IS APRIL TO JULY RUNOFF REALLY DECREASING IN THE WESTERN UNITED STATES?

By Kenneth L. Wahl[1]

INTRODUCTION

Global warming has been the topic of a great deal of heated discussion and debate in recent years, both in the lay press and in scientific journals. The debate is about whether we are beginning to detect signs of a buildup of greenhouse gases on a global scale. A major part of the debate concerns the possible effects on climate and on the future availability of water resources. The ongoing drought in California has added impetus to the debate, serving notice of the serious consequences of any prolonged decrease in the availability of adequate water supplies.

The progressive increase in carbon dioxide levels since at least the mid-1950's has been widely reported (Committee on Geology and Climate, 1978, U.S. Department of Energy, 1990). This has produced a flurry of activity in meteorological circles as attempts are made to project the effect on global temperature patterns if carbon dioxide, methane, and other greenhouse gases are in fact increasing at the reported rates. General circulation models (GCMs) are being used to estimate projected patterns for global temperature and climate changes. These models can then be linked with hydrologic models to estimate possible effects on hydrologic processes. Unfortunately, the grid scale on most GCMs is so coarse that orographic and other regional or local effects that are extremely important to the hydrologic processes are often obscured. We can, however, examine existing climatic and hydrologic data for evidence of trends that would be consistent with such changes in climate.

Roos (1987) examined both total water-year runoff and April-July runoff for the Sacramento Four Basin Index for trends over the past 80 years. The Sacramento Four Basin Index is the sum of the estimated unimpaired flow of the Sacramento, Feather, Yuba, and American Rivers; unimpaired flow is the estimated runoff that would have occurred if there had been no upstream storage or diversion of flow. Total water-year runoff appeared to be increasing slightly, but confidence in that trend was low. He also examined the trend of the April-July runoff expressed as a percentage of the annual runoff; Roos concluded (1987, p.22) "Since 1950 the snowmelt portion (April through July) of the total water year runoff has been decreasing. A similar trend, although not as large, was noted in the higher elevation Kings and San Joaquin River watersheds. These changes may be an indication of climatic change."

Karl and Riebsame (1989) studied the effect of fluctuations in temperature and precipitation on runoff across the United States. They used runoff for rivers that had been only minimally influenced by humans and found that the effects of temperature on streamflow were minimal, but the effects of precipitation changes were amplified in runoff. They concluded that confidence in hypothetical changes in runoff due to global warming would be directly dependent on reliable projections of precipitation changes.

Cayan (1990) examined trends in seasonal runoff from 63 streams in Western North America and Hawaii. The year was separated into four seasons with the spring runoff season represented by the May through July (MJJ) runoff. Cayan concluded (1990, p.1) "...that many streams in the West have a significant decline in spring-early summer fractional runoff as seen from a network of river gauging stations from Alaska south to Arizona and from California east to the Rockies. The cause of the trends at these stations is complex, involving both precipitation and temperature." With regard to the trend toward decreasing MJJ fractional runoff, Cayan found (1990, p.3) "Including the Sierra stations, 28 of the 63 total streams had 'significant' trends. Only 5 of the 63 total stations show significant increasing trends." In a related study, Riddle and others (1990) presented correlations between fractional runoff and climatic variables for selected California and Oregon river basins. They also represented the snowmelt-runoff season with the fractional runoff for May through July.

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Pupacko (1991) used mass diagrams (cumulative runoff versus time) to examine trends in the 1939-90 monthly and water year runoff for the West Fork of the Carson River, which drains east from the Sierra Nevada. He used total volume for each month rather than the fractional runoff and found that both the amount and variability of annual runoff have increased since the mid-1960s. Runoff also increased for most of the individual months. However, runoff for April and May appeared to be essentially unchanged. He noted that April-June runoff represents about 65 percent of the annual runoff.

This paper has three primary objectives: (1) To evaluate the ramifications of using fractional runoff rather than total runoff to define trends in runoff; (2) to analyze additional streamflow data for the presence and extent of trends in annual and seasonal runoff volume for the conterminous Western United States; and (3) to examine the influence of the current California drought on indicators of trend.

ANALYSIS

Site Selection

Much of the previous study of trends in streamflow in the Western United States has, by necessity, included data from gaging stations that are influenced by significant amounts of regulation and/or diversions. Riddle and others (1990) acknowledged that many river basins have undergone change over the last 80 years. They omitted stations with recognizable steps in the data under the assumption that such steps reflected regulation or diversions. In the absence of such steps, long records that met geographical coverage requirements were used. Roos (1987) worked with unimpaired flow data--data that had been reconstructed to remove the effect of upstream regulation or diversion.

Including reconstructed or regulated record leaves open the possibility that the process of reconstructing the record may induce a trend (or may have obscured an existing trend). To eliminate that possibility, streamflow gaging records used in this study were selected to represent natural conditions. Most of the gaging stations selected have no known regulation or diversions. Those that have known regulation or diversions were reviewed to determine if the influence was sufficiently large to warrant eliminating the record from the analysis; each record used was considered by the office operating the gage to be suitable for use in trend analysis. In addition, the stations were required to have a continuous record (all years complete) dating back to at least the mid-1950s to include the period of rapid increase of atmospheric carbon dioxide.

Records for 58 gaging stations from 10 western States were selected for analysis. The stations provide a representative sample of natural flow conditions from the broad geographical area. Locations of the gaging stations are shown on Figure 1; the stations and periods of record used are shown in Table 1. No stations were included for Arizona as none of the stations meeting the criterion had significant amounts of snowmelt runoff. Only those portions of the record that were continuous from year to year were used in the analysis. The records used in the study had a median length of 60 years and ranged in length from 37 to 81 years. The analysis used about 3,500 station-years of record.

