Appendix E. A Test for Random Peaks.

A usual test for randomness is to check each series of annual peaks for a statistically significant linear correlation, i.e., a trend (Thomas and others, 1993; Wiley and others, 2000). A significant trend suggests that systematic, non-random changes in peak discharge characteristics are occurring in time. A trend test is not definitive; it is cause for investigation, not necessarily for the elimination of a gaging station from the analysis.

The peak discharges from the 376 gaging stations were tested for linear correlation. The resulting information was analyzed in two ways: (1) to check for regional, climate dependent trends, and (2) to check for local trends resulting from significant physical changes to a watershed. Local trends can be caused by changes in land use or water management as well as by natural changes such as a volcanic eruption. Local trends that can be attributed to physical changes in the watershed may require all or part of a gaging station's period of record to be removed from consideration.

Almost all gaging station records exhibit some degree of linear correlation. Most of these trends result from natural random variation in peak flows, not from either long-term climate change or physical changes to the watershed. A statistical test determines which of the trends is significant, that is, the least likely to have occurred by chance. These unlikely trends represent the gaging station records to be investigated.

A significant trend does not necessarily mean a series of peaks is non-random. For any group of gaging stations, a few of the annual series will have significant trends by chance. The level of significance of the statistical test determines how many of these significant but chance trends are to be expected. For example, for a 0.05 level of significance, about five percent of stations should show a significant trend. Although all significant trends should be investigated for physical changes to the gaging station's watershed, a regional trend requires that the number of significant trends is greater than is expected by chance.

In the regional analysis, no consistent long-term trend was found, although there is evidence of a regional fluctuation of peak discharges between wet and dry periods. This fluctuation led to a higher than expected number of significant trends in long-term gaging station records. The evidence is too weak, however, to support a strong conclusion as to whether the fluctuation is truly periodic or what the period might be. Locally, no significant trend could be linked to physical changes in the associated watershed. Note, however, that no watersheds significantly affected by regulation, diversion, urbanization or the eruption of Mount St. Helens were included in the analysis.

The Statistical Test—Kendall's tau, a nonparametric measure of linear correlation, was used to determine the degree and direction of correlation, and the correlation's statistical significance, for each of the 376 annual series of peaks. A positive value of tau indicated a positive correlation, and a negative value, a negative correlation. Small values of the probability associated with tau indicated a significant correlation. Calculations of Kendall's tau and its associated probability for each series were made using the algorithm given by Press and others (1986). Appendix B shows the value of tau and its associated probability for each gaging station.

Test for Significance—Statistical significance was determined by a two-sided test at the 0.05 level. For this test, the null hypothesis, H_o, states there is no trend. H_o is accepted if the probability associated with tau is greater than 0.05 and is rejected otherwise. By chance, five percent of the gaging stations are likely to show a significant trend. The significant, but chance, trends are likely to be about half positive and half negative.

Checking for Regional Trends—In an initial check for regional trends, only the 129 gaging stations with more than 30 years of record were used. These long-term records were considered least likely to be affected by random variation in the annual series of peak discharges. By chance, five percent of the gaging stations (about 7 stations) are likely to show a significant trend.

Table E-1 summarizes the results of the test for significance for the long-term stations. Twelve stations (9.4 percent) showed a significant trend. Of these, six showed a positive trend and six a negative trend. Region 2B had the highest percentage of statistically significant trends (13.8 percent) and region 2A, the fewest (4.2 percent).

More significant trends occurred than are expected by chance. Further, if the twelve gaging stations are sorted by beginning year of period of record, a pattern emerges (table E-2). All but two of the stations fall into three distinct groups: (1) stations with records beginning about 1880 (negative trends), (2) stations with records beginning from 1928 to 1930 (positive trends), and (3) stations with records beginning from 1955 to 1959 (positive trends). Figure E-1 shows the trend line for a gaging station from each group.

These results suggest that peak discharges are not entirely random; that they exhibit long-term fluctuations between wet and dry periods—dry around 1930 and 1985 and wet around 1890 and 1960. These observations are consistent with observations made about precipitation in Oregon by Taylor and Hannan (1999) who suggest alternating periods of relatively high and low precipitation. Based on long-term precipitation records from the coast and in Portland, weather was cool and wet from 1896 to 1916, warm and dry from 1916 to 1946, cool and wet from 1946 to 1976, and warm and dry from 1976 to 1995. Precipitation records after 1995 suggest the start of another wet period.

If peak discharges are in fact subject to serial correlation due to long-term fluctuations in weather, it should be possible

Table E-1. Trends in annual series of peak discharges by region for gaging stations with 30 or more years of record.

