,920	0
Latir Creek	19.6	12,700–8,740	0
Ute Creek	17.2	12,880–8,100	1D
Costilla Creek below Costilla	32.4	7,900–7,380	1A, 1D
Sunshine Valley	107	10,370–7,300	0
West Latir Creek	35.3	12,730–7,250	1D
Cerro/Guadalupe	40	12,450–7,110	0
Red River	188	13,160–6,600	4A, 3D
Cabresto Creek	39.5	12,630–7,340	2A
Garrapata and San Cristobal	30.6	11,800–6,550	0
Rio Hondo	75	13,160–6,470	1A, 1D
Rio Pueblo de Taos	418		4A, 4D
Upper Rio Pueblo de Taos	78.6	13,110–6,880	1A
Rio Lucero	31.5	13,110–6,880	1A
Rio Fernando de Taos	68.3	10,830–6,755	1D
Arroyo Seco	16.2	11,980–6,710	0
Rio Grande del Rancho	150	11,940–6,710	1A, 1D
Lower Rio Pueblo de Taos	63.4	10,600–6,200	1A, 2D
Pilar	33.4		
Arroyo Hondo	8.8	10,600–6,060	0
Agua Caliente	18.2	9,400–6,020	0
Pilar Cliffs	6.5	7,500–5,900	0
Embudo Creek	320	12,800–6,600	3A, 1D
Rio Pueblo de Picuris	142	12,470–7,160	1D
Rio Santa Barbara	67	12,840–7,160	1A
Chamizal Creek	9.3	9,840–7,070	0
Rio de las Trampas	42	12,800–6,600	0
Taos Plateau	738	9,000–6,060	0

[1] Area values calculated using GIS ARC/INFO software at 1:100,000 scale.
[2] Number of gage stations that are Active or Discontinued.

As the perennial streams enter the piedmont terrain at the base of the Sangre de Cristo and Picuris Mountains, surface flow is generally lost to infiltration in the coarse gravel of alluvial-fan and alluvial-slope deposits. However, complex geologic conditions and structural features in the high piedmont terrain give rise to enigmatic stream/aquifer interactions at several locations. The upper piedmont zone in the Red River, Rio Hondo, and Rio Pueblo de Taos drainages is the focus for numerous wetlands, springs, and seeps, and stream-discharge data document significant stream gains in these areas.

The USGS has maintained numerous gage stations over the last century on all the major streams and rivers flowing through Taos County, beginning with the Embudo station on the Rio Grande in 1889. Streamflow entering New Mexico in the Rio Grande is monitored near Lobatos, Colorado. Current or historic gaged streams include the Rio Grande, Costilla Creek, Red River, Latir Creek, the Rio Hondo, the Rio Pueblo de Taos (and its four tributaries, the Rio Lucero, the Rio Grande del Rancho, the Rio Fernando de Taos, and the Rio Chiquito), the Rio Santa Barbara, the Rio Pueblo de Picuris, and Embudo Creek. Stream discharge is also monitored on the Rio Grande at the southern Taos County Line by the Embudo gage. The locations of 35 active and discontinued USGS gage stations on streams and rivers in Taos County are shown in Fig. 3. The streamflow data and basin characteristics for each station are summarized in Table 2. Active subbasins that are not directly gaged include San Cristobal Canyon, Hondo Canyon, Agua Caliente, Chamizal Creek, and the Rio Trampas.

Statistical summaries of streamflow data

The USGS daily streamflow values (Hydrosphere, 1996) provide a compilation of monthly and daily streamflow data and statistics for all existing and discontinued gage stations in and immediately adjacent to Taos County. Streamflow data from all stations in Taos County and adjacent localities in Colorado and Rio Arriba County with more than 10 yrs of record were compiled through the end of water year (September) 1994. The data were evaluated for standard statistical parameters, including annual mean, median, minimum, maximum, and 10th, 25th, 75th, and 90th percentile values.

Standard statistical summaries of streamflow data (e.g. Riggs, 1968; Waltemeyer, 1989) apply classical measures of sample characteristics, including the mean, standard deviation, minimum and maximum values, coefficient of variation, and skew of the data, to groupings of monthly and annual stream discharges. These classical measures, specifically the mean and standard deviation, are also the most sensitive and least resistant mea-