This analysis follows the lead of Roos (1987) and focuses on spring-time runoff as that occurring from April through July. The conclusions would not have changed if the spring-runoff period had been defined instead by May-July runoff. The April-July fractional runoff is the total runoff volume for April, May, June, and July (AMJJ) divided by the total annual runoff for the water year (ANN). The resulting variable for fractional runoff (AMJJ/ANN) is a dimensionless ratio that can range from 0 to 1.0. In addition, annual and seasonal runoff values were normalized as follows: 1) the annual runoff for each individual water year was divided by the average annual runoff for the period used; 2) the sum of the runoff for April, May, June, and July was divided by the average of the sums of runoff for those 4 months; and 3) the runoff for the remaining 8 months (where analyzed) was divided by the long-term average for those 8 months. Thus, the variables used in the trend tests are dimensionless ratios and, except for April-July fractional runoff, average 1.00.

For most of the streamflow gages used in this study, snowmelt runoff is a principal component of the annual runoff. The median value of the ratio AMJJ/ANN is 0.66, and 75 percent of the values are greater than 0.49. However, several records in Northern

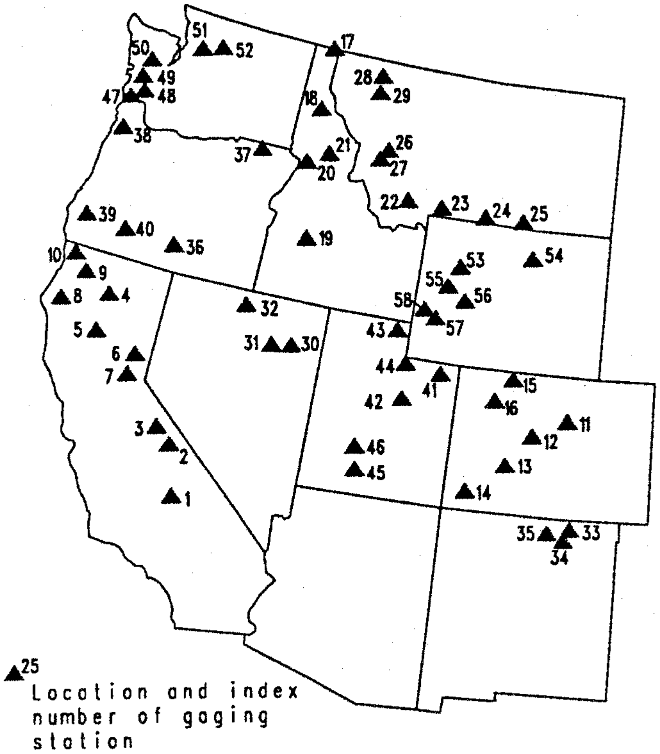

Figure 1. locations of streamflow gaging-stations used in the trend analyses.

California and Western Oregon and Washington have AMJJ/ANN ratios of less than 0.25. These were included to determine whether these basins had trends that were similar to basins in which snowmelt is the dominant process in annual runoff.

Interpretation of Trends in Ratios

There are legitimate reasons for analyzing changes in the ratio of seasonal (within-year) runoff to annual runoff. For example, operating rules for reservoirs may be predicated on assumptions regarding the expected distribution of runoff volume throughout the year. If within-year distribution changes, revisions in the operating rules may be necessary. There are, however, problems inherent in using ratios (fractional runoff) in statistical analyses. Use of ratios in correlation and regression analyses can produce spurious correlation coefficients (Pearson, 1897, Benson, 1965, Kenny, 1982). The presence of such spurious correlation by itself does not necessarily invalidate the resulting regression relations; but interpretation of the results should be restricted to the ratios and should not be extended to the variables that form the ratio (Gilroy and others, 1990, Wahl, 1990).

Use of ratios in trend analyses presents a related, but somewhat different, problem. Trend analysis essentially represents a form of correlation in which one variable is time. Interpretation of trends in fractional runoff poses a dilemma; do the indicated trends represent a trend in seasonal runoff, or might they reflect a more complex interaction between the two variables used to form the ratio? Given a ratio between April-July runoff and annual runoff, the ratio will show a decrease with time under the following four conditions:

1. April-July runoff decreases and annual runoff either remains constant or increases.
2. April-July runoff decreases and annual runoff decreases less rapidly.
3. April-July runoff remains unchanged and annual runoff increases.
4. April-July runoff increases and annual runoff increases more rapidly.