Region	Total number of stations	Positive trend		Negative trend		No trend	
		Number of stations	Percent of total	Number of stations	Percent of total	Number of stations	Percent of total
1	16	1	6.3	0	0.0	15	93.7
2a	48	2	4.2	0	0.0	46	95.8
2b	65	3	4.6	6	9.2	56	86.2
All	129	6	4.7	6	4.7	117	90.7

Table E-2. The 12 gaging stations with significant trends and more than 30 years of record. The list is sorted on the beginning year of the period of record.

Gage number	Period of record	Number of peaks	Trend direction	Region
14174000	1878–1882, 1884, 1890, 1893–1941	56	-	2B
14191000	1881, 1890, 1893–1941	50	-	2B
14137000	1912–2000	89	+	2A
14314500	1928–1976, 1978	50	+	2A
14309000	1928–1931, 1933–1985	57	+	2B
12025000	1929–1931, 1943–1981, 1983–1999	59	+	2B
12010000	1930–1999	70	+	1
14128500	1935–1979, 1996–1997	47	+	2B
14375500	1955–1978, 1980–1985	30	-	2B
14320700	1956–1976, 1978–1986, 1988–2000	43	-	2B
14309500	1956–2000	45	-	2B
14194300	1959–1966, 1968–1995	36	-	2B

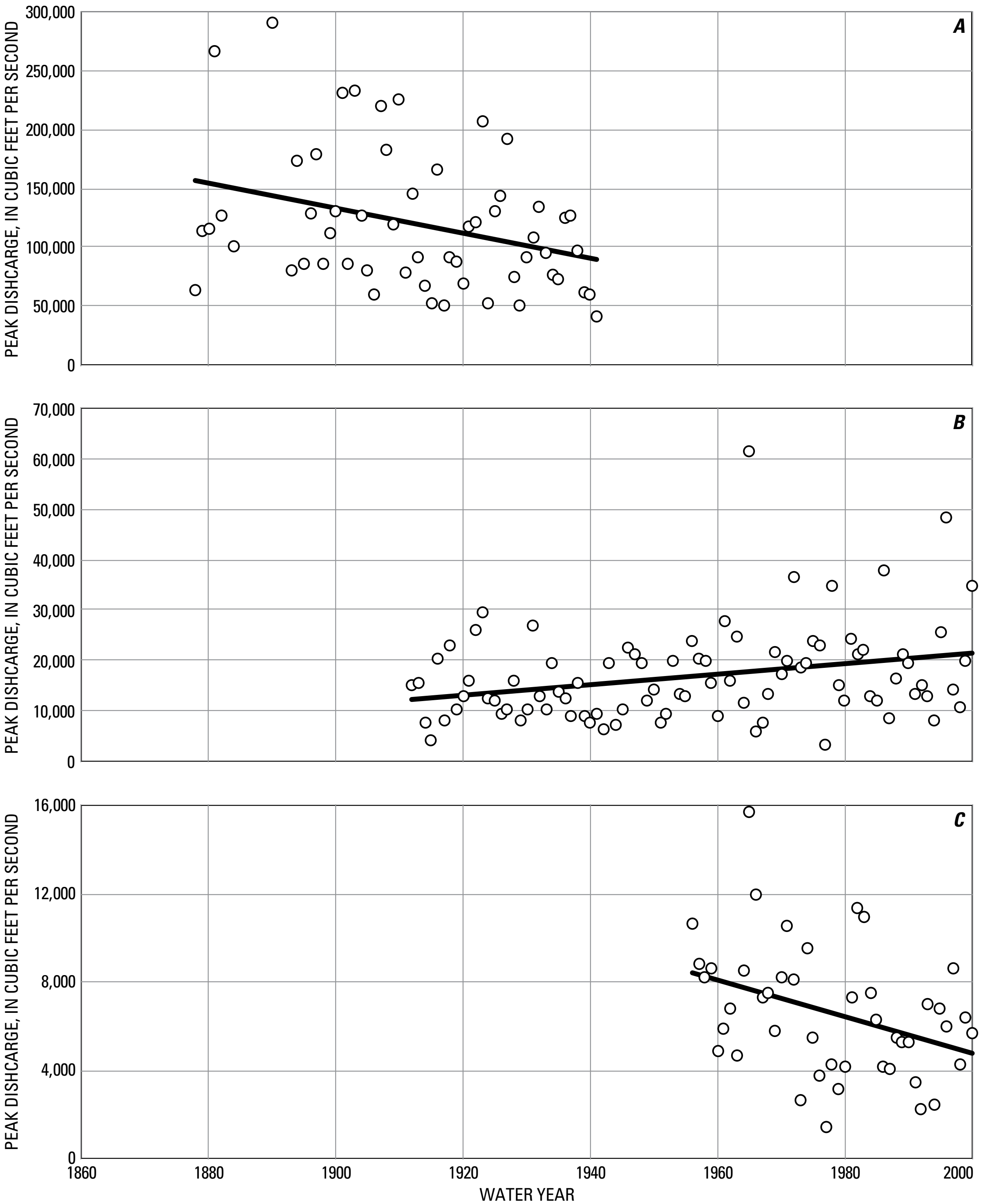

Figure E-1. Trend as a function of period of record (A) the Willamette River at Albany, Oregon (14147000), (B) the Sandy River near Marmot, Oregon (14137000), and (C) the West Fork Cow Creek near Glendale, Oregon (14309500).

to demonstrate that the direction and the statistical significance of a trend are functions of the length of the record on which the trend is based and the record's location in time. In order to make this test, all record lengths must be the same. To that end, the gaging station records were divided into all possible records of 10, 20, 30, 40, 50, 60, 70, and 80 years and Kendall's tau determined for each. Of the 376 gaging stations, five were not used because they had gaps of longer than five years.