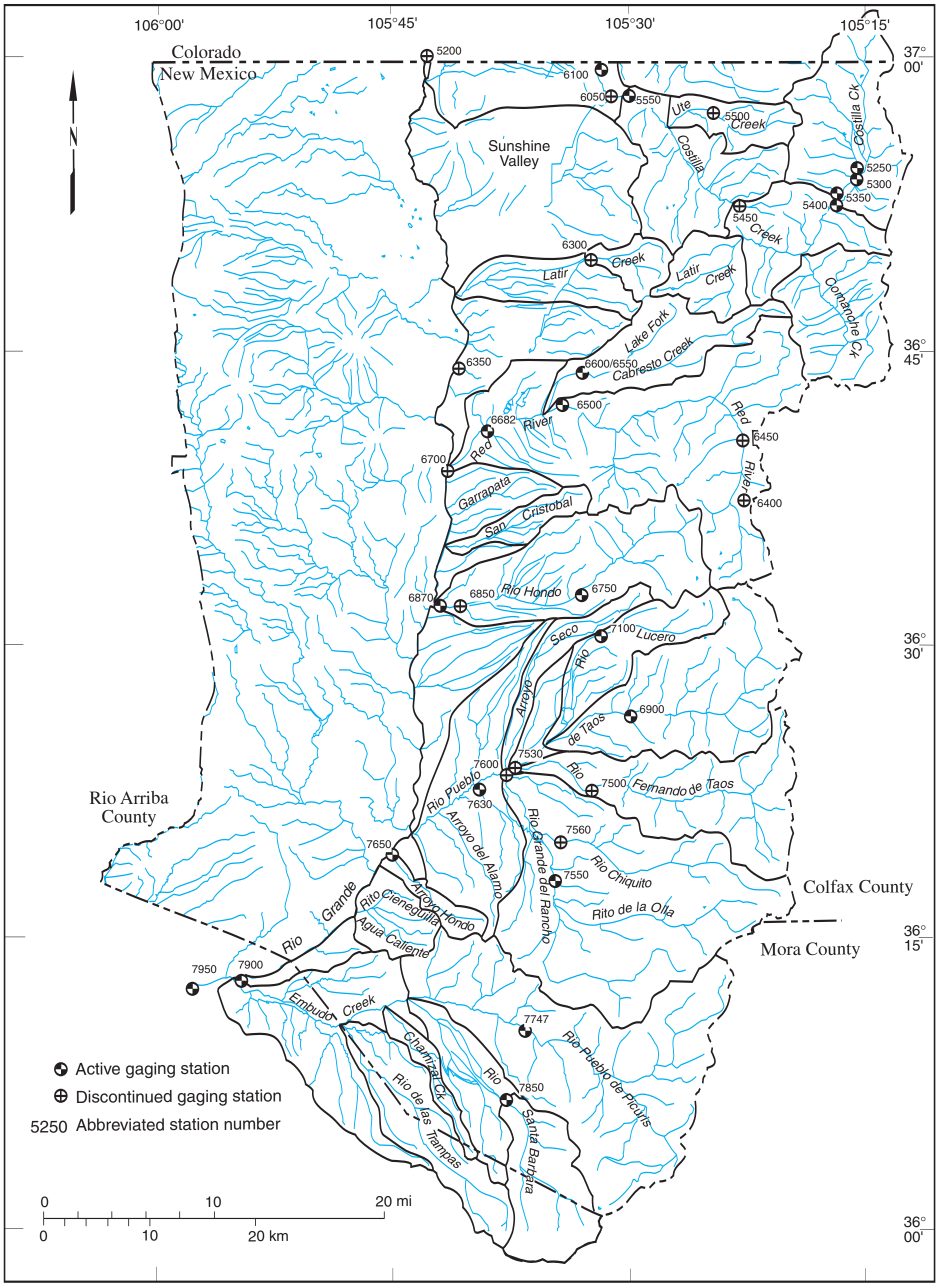

FIGURE 3—USGS surface-water gaging stations in and adjacent to Taos County.

sures of average stream discharge and its variability in that they are strongly influenced by outlying or extreme events. A large-magnitude flood, which may occur with a return period of 100 or 50 yrs, will significantly increase the mean streamflow value. Furthermore, because the standard deviation is computed using the squares of deviations of data from the mean, outliers influence its magnitude even more so than for the mean itself. When this strong influence of a few observations is desirable, the mean and standard deviation are appropriate measures. If a more resistant measure of the central value is desired, the median, or 50th percentile ($P_{.50}$), is more appropriate. The median is only minimally affected by the magnitude of a single extreme observation. The most appropriate corresponding resistant measure of spread or variability is the median absolute deviation, or MAD. The MAD is computed by first listing the absolute value of all differences between each observation and the median. The median of these absolute values is the MAD.

Streamflow data typically show a positive skew, meaning that the data are not symmetric around the mean because extreme values (high discharges) extend the right tail of the distribution. When data are positively skewed, the mean exceeds more than 50% of the data, and the standard deviation is inflated by data in the tail. Other than providing the necessary parameters for frequency analysis, tables summarizing streamflow statistics that include only the mean and standard deviation or variance are of limited value for characterizing streamflow data, as those data typically have a positive skew. Summary tables that include the median, MAD, and other percentiles have far greater applicability to skewed data and should be applied to water-availability assessments.