Table 1.--Streamflow records used in this study

Index Number	USGS Number	Name	Drainage Area (sq km)	Water Years Used	Years	Average Ratio (AMJJ/ANN)
1	11186001	Combined flow of Kern River and Kern River No. 3 Canal near Kernville, CA	2,191	1912-89	78	0.651
2	11230500	Bear Creek near Lake Thomas A. Edison, CA	136	1922-89	68	.805
3	11264500	Merced River at Happy Isles Bridge near Yosemite, CA	469	1916-89	74	.836
4	11342000	Sacramento River at Delta, CA	1,101	1945-89	45	.312
5	11382000	Thomes Creek at Paskenta, CA	526	1921-89	69	.350
6	11413000	North Yuba River below Goodyears Bar, CA	648	1931-89	58	.525
7	11427000	North Fork American River at North Fork Dam, CA	886	1942-89	48	.450
8	11477000	Eel River at Scotia, CA	8,063	1917-89	73	.170
9	11522500	Salmon River at Somes Bar, CA	1,945	1928-89	62	.413
10	11532500	Smith River near Cresent City, CA	1,577	1932-89	58	.202
11	06710500	Bear Creek at Morrison, CO.	425	1920-90	71	.590
12	07083000	Halfmoon Creek near Malta, CO.	61	1947-89	43	.745
13	09124500	Lake Fork at Gateview, CO.	865	1938-90	53	.747
14	09165000	Dolores River below Rico, CO.	272	1952-89	38	.796
15	09245000	Elkhead Creek near Elkhead, CO.	166	1954-90	37	.920
16	09304500	White River near Meeker, CO.	1,955	1910-90	81	.616
17	12306500	Moyie River at Eastport, ID	1,476	1930-90	61	.833
18	12414500	St Joe River at Calder, ID	2,668	1921-89	69	.701
19	13185000	Boise River near Twin Springs, ID	2,150	1912-90	79	.718
20	13317000	Salmon River at White Bird, ID	35,095	1920-90	71	.705
21	13336500	Selway River near Lowell, ID	4,947	1930-88	59	.775
22	06019500	Ruby River above Reservoir, near Alder, MT.	1,393	1939-90	52	.569
23	06191500	Yellowstone River at Corwin Springs, MT.	6,786	1911-90	80	.689
24	06207500	Clarks Fork Yellowstone River near Belfry, MT	2,989	1922-90	69	.778
25	06289000	Little Bighorn River at State Line near Wyola, MT	500	1940-90	51	.636
26	12330000	Boulder Creek near Maxville, MT.	185	1940-89	50	.694
27	12332000	Middle Fork Rock Creek near Philipsburg, MT.	319	1938-89	52	.749
28	12358500	M F Flathead River near West Glacier, MT.	2,901	1940-89	50	.783
29	12370000	Swan River near Bigfoot, MT.	1,738	1923-89	67	.675
30	10316500	Lamoille Creek near Lamoille, NV	67	1944-89	46	.875
31	10322500	Humbolt River at Palisade, NV	12,976	1914-89	76	.670
32	10329500	Martin Creek Paradise Valley, NV	445	1923-89	67	.623
33	07203000	Vermeyo River near Dawson, NM	780	1928-89	62	.538
34	07208500	Rayado Creek at Sauble Ranch, near Cimarron, NM	168	1931-89	59	.634
35	08267500	Rio Hondo near Valdez, NM	94	1935-89	55	.656
36	10384000	Chewaucan River near Paisley, OR	712	1925-89	65	.642
37	14010000	South Fork Walla Walla River near Milton-Freewater, OR	163	1932-89	58	.429
38	14301500	Wilson River near Tillamook, OR	417	1932-89	58	.166
39	14325000	South Fork Coquille River at Powers, OR	438	1930-89	60	.172
40	14328000	Rogue River above Prospect, OR	808	1924-89	66	.415
41	09299500	Whiterocks River near Whiterocks, UT	293	1930-90	61	.652
42	09310500	Fish Creek above Reservior near Scofield, UT	156	1939-90	52	.830
43	10113500	Blacksmith Fork above Utah Power & Light Company's Dam near Hyrun, UT	681	1919-90	72	.506
44	10128500	Weber River near Oakley, UT	420	1910-90	81	.776
45	10174500	Sevier River at Hatch, UT	881	1940-90	51	.546
46	10234500	Beaver River near Beaver, UT	236	1915-90	76	.677
47	12010000	Nasalle River near Naselle, WA	142	1930-89	60	.164
48	12020000	Chehalis River near Doty, WA	293	1940-89	50	.159
49	12035000	Satsop River near Satsop, WA	774	1930-89	60	.186
50	12056500	North Fork Skokomish River below Staircase Rapids near Hoodsport, WA	148	1925-89	65	.359
51	12186000	Sauk River above White Chuck River near Darrington, WA	394	1929-89	61	.499
52	12451000	Stehekin River at Stehekin, WA	831	1928-89	62	.702
53	06218500	Wind River near Dubois, WY	601	1946-89	44	.690
54	06311000	North Fork Powder River near Hazelton, WY	63	1947-90	44	.826
55	09188500	Green River at Warren Bridge, near Daniel, WY	1,212	1932-89	58	.722
56	09203000	East Fork River near Big Sandy, WY	205	1939-90	52	.886
57	09210500	Fontenelle Creek near Herschler Ranch, near Fontenelle, WY	394	1952-90	39	.693
58	10032000	Smiths Fork near Border, WY	427	1943-90	48	.688

Similarly, there are four conditions under which the ratio of seasonal runoff to annual runoff could increase while the volume of seasonal runoff was either unchanged or was decreasing. Under conditions 3 and 4 above, the ratio has decreased but April-July runoff has not. Given those conditions, a conclusion that April-July runoff had decreased would be spurious. Because of this ambiguity, interpretations of trend based on ratios (fractional runoff) are limited to the ratios themselves and cannot be extended to the individual components of the ratios.

The principles discussed above are demonstrated by the example for Bear Creek above Lake Thomas A. Edison, California (Figure 2). The patterns shown in Figure 2 for Bear Creek are typical of the California gaging stations examined. The ratio of the April-July