Historic availability and variability of streamflow

Historic streamflow data are interpreted using statistical summaries, data plots, and smoothing techniques to characterize annual and seasonal variability and long-term trends and cycles in stream discharge. To provide a sound basis for planning and future development of surface-water resources, water planners and managers want to know how much surface water is available in an "average" or typical year, in a "dry" year, and in a "wet" year; however, the terms "average," "wet," and "dry" are not defined by either statistical or descriptive means. Both planners and water consumers also want to know whether sufficient water will be available when it is needed. An evaluation of the seasonal variation is important in determining whether the local demand for surface water can be met in real time and without the need for costly storage facilities. Interpretation of annual and monthly streamflow data using alternative statistical summaries can address both issues and provide sound estimates of surface-water yields for "average," "wet," and "dry" years.

Although the average annual surface discharge is most commonly approximated using the traditional mean, the annual median is a more representative central value for positively skewed data such as stream discharge. The median is consistently lower than the mean, and it is a more conservative and accurate estimate of average flow. Dry-year and wet-year stream discharge values can be constrained by minimum and maximum values, respectively, for the periods of record. However, as these values represent extreme events, maximums and minimums are not truly representative of discharges expected during normal fluctuations between wet and dry years. For planning purposes, alternative values that more accurately represent typical dry and wet years are needed. Discharge values reflected by the 25th and 75th percentiles are more representative of dry and wet years, respectively, and are suitable for most planning objectives. The variability of annual stream discharge in Taos County is summarized in Table 3 using both classic (period of record mean, standard deviation, maximum, and minimum) and resistant (median, 75th, and 25th percentile discharge values, and MAD) mea-

TABLE 2—Active and discontinued stream gage stations in and near Taos County and summary of streamflow data and basin characteristics.

Station ID	Gage location	Status[1]	Years of record[2]	Period of record	Drainage area[7] (mi^2)	Mean Q[8] (acre-ft/yr)	s[8] (acre-ft/yr)	Mean basin elevation[9] (ft)
8251500	Rio Grande near Lobatos, CO	A	95	1900–pres	4,760*	418,330	285,800	nd
8252000	Rio Grande at CO–NM State Line	D	29	1954–1982	4,950*	254,610	156,110	nd
8252500	Costilla Creek above dam	A		1937–pres[3]	25.1	3,481	2,096	11,400
8253000	Casias Creek near Costilla	A		1937–pres[3]	16.6	4,844	2,710	11,100
8253500	Santistevan Creek near Costilla	A		1937–pres[3]	2.15	846	404	10,500
8254000	Costilla Creek below dam	A		1937–pres[3,4]	54.6	14,629	6,153	10,693*
8254500	Costilla Creek near Amalia	D		1949–1981[3]	152	19,051	7,749	nd
8255000	Ute Creek near Amalia	D		1949–1959[3]	12	1,,747	1,175	10,700
8255500	Costilla Creek near Costilla	A	34	1961–pres[5]	195	32,945	14,597	10,100*
8260500	Costilla Creek bel div @ Costilla	D		1965–1986[3]	197	6,117	7,976	nd
8261000	Costilla Creek at Garcia, CO	A		1966–pres[3]	200	5,618	7,108	nd
8263000	Latir Creek near Cerro	D	25	1946–1970	10.5	3,904	1,304	11,500
8263500	Rio Grande near Cerro	D	46	1949–1994	5,500*	333,490	203,350	nd
8264000	Red River near Red River	D	14	1944–1964[6]	19.2	11,213	4,168	10,800
8264500	Red River below Zwergle damsite	D	10	1964–1973	25.7	12,818	4,505	10,530
8265000	Red River near Questa	A	65	1925, 1931–pres[6]	113	31,101	14,602	9,930
8265500	Llano Ditch near Questa	A		1944–pres[3]	na	1,678	1,030	na
8266000	Cabresto Creek near Questa	A	51	1944–pres	36.7	7,844	3,273	10,184*
8266820	Red River below fish hatchery near Questa	A	16	1979–pres	185	63,154	17,287	nd
8267000	Red River at mouth near Questa	D	27	1952–1978	190	54,682	13,640	9,500
8267500	Arroyo Hondo near Valdez	A	60	1935–pres	36.2	25,853	10,097	10,100
8268500	Arroyo Hondo at Arroyo Hondo	D	67	1913–1985[6]	65.6	19,835	11,046	9,730
8268700	Rio Grande near Arroyo Hondo	A	31	1964–pres	5,820*	492,570	234,440	nd
8269000	Rio Pueblo de Taos near Taos	A	43	1915, 1941–pres[6]	66.6	21,966	11,896	9,500
8271000	Rio Lucero near Arroyo Seco	A	50	1914–1915, 1935–pres[6]	16.6	16,310	5,990	10,800
8275000	Rio Fernando de Taos near Taos	D	17	1964–1980	71.7	4,139	3,781	8,870
8275300	Rio Pueblo de Taos near Ranchito	D	23	1958–1980	199	22,209	17,230	nd
8275500	Rio Grande del Rancho near Talpa	A	39	1953–pres[6]	83	15,338	7,801	9,400
8275600	Rio Chiquito near Talpa	D	23	1958–1980	37	6,090	3,453	9,350
8276000	Rio Pueblo de Taos at Los Cordovas	D	54	1911–1965[6]	359	42,378	27,812	nd
8276300	Rio Pueblo de Taos below Los Cordovas	A	37	1958–pres	380	48,076	33,424	nd
8276500	Rio Grande below Taos Junction	A	68	1927–pres	6,790*	548,090	270,020	nd
8277470	Rio Pueblo near Peñasco	A	3	1991–pres	nd	43,333	29,674	9,860*
8278500	Rio Santa Barbara near Peñasco	A	7	1953–1957, 1993–pres[6]	39+	24,712	10,596	10,309*
8279000	Embudo Creek at Dixon, NM	A	62	1924–pres[6]	305	61,434	36,172	8,980
8279500	Rio Grande at Embudo, NM	A	95	1890–pres[6]	7,460*	676,490	319,180	nd

[1] A = active, D = discontinued.

[2] Full water years of record.

[3] Partial year records from the irrigation season.

[4] Discharge regulated by Costilla Reservoir.

[5] Streamflow data exist for 1936–1994; data for 1936–1960 unavailable from Hydrosphere (1996).

[6] Period of record includes missing years.

[7] Drainage area above gage station from USGS daily values (Hydrosphere, 1996); * = drainage area excludes 2,940 mi^2 of closed basin in Colorado; + = drainage area calculated using GIS ARC/INFO software at 1:100,000.

[8] Mean annual discharge and standard deviation calculated from daily discharge for period of record through 1994, USGS daily values (Hydrosphere, 1996).

[9] Mean basin elevation values from Waltemeyer (1986, 1996); * = values from New Mexico State Engineer Office internal files (1997).

nd = no data; na = not applicable

TABLE 3—Summary statistics for annual stream discharge and comparison of classic and resistant measures of location and spread (all units in acre-ft/yr).

Station ID[1, 2, 3]	Mean Q [4]	s	Maximum Q[5]	Minimum Q[6]	Median Q[7]	90th Percentile Q	75th Percentile Q	25th Percentile Q	10th Percentile Q	MAD[8]
5150 Rio Grande at Lobatos[3]	418,330	285,800	1,494,954 [1907]	51,209 [1964]	355,159	846,449	582,956	188,979	103,868	202,962
6350 Rio Grande at Cerro[3]	333,490	203,350	923,159 [1987]	80,801 [1964]	325,955	564,363	440,367	175,997	104,321	136,957
6870 Rio Grande at Arroyo Hondo[3]	492,570	234,440	1,101,619 [1987]	168,441 [1964]	445,044	865,255	580,018	302,163	256,120	153,230
7650 Rio Grande at Taos Junction[3]	548,090	270,200	1,332,201 [1942]	196,253 [1964]	515,131	886,371	688,019	319,589	243,444	190,865
7950 Rio Grande at Embudo[3]	676,490	319,180	1,503,324 [1942]	223,138 [1977]	615,883	1,111,032	899,011	399,664	292,286	249,502
5550 Costilla Ck near Costilla[2]	32,945	14,597	63,234 [1983]	11,990 [1964]	28,966	56,723	41,134	20,559	15,782	10,346
6300 Latir Creek[1]	3,904	1,304	6,382 [1957]	2,095 [1956]	3,647	5,627	5,176	2,998	2,266	1,054
6400 Red River near Red River[1]	11,213	4,168	18,920 [1952]	5,565 [1963]	10,904	16,577	13,804	7,754	6,959	3,111
6500 Red River near Questa[2]*	31,101	14,602	63,440 [1979]	8,555 [1971]	29,286	52,210	44,441	23,470	17,453	11,338
6700 Red River at mouth[3]	54,682	13,640	86,073 [1952]	34,953 [1977]	54,371	73,405	60,836	42,465	40,345	9,588
6682 Red River below fish hatchery[3]	63,154	17,287	93,353 [1979]	30,359 [1981]	61,537	83,243	75,117	50,402	43,647	12,352
6600 & 6550 Cabresto Ck[2] and Llano Ditch	9,725	3,981	18,039 [1979]	3,887 [1977]	8,775	14,933	12,262	6,855	4,725	3,424
6750 Arroyo Hondo near Valdez[1]	25,853	10,097	50,571 [1942]	11,291 [1971]	23,392	40,152	31,108	19,112	13,402	6,457
6850 Arroyo Hondo at Arroyo Hondo[3]	19,835	11,046	47,355 [1916]	6,934 [1974]	15,317	39,647	25,357	11,769	8,490	6,356
7100 Rio Lucero[1]	16,310	5,990	33,807 [1941]	7,184 [1972]	15,488	23,296	20,041	12,586	8,309	3,486
6900 Rio Pueblo de Taos near Taos[1]	21,966	11,896	52,348 [1979]	5,610 [1972]	18,344	38,433	28,507	13,507	8,901	7,717
7530 Rio Pueblo near Ranchito[3]	22,209	17,230	78,476 [1979]	6,651 [1972]	17,856	41,422	25,754	10,618	7,525	7,515
7500 Rio Fernando de Taos[2]	4,139	3,781	14,155 [1979]	922 [1971]	2,735	10,120	4,653	1,979	1,131	1,210
7560 Rio Chiquito[1]	6,090	3,453	15,458 [1979]	1,892 [1972]	5,346	10,417	7,803	4,064	2,228	2,039
7550 Rio Grande del Rancho[2]	15,338	7,801	31,865 [1994]	4,320 [1972]	13,577	26,082	21,467	9,582	5,370	6,136
7600 Rio Pueblo at Los Cordovas[3]	42,378	27,812	147,644 [1942]	11,170 [1951]	35,648	77,822	54,808	21,304	15,706	16,291
7630 Rio Pueblo below Los Cordovas[3]	48,076	33,424	139,608 [1994]	10,455 [1972]	31,492	94,757	70,870	23,895	14,350	16,828
7850 Rio Santa Barbara[1]	24,712	10,596	36,574 [1957]	8,698 [1956]	22,928	35,812	33,924	18,467	12,581	9,617
7900 Embudo Creek at Dixon[3]	61,434	36,172	170,452 [1941]	9,253 [1951]	52,229	106,305	87,436	38,775	19,449	25,016