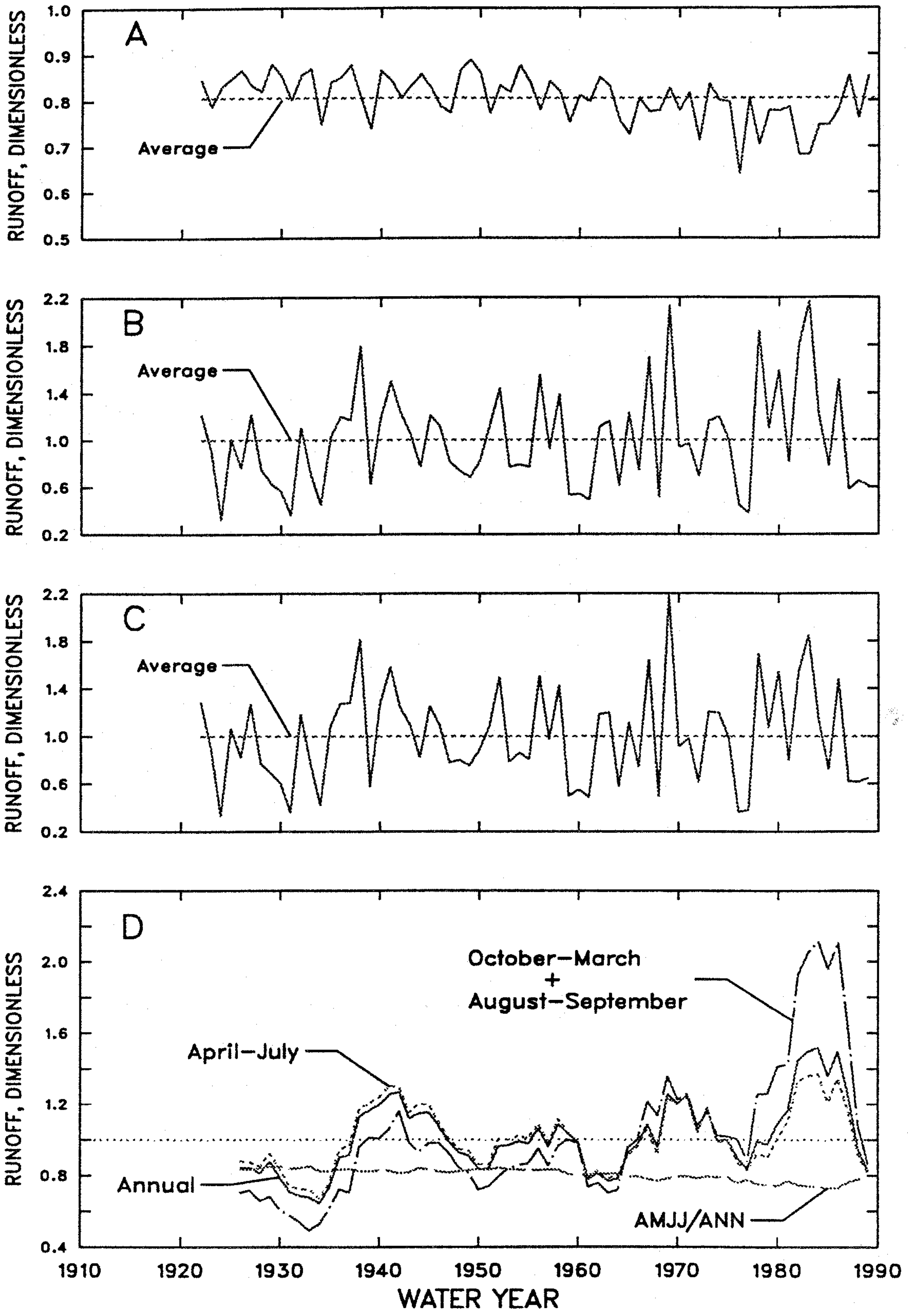

Figure 2. Runoff for Bear Creek near Lake Thomas A. Edison, California for A) April-July fractional runoff; B) Annual runoff; C) April-July runoff; and D) 5-Year moving averages of seasonal and annual runoff and of April-July fractional runoff.

runoff divided by the annual runoff (Figure 2A) shows a noticeable decline with time, beginning sometime between 1955 and 1960. However, the annual runoff (Figure 2B) and the April-July runoff (Figure 2C), both expressed as ratios to their long-term averages, show cyclical patterns, but no discernable long-term trend. Superimposing 5-year moving averages (Figure 2D) shows that the April-July runoff and annual runoff are in phase, but the relative amplitudes appear to have changed over time. There is nothing in the moving averages to suggest that either annual or April-July runoff has declined; rather, annual runoff has had a greater increase recently in large runoff years, and perhaps a smaller decrease in small runoff years, than has April-July runoff.

Procedures Used in Tests for Trend

Two related procedures were used in this paper to test for trends. A form of a procedure commonly called Kendall's tau (Kendall, 1938, 1975) was used to test for the presence of trends. In addition, a Kendall slope estimator (Sen, 1968) was used to estimate trend magnitude. See Hirsch and others (1982) for a description of the slope estimator. The procedures are designed to identify whether monotonic changes are occurring with time and to estimate the rate of change. They are not intended for testing a hypothesis that a change occurred at a specific time. However, if such a change is suspected, the data can be subdivided at the point the change is believed to have begun. The individual periods can then be tested independently, assuming that the subdivided record lengths are sufficiently long to permit testing. Although the methods are exploratory, they can be used in this manner in combination with other techniques (such as graphical exploration) to investigate hypotheses of timing and cause. The power of the Kendall tau and the seasonal Kendall slope estimator is that they are non-parametric; they do not require that the test variable be normally distributed. The tests are insensitive to the presence of individual outliers and are applicable even when the record under test has values missing.

Kendall's tau is determined in the following manner: Given a time series $x_1, x_2,$ ------- $, x_n$, of length n, the differences $d_{ij} = x_i - x_j$ are determined for $1 \leq j < i \leq n$. There are n(n-1)/2 differences. If P is the number of positive differences and N is the number of negative differences, then:

$$\text{tau} = (P - N) / [n(n-1)/2] \qquad (1)$$

If all differences are positive, tau = +1; if all the differences are negative, tau = -1. However, if the number of positive differences is equal to the number of negative differences (P = N), tau = 0. Tau is, therefore, a measure of the correlation between the series of x_i and time.