[1] Unimpaired, natural flow.

[2] Flow slightly impaired by minor diversion and/or regulation; * = values reflect the period 1966 through 1994 (after mine pipeline bypass).

[3] Impaired flow.

[4] Mean annual discharge calculated for period of record through 1994 (includes missing years that could affect mean discharge values).

[5] Maximum annual discharge for period of record and [year of occurrence].

[6] Minimum annual discharge for period of record and [year of occurrence].

[7] Median annual discharge calculated for period of record through 1994 (includes missing years that could affect median discharge values).

[8] Median absolute deviation.

sures of location and spread for select gage stations. The fluctuation of stream discharge about the mean and median is illustrated in the box plots presented in Fig. 4, which depict discharge variability at gage stations on the Rio Grande.

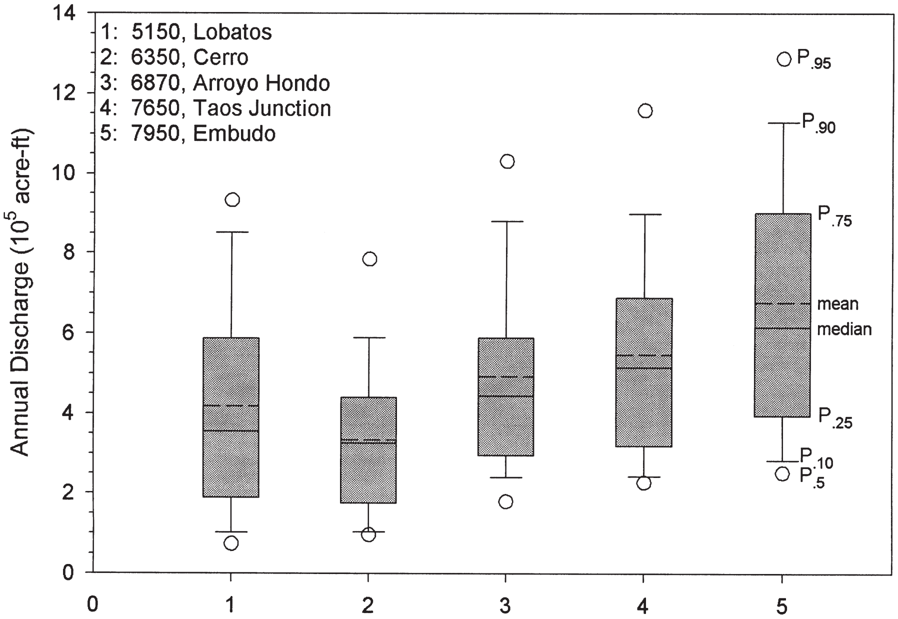

FIGURE 4—Variability of annual discharge for Rio Grande gage stations.

TABLE 4—Estimates of annual surface-water yield for the major drainage basins in Taos County based on median (average year), $P_{.25}$ (dry year), and $P_{.75}$ (wet year) discharges (all units rounded in acre-ft/yr); na = not applicable; nd = no data.