Slopes between individual pairs of x_i are computed as $d_{ij}/(i-j)$, and the Kendall slope estimator is defined as the median of the slopes. The slope estimator is based on the same set of differences as tau and, therefore, can be computed concurrently.

In application, the procedure tests the null hypothesis that the data are random samples that are identically distributed and not time dependent. Although the hypothesis is based on the assumption that the data are identically distributed, no assumption is required regarding the underlying distribution. If the test shows tau is not statistically different from 0, the null hypothesis is accepted, and the data are considered to be free from time trends. However, if tau is different from 0 at the specified probability level, the null hypothesis is rejected, and a time trend is confirmed; the sign of tau indicates the direction of the trend. Probabilities of the tau distribution are given in statistics texts, including Gibbons (1976).

Where trends are indicated, the apparent trend can be described in an equation of the form

$$Q = A + St, \qquad (2)$$

where Q is discharge; S is the Kendall slope estimator; t is time, in years (t=0 at the first year of record); and A is a constant, defined as the value that causes the equation to pass through the median value of Q at the midpoint of the time period. Although the above equation is linear, the procedures do not test whether the trends are linear.

Discussion of Results

Table. 2--Summary Statistics on Kendall Tau Tests for Trend.
[Slope is in percent of the median per year; P is the probability associated with tau; trends significant at the 90-percent level (P less than or equal to 0.10) are marked with an asterisk]

Index		April-July Fractional Runoff				Annual Runoff				April-July Runoff			
Number	State	Median	Slope	Tau	P	Median	Slope	Tau	P	Median	Slope	Tau	P
1	CA	0.665	-0.1	-0.15	0.05*	0.825	0.1	0.04	0.64	0.824	0.0	0.00	0.97
2	CA	.814	-.2	-.35	.00*	.955	.2	.07	.38	.978	.1	.03	.76
3	CA	.846	-.1	-.23	.00*	.980	.1	.03	.75	1.011	-.1	-.02	.83
4	CA	.338	-.7	-.25	.02*	.990	.0	.01	.92	.900	-.7	-.16	.13
5	CA	.287	-.5	-.14	.08*	.860	.6	.12	.14	.840	-.1	-.03	.72
6	CA	.524	-.5	-.25	.01*	.950	.4	.09	.34	.961	-.1	-.03	.75
7	CA	.446	-.7	-.23	.02*	.895	-.3	-.04	.72	.948	-.8	-.16	.12
8	CA	.142	-.8	-.22	.01*	.870	.7	.18	.02*	.857	-.2	-.05	.54
9	CA	.405	-.5	-.21	.01*	.910	.5	.15	.09*	.974	-.1	-.04	.64
10	CA	.177	-.5	-.15	.09*	.985	.2	.07	.45	.933	-.4	-.13	.16
11	CO	.582	.1	.02	.80	.830	-.3	-.08	.33	.808	-.2	-.04	.61
12	CO	.750	.0	-.06	.56	.950	.1	.05	.62	.976	.1	.04	.75
13	CO	.752	-.1	-.14	.13	.970	-.3	-.09	.35	.975	-.4	-.09	.33
14	CO	.801	-.2	-.16	.16	.980	.7	.12	.31	.938	.4	.07	.55
15	CO	.926	-.1	-.24	.03*	1.090	1.1	.18	.11	1.101	.9	.15	.19
16	CO	.631	.0	.04	.62	.990	-.1	-.06	.44	.971	-.1	-.04	.62
17	ID	.850	.0	-.08	.35	1.000	.0	.00	.97	1.036	.0	-.01	.95
18	ID	.721	-.1	-.09	.30	.980	.0	.01	.95	1.010	-.1	-.03	.75
19	ID	.728	-.1	-.19	.02*	.980	.1	.06	.42	1.022	.1	.02	.80
20	ID	.712	-.1	-.12	.13	1.000	.3	.15	.06*	1.023	.3	.11	.18
21	ID	.790	-.1	-.16	.08*	1.020	.2	.10	.28	1.003	.1	.07	.45
22	MT	.575	.1	.08	.39	.960	.6	.24	.01*	.913	.8	.20	.04*
23	MT	.698	.0	.07	.34	.980	.0	.03	.68	.980	.0	.03	.66
24	MT	.785	.0	-.03	.69	.960	.1	.03	.67	.980	.1	.02	.81
25	MT	.638	.1	.07	.45	.950	.0	-.01	.95	.974	.0	.01	.95
26	MT	.710	-.1	-.13	.18	.980	-.1	-.04	.72	1.006	-.2	-.07	.47
27	MT	.764	-.1	-.11	.26	1.025	.0	.01	.92	1.027	-.1	-.02	.83
28	MT	.788	-.1	-.07	.47	1.000	-.1	-.04	.71	1.002	-.2	.07	.50
29	MT	.684	-.1	-.18	.03*	1.000	.2	.11	.18	.994	.1	.06	.44
30	NV	.884	-.1	-.24	.02*	1.035	.2	.05	.64	1.050	.2	.05	.66
31	NV	.704	-.2	-.11	.18	.860	.7	.14	.06*	.862	.5	.10	.19
32	NV	.632	-.1	-.07	.44	.800	1.0	.20	.02*	.855	.7	.15	.08*
33	NM	.558	-.1	-.04	.61	.840	-.1	-.02	.83	.734	-.3	-.04	.63
34	NM	.690	-.1	-.06	.48	.790	.0	-.01	.94	.755	-.2	-.03	.77
35	NM	.673	-.2	-.13	.15	.920	-.4	-.11	.23	.830	-.8	-.12	.20
36	OR	.642	-.2	-.14	.11	.900	.9	.22	.01*	.961	.6	.15	.08*
37	OR	.436	-.3	-.26	.00*	1.015	.0	.01	.95	.984	-.2	-.10	.29
38	OR	.156	.2	.06	.49	1.000	-.4	-.16	.08*	.947	-.2	-.08	.38
39	OR	.154	-.1	-.04	.69	.970	.2	.07	.42	.907	.0	.01	.91
40	OR	.407	-.2	-.11	.18	.980	.4	.19	.02*	1.035	.1	.05	.53
41	UT	.667	.0	.05	.60	.980	.1	.03	.71	.923	.2	.05	.58
42	UT	.884	.0	-.07	.44	.930	.4	.08	.38	.926	.4	.07	.49
43	UT	.518	-.1	-.05	.52	.935	.3	.08	.34	.956	.2	.07	.39
44	UT	.773	.0	-.09	.26	.980	-.2	-.09	.26	.997	-.2	.08	.32
45	UT	.544	-.1	-.01	.88	.920	.0	-.01	.95	.843	.0	-.01	.93
46	UT	.688	-.1	-.09	.27	.955	-.3	-.11	.16	.947	-.3	-.10	.23
47	WA	.154	.1	.02	.78	.950	-.1	-.06	.47	.990	.0	.01	.94
48	WA	.146	.0	.01	.94	.950	.0	-.02	.81	.959	.1	.03	.77
49	WA	.176	-.1	-.03	.71	.975	.1	.06	.49	.946	.1	.07	.41
50	WA	.350	-.1	-.06	.48	1.020	.3	.15	.07*	.980	.1	.03	.71
51	WA	.498	-.2	-.15	.09*	.980	.1	.05	.60	1.000	-.1	-.05	.58
52	WA	.713	-.1	-.11	.20	1.000	.1	.03	.72	1.007	.0	-.02	.79
53	WY	.700	.0	-.03	.81	.960	-.1	-.03	.78	.962	-.2	-.05	.65
54	WY	.838	.0	-.07	.54	.935	.1	.01	.92	.918	.1	.01	.91
55	WY	.733	-.1	-.11	.23	.995	.1	.03	.72	1.004	.0	.00	.98
56	WY	.894	.0	-.07	.48	.975	.2	.05	.59	.996	.1	.05	.59
57	WY	.718	.0	-.01	.95	.910	-.4	-.08	.47	.819	.4	.06	.60
58	WY	.703	.0	-.04	.68	.990	.0	.00	.98	.980	-.1	-.01	.94