	Surface-water yield				
Drainage basin	Average year this report	Hearne and Dewey, 1988	Wilson et al., 1978	Dry year this report	Wet year this report
Costilla Creek[1]	29,000	56,500	36,548	20,600	41,100
Latir Creek[2]	3,650	na	nd	3,000	5,200
Cabresto Creek[3]	8,800	8,000	na	6,900	12,300
Red River[4]	49,700	30,400	47,151	43,900	64,900
Arroyo Hondo[5]	29,000	21,700	24,847	24,700	36,700
Rio Pueblo de Taos[6]	65,200	58,600	69,761	51,500	92,200
Embudo[7]	52,200	47,800	53,206	38,800	87,400
TOTAL	237,550	223,000	231,500	189,400	339,800

[1] Estimates based on discharge for station 5550 (Costilla Creek near Costilla).

[2] Estimates based on discharge for station 6300 (Latir Creek).

[3] Estimates based on discharges for stations 6550 (Llano Ditch near Questa) and 6600 (Cabresto Creek near Questa).

[4] Estimates based on discharges for stations 6500 (Red River near Questa), plus baseflow discharge for station 6682 (Red River below fish hatchery) (see Table 5).

[5] Estimates based on discharge for station 6750 (Arroyo Hondo near Valdez), plus baseflow discharge for station 6850 (Arroyo Hondo near Arroyo Hondo).

[6] Estimates based on discharges for stations 6900 (Rio Pueblo de Taos near Taos), 7100 (Rio Lucero), 7500 (Rio Fernando de Taos), 7550 (Rio Grande del Rancho), and 7560 (Rio Chiquito), plus baseflow discharge for station 7630 (Rio Pueblo de Taos below Los Cordovas).

[7] Estimates based on discharge for station 7900 (Embudo Creek at Dixon).

Surface-water yield

Estimates of average annual surface-water yield for the major drainage basins in Taos County, on the basis of median stream discharge at select stations for the period of record through 1994, are summarized in Table 4. The discharge data are from stations located at the most down-gradient points in the basin that are above any significant surface diversion. Estimates thus reflect basin yields for the upper, unimpaired drainages that produce most of the natural surface runoff for the county. The large stream gains along the lower reaches of Red River, Rio Hondo, and the Rio Pueblo de Taos are accounted for by incorporating estimates of baseflow from lower-reach gages (see Table 5). Estimates are also developed for "dry" and "wet" year drainage-basin yields derived from $P_{.25}$ and $P_{.75}$ discharges, respectively. Average yields compare well with previous estimates of surface runoff for Taos County (Wilson et al., 1978, 1980; Hearne and Dewey, 1988). On the basis of median stream discharges, an estimated 238,000 acre-ft of surface water originates from the major drainage basins in Taos County each year. Total surface discharge for the county is expected to vary from about 189,000 acre-ft in a dry year to as much as 340,000 acre-ft in a typical wet year.

Seasonal variability of streamflow

Seasonal variability of streamflow is evaluated using monthly discharge data, and the results can support water-management decisions regarding temporal correlation between surface-water supply and demand. Seasonal streamflow patterns are fairly uniform throughout Taos County, with minor variation between drainages. The streamflow patterns and pattern variability are controlled by the geologic, watershed, and water-storage characteristics of each drainage. Seasonal discharge estimates are summarized in Table 5 for spring (April, May, June), summer (July, August, September, October), and winter (November, December, January, February, and March) periods, each of which respectively reflect snow melt, monsoonal precipitation, and low baseflow conditions.

In all areas, stream discharges are largest during the peak snow-melt months of May and June, when between 50% and 65% of annual discharges are measured. The combined spring and summer periods (April through October), which correspond to the irrigation season in Taos County, contribute from 70% to 90% of annual stream discharges. December, January, and February are the lowest discharge months. In 1995, 102,584 acre-ft of surface water was withdrawn to serve irrigated agriculture (Wilson and Lucero, 1997). When evaluated on a county-wide scale, a sufficient surface-water supply appears to be available throughout the irrigation season to meet the agricultural demand in most years. However, when water supplies are evaluated on a monthly basis and at a drainage or river-reach scale, agricultural demands may not always be met. When low winter precipitation is followed directly by below-average summer precipitation, the surface-water supply may be insufficient to accommodate the irrigation season demand. Such local summer shortages have been recognized.

Baseflow estimates

Minimum stream-discharge values during the low-flow winter months of December through February can provide an estimate of mean annual baseflow for

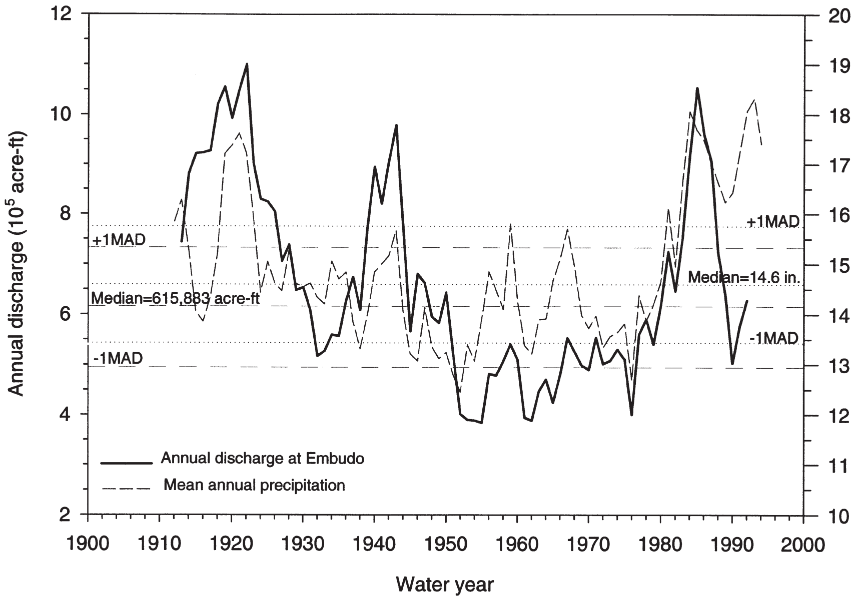

FIGURE 5—Five-year moving average of annual discharge for the Rio Grande at Embudo, and annual precipitation for Cerro, Red River, and Taos. Reference lines reflect the median of the moving average and ±one median absolute deviation (MAD).

TABLE 5—Seasonal discharge and baseflow estimates for select Taos County gage stations (all units in acre-ft) based on monthly discharge data.

Station ID[1, 2, 3]	Annual[4]	Spring[5]	Summer[6]	Winter[7]	Baseflow[8] [% of annual]
5550 Costilla Creek near Costilla[2]	28,621	13,579	12,087	2,955	2,447[8.5]
6300 Latir Creek[1]	3,511	1,687	1,142	682	420[12]
6400 Red River near Red River[1]	10,902	6,482	3,033	1,387	1,709[16]
6500 Red River near Questa[3]	29,364	16,082	8,277	5,004	2,809[9.6]
6550&6600 Cabresto Creek[2]	8,195	4,312	2,475	1,407	1,665[20]
6682 Red River below fish hatchery[3]	61,165	30,723	16,889	13,553	20,410[33]
6750 Arroyo Hondo near Valdez[1]	22,776	12,868	6,289	3,619	4,366[19]
6850 Arroyo Hondo at Arroyo Hondo[3]	15,113	7,490	2,881	4,742	5,618[37]
6900 Rio Pueblo de Taos near Taos[1]	18,618	12,807	3,264	2,547	2,454[13]
7100 Rio Lucero[1]	14,932	8,826	3,970	2,137	2,512[17]
7500 Rio Fernando de Taos[2]	2,741	1,943	303	495	22[1]
7550 Rio Grande del Rancho[2]	13,468	9,399	2,261	1,807	1,491[11]
7560 Rio Chiquito[1]	5,052	3,137	1,052	862	1,057[21]
7600 Rio Pueblo de Taos at Los Cordovas[3]	33,303	20,657	3,530	9,116	10,462[31]
7630 Rio Pueblo de Taos below Los Cordovas[3]	32,886	18,247	4,470	10,169	9,760[30]
7850 Rio Santa Barbara[1]	23,105	15,651	5,083	2,371	2,845[12]
7900 Embudo Creek at Dixon[3]	52,055	34,659	7,817	9,579	7,059[13]

the reach of stream above the station (Table 5). Stream discharge during these winter months is not significantly affected by diversion, evaporation, or runoff. The minimum instantaneous discharge during the coldest winter months should generally reflect the minimum baseflow discharge to the stream reach upgradient of the gage location. Annual baseflow discharge is thus estimated using the minimum monthly stream discharge from the lowest flow months, projected to an annual flux. These baseflow estimates vary from 1% to 37% of annual discharge, the high variability primarily attributable to differences in geologic conditions within and between the basins.