Trend tests were conducted separately for the April-July fractional runoff (AMJJ/ANN), the annual runoff, and the April-July runoff. The results of those tests are summarized in Table 2 above. The values shown for slope are expressed as a percentage of the median value per year. Because the average values of the statistics for annual and April-July runoff were 1.00, median values that differ significantly from 1.00 indicate non-normality. A trend was considered to be in evidence when the null hypothesis was rejected for a two-tailed test at the 90-percent confidence level (probability equal to or less than 0.10).

The results in Table 2, if viewed out of context, appear to be contradictory. For April-July fractional runoff, 17 records indicated significant negative trends, and none indicated significant positive trends. All 10 California records were included in the 17 as were 2 for Idaho; the remaining 5 were in 5 different States. On the other hand, 9 records from 6 states had significant positive trends for annual runoff; only one (in Oregon) had a significant negative trend. Only 3 records, 1 each in Montana, Nevada, and Oregon, showed significant trends for April-July runoff; all 3 trends were positive.

If a large part of the trend for April-July fractional runoff is produced by a trend in April-July runoff, correlation between Kendall's tau for those variables would be large. But the correlation between April-July fractional runoff and April-July runoff is only 0.22 (see Figure 3A). A linear regression fit to those data would explain only 5-percent of the sample variance; in other words, the tau values are essentially unrelated. The correlation between tau values for April-July runoff and annual runoff is 0.59 (see Figure 3B); a linear regression would explain 35-percent of the sample variance.

The distributions of the probabilities and tau values from Table 2 are summarized in Figure 4. Probability for a specific value of tau is a function of both the distribution (normal) and sample size. Because the number of years of record were not equal for all records, the data points in Figure 4 do not form a perfectly smooth bell-shaped curve. The figure is useful, however, as it facilitates direct comparison of both the number and the statistical significance of indicated positive and negative trends. Points that are below the dotted line (probability = 0.10) are statistically significant.

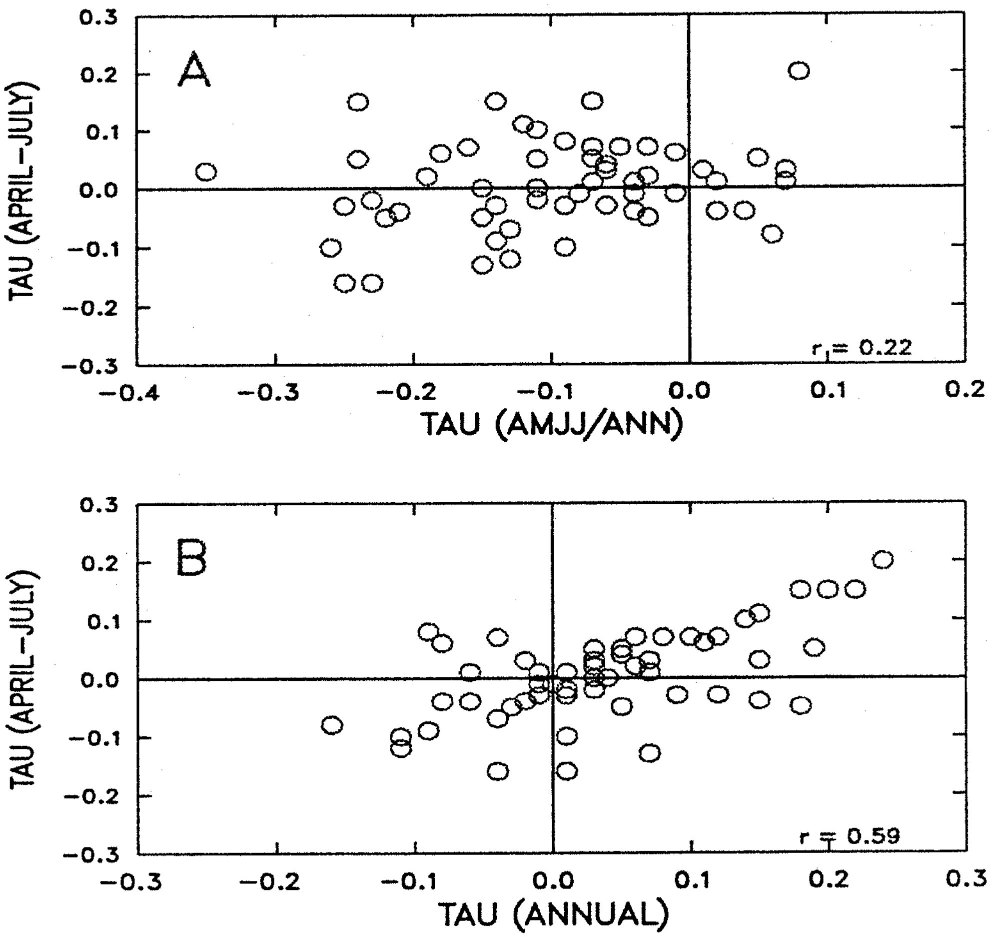

Figure 3. Relationships between: A) Tau for April-July runoff and tau for April-July fractional runoff; and B) tau for April-July runoff and tau for annual runoff.

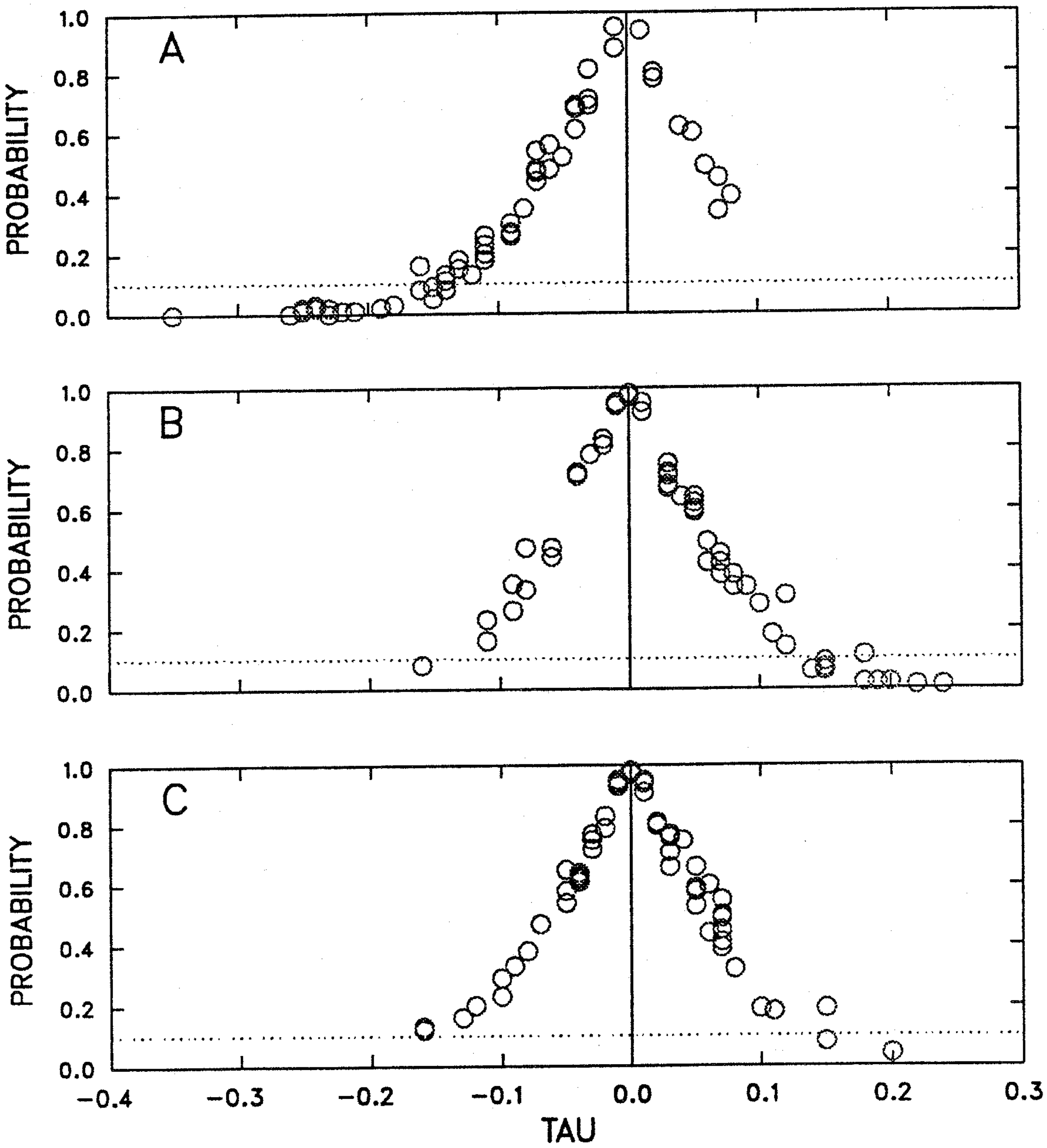

Figure 4. Distribution of values for probability and tau for: A) April-July fractional runoff; B) annual runoff; and C) April-July runoff. [Values that are below the dotted line at probability = 0.10 are statistically significant.]