Geologic factors affecting variability of the baseflow flux include the lithology of the aquifer material in the drainage (i.e., crystalline bedrock, sedimentary bedrock, or unconsolidated alluvium) and the location of large-scale, basin-margin faults that alter aquifer geometry and control the degree of stream-aquifer interaction. The extremely low baseflow discharge (1% of annual discharge) along the Rio Fernando de Taos, for example, reflects the sedimentary lithologic character of the catchment. The sediments have a low to intermediate permeability and a relatively large aquifer storage. These physical constraints limit the degree of interaction between the stream and adjacent aquifer. In comparison, moderate to high baseflow discharges (from 9% to 20% of annual discharge) occur in the upper reaches of most other basins where fractured crystalline rocks with high permeability and relatively low aquifer storage dominate. The highest baseflow estimates (from 30% to 37%) are calculated for the lower reaches of the Red River, Rio Hondo, and the Rio Pueblo de Taos because these streams cross Santa Fe Group basin fill. Baseflow estimated for the lower Red River using this approach (33%) is consistent with seepage measurements by Bliss (1928, in Winograd, 1959), which show a gain of 31 ft^3/s, out of a total flow of 84 ft^3/s at the mouth (37%), for the 7-mi reach between the mouth and the head of Red River canyon. I propose that these extremely high ground-water accretion rates result from dramatic changes in aquifer geometry and/or depositional facies within the Santa Fe Group basin fill, produced by large-scale, rift-related faults, the locations and geometries of which are incompletely understood. The collection of additional surface and subsurface geologic data is necessary to better define these structures and their effect on surface-water/ground-water interactions.

Long-term variability of streamflow

To develop surface water as a sustainable resource over decades of time, an understanding of the character and magnitude of long-term trends and cycles in stream discharge is also important. On the basis of the last 80 yrs of stream-discharge data for the Rio Grande station at Embudo, an evaluation of streamflow variability on a decadal scale was completed. A 5-yr running average smooth was applied to both annual discharge for the Rio Grande at Embudo and to annual precipitation averaged from weather stations at Red River, Cerro, and Taos (Fig. 5) in order to highlight trends and patterns in the time-series data. Deviations in stream discharge and precipitation from "normal" or median values were evaluated using the median absolute deviation (MAD) to help classify climatic episodes as above or below normal.

On the basis of these records, it is apparent that "average" precipitation and streamflow conditions are the exception rather than the rule. In only one decadal interval, from approximately 1927 to 1939, did stream discharge vary continuously within one MAD of the median. In general, historic discharge fluctuates between periods of above normal (+1 MAD) and below normal (-1 MAD) discharge, separated by short periods of transition. The most severe dry conditions occurred between 1950 and 1964, wherein annual discharge for this 15-yr period averaged only 341,200 acre-ft or 56% of the median. Below average discharge actually prevailed for another 14 yrs through 1978, resulting in a 30-yr average discharge that was 64% of the period of record median. In comparison, the highest discharge periods were between 1914 and 1929 and between 1983 and 1987. For the 16-yr period beginning in 1914, annual stream discharge at Embudo averaged nearly 1 million acre-ft, or 150% of the median. Discharges of a similar magnitude occurred during the strong El Niño events of the mid-1980s, resulting in a 5-yr average flow that was 177% of the median.

The precipitation record is generally similar to the stream-discharge record, with precipitation highs in the early 1920s and 1980s and lows between the mid-1940s and the mid-1950s. The two records are not directly correlative, as the magnitude of stream discharge is controlled through the complex interaction of a number of basin and climatic factors (some of which are influenced by hysteretic and transient storage effects), including basin area, elevation, and geologic characteristics, stream-aquifer interactions, precipitation amount and intensity, runoff-precipitation ratio, and changes in watershed management. The magnitude of variability of precipitation over time is, by comparison, much less than for stream discharge. For example, highest precipitation was recorded during the period from 1985 to 1995 when median annual precipitation was 19.0 inches, or 130% of normal. During the drought of the 1950s, rainfall averaged 13.3 inches, or 91% of normal, for the period from 1950 to 1964.

Conclusions and recommendations

The assessment of surface-water availability and variability is a crucial first step for regional water planning in river basins that rely heavily on surface-water withdrawals for municipal, industrial, and/or agricultural uses. Accordingly, existing stream-discharge data of adequate geographic coverage and duration are a necessity. Sufficient stream-discharge data exist to support a surface-water assessment in all drainage basins in Taos County except the Rio Pueblo de Picuris and the Rio Santa Barbara, tributaries of Embudo Creek. Both tributaries have active and well-placed gage stations, but the discharge data are of insufficient duration to provide a reliable base for evaluation. Previous analyses of these existing data have focused on regional analysis, flow-(flood-) frequency analysis, and flow-duration analysis, and accordingly, the supporting statistical summaries of discharge data have always provided conventional measures of the average discharge value and its spread. Planning decisions that affect water-resource development require a more accurate measurement of normal flow. This assessment uses median, $P_{.25}$, and $P_{.75}$ values to estimate "average," "dry," and "wet" year surface-water yields.

Additional discharge measurements are required, however, to support evaluations of surface-water/ground-water interactions and for a more precise quantification of baseflow and surface-water yields. These data can be obtained by measuring discharge at several ungaged intervals along a channel reach during periods of baseflow. Measurements of temperature and specific conductance should be made concurrently. Data from such seepage runs are critical for identification of channel gains or losses and thus help in the interpretation of other regional ground-water data and in validation of ground-water flow models.

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