The dichotomy between the relationships for April-July fractional runoff (Figure 4A) and the comparable relationships for annual runoff (Figure 4B) and April-July runoff (Figure 4C) is pronounced. Looking only at the signs of computed trends for the 58 records, 49 are negative for April-July fractional runoff; only 18 are negative for annual runoff; and 26 are negative for April-July runoff. All statistically significant trends for April-July fractional runoff were negative, but only one of the significant trends for annual and April-July runoff was negative. The lack of agreement between those relations reinforces the conviction that trend results for the April-July fractional runoff (a ratio) cannot be used to draw conclusions about trends in the components of the ratio.

The strong trend in April-July fractional runoff in California was not reflected in either annual or April-July runoff volume. Therefore, trend tests were done for the sum of the runoff for October-March plus August and September. Those results are shown in Table 3. All 10 stations show positive trends, and 6 of the 10 increases are statistically significant.

Table 3.--Summary Statistics on Kendall Tau Tests for Trend for California for the Sum of Runoff for the Months of October-March and August-September. [Slope is in percent of the median per year; P is the probability associated with tau; trends significant at the 90-percent level are marked with an asterisk]

Index Number	Water Years Used	Years	October-March + August-September Runoff (Dimensionless) Median	Slope	Tau	P
1	1912-89	78	0.845	0.4	.11	.15
2	1922-89	68	.861	.9	.24	.00*
3	1916-89	74	.874	.6	.15	.06*
4	1945-89	45	.983	.4	.10	.35
5	1921-89	69	.798	.9	.18	.03*
6	1931-89	58	.834	.8	.16	.07*
7	1942-89	48	.746	.3	.04	.68
8	1917-89	73	.859	.9	.23	.00*
9	1928-89	62	.858	.9	.23	.01*
10	1932-89	58	.941	.4	.13	.16

<u>Influence of Current Drought on Trend Tests</u>

Tests for trend are, by their nature, sensitive to extreme events that occur at either end of the sequence of data under test. California is currently experiencing a major drought that began near the end of the 1986 water year. In order to test for sensitivity to the drought, the data for 1987-89 was deleted, and the trend tests were rerun for the 10 California gaging stations (see Table 4). Using the full period (through 1989), 8 of the 10 gages showed negative trends in April-July runoff, but none were statistically significant. Without 1987-89, only 3 records show a negative trend; again, none of the trends for April-July runoff were statistically significant. Annual runoff for the entire period was increasing significantly at 2 of the 10 stations; after elimination of 1987-89, 5 records had significant increases, and tau (slope) was positive for annual runoff at all California stations tested.

Table 4.--Summary Statistics on Kendall Tau Tests for Trend for California with 1987-89 Drought Years Omitted. [Slope is in percent of the median per year; P is the probability associated with tau; trends significant at the 90-percent level are marked with an asterisk]

			Annual Runoff				April-July Runoff			
Index Number	Water Years Used	Years	Median	Slope	Tau	P	Median	Slope	Tau	P
1	1912-86	75	0.840	0.3	0.09	0.26	0.844	.2	0.06	0.47
2	1922-86	65	1.000	.5	.14	.09*	0.992	.3	.08	.32
3	1916-86	71	1.010	.3	.08	.30	1.028	.1	.04	.63
4	1945-86	42	1.010	.4	.09	.39	0.976	-.4	-.08	.46
5	1921-86	66	0.890	.9	.16	.05*	0.861	.1	.02	.81
6	1931-86	55	0.980	.8	.16	.08*	0.982	.2	.04	.71
7	1942-86	45	0.960	.3	.04	.67	0.973	-.4	-.08	.42
8	1917-86	70	0.900	1.0	.23	.00*	0.876	.0	.00	.98
9	1928-86	59	0.910	.8	.21	.02*	0.993	.1	.01	.88
10	1932-86	55	0.990	.4	.14	.13	0.953	-.4	-.09	.33

CONCLUSIONS

The title of this paper posed the question, is April-July runoff really decreasing in the Western United States? The answer, based on analysis of about 3,500 station years of natural-flow record from 58 gaging stations in 10 States, is that there is no evidence to support such a conclusion. Tests for trend produced statistically significant results for only 3 records, and those trends showed increasing runoff. Evaluation of the entire period of record suggests a decline, although not statistically significant, in April-July runoff in California; Kendall's tau was negative for 8 of the 10 California records. The tests for trend were unduly influenced by the current drought (because it occurred at the end of the period tested). Reanalysis of the California data, excluding data for the drought years (1987-89) produced positive tau values for April-July runoff at 7 of the 10 records. Median length of the California records without 1987-89 was 62 years.

There is evidence that annual runoff has increased at selected locations. Statistically significant positive trends were found for 9 of the records, and only 1 record showed a significant decrease. However, there was little evidence of a regional pattern in the increases; the 10 records were distributed over 6 States.

There is strong evidence that the April-July contribution (fractional runoff) to annual runoff is decreasing in California. All 10 of the records tested for California showed a significant decline in this ratio. The other 7 records that showed a significant decline were distributed across 6 States. There is no evidence to support a conclusion that this is produced by a diminution of the April-July runoff as none of the 17 sites showed a statistically significant decline in April-July runoff. Seven of the 17 sites had increases, though not statistically significant, in April-July runoff. Furthermore, only 2 of the 17 sites show a statistically significant increase in annual runoff.

The apparent decline in April-July fractional runoff in California is not pervasive and is evidently a result of complex interaction between the components of the ratio. Although there is little evidence of a decline in April-July runoff, there is evidence of a trend toward increased runoff in California for the remainder of the year.

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