A long-term gage contributes a number of records in this scheme. For example, a gaging station with 50 years of data yields 21 records 30 years in length. The total number of sampled records varies as a function of total record length—the longer the sample, the fewer the possible records (table E-3).

Table E-3 shows that trend direction and statistical significance are functions of record length. Trends are about equally positive and negative for record lengths of 40 years or less, but the percentage of positive trends increases rapidly with longer records.

Finally, for record lengths of 30 years or less, the percentage of significant trends is about what is expected by chance. For record lengths of more than 30 years, the percentage of significant trends increases rapidly with increasing record length.

In figure E-2, for each record, the number of standard deviations Kendall's tau departs from the mean (i.e., its z score) is plotted against the beginning year of the period of record. Plotted in this way, tau gives the direction of the trend and is proportional to its statistical significance. All records of a given length are plotted on the same chart. The solid black sinusoidal line on each chart is a fourth order polynomial fitted to the plotted points. Each represents the trend of its associated z scores.

Figure E-2 shows that, for records longer than about 30 years, the likelihood a trend will be in a certain direction or will be significant or both varies as both a function of length of record and the record's place in time. For example, for records 30 years in length (fig. E-2C) a record beginning between 1915 and 1951 is more likely to be positive than negative, and if beginning before 1915 or after 1951, more likely to be negative. Significant trends (tau more than about two standard deviations from the mean) are most likely to occur near the maximum and minimum points of the fitted line: 1930 and 1965.

The sinusoidal trend lines of the z scores in figure E-2 suggest that the linear trends on which the z scores are based fluctuate systematically between positive and negative. These region-wide fluctuations explain the over abundance of significant trends in the long-term gages and the pattern of alternating negative and positive trends shown in table E-2. They also explain why the percentage of significant trends and the number of positive trends both increase with record length (table E-3).

To understand how the z scores of the linear trends relate to the original time series of peak discharges, it is helpful to look at the behavior of z scores of linear trends sampled from a theoretical, perfectly sinusoidal population. A sine curve with a period of 60 years and beginning in 1880 was sampled for all possible periods of lengths of 10, 20, 30, 40, 50, and 60 years. Kendall's tau and the associated z score were calculated for each sample. The population curve and the z scores of the trend lines for each period of record are plotted in figure E-3.

The z scores based on the samples from the sine curve (fig. E-3) behave in a fashion similar to the z scores from the actual peak discharges (fig. E-2). The z scores are sinusoidal in both cases and their periods shorten as the length of sampled record increases. Also the most significant trends occur near the maximum and minimum points of the curves.

Note that when the length of the sampled record is half that of the period of the population curve, the z scores and the population curve are exactly 180 degrees out of phase. This means that for periods beginning in wet years, trend lines will tend to be negative, and beginning in dry years, positive.

For the z scores for actual peak discharges, the z scores and the sine curve are 180 degrees out of phase for a period of 75 years and a period of record of 35 years (fig. E-4). The time line is divided into wet and dry periods. The breaks occur where the two sinusoidal curves meet as they cross zero. Interestingly these periods match reasonably well those observed by Taylor and Hannan (1999).

Although this analysis suggests a periodicity to peak discharges, only a little over one complete period is represented in the record. Whether these observed fluctuations are truly periodic with a constant period remains to be seen. Further, the data points are scattered widely about the trend lines indicating that a trend line of the z scores for any single gaging station may vary considerably from the trend line for z scores from all gaging stations (fig. E-5). So, while the fluctuations appear to have a general, regional basis, locally there is considerable variation.

Based on this analysis, it is concluded that while the time series of peak discharges exhibit some serial correlation, the correlation is due to fluctuations between wet and dry periods and not to a continuous upward or downward trend. Over the long term, peak discharge characteristics remain constant. Further, it is concluded that the available peak discharge records represent long-term peak discharge characteristics and that they adequately represent the variability exhibited by long-term peak discharges.

Checking for Local Trends—Table E-4 summarizes the results of the tests for significance for all 376 stations. For these stations, 27 (7.3 percent) showed a significant trend. Of these, 14 showed a positive trend and 13, a negative trend. Region 2B had the highest percentage of significant trends (7.9 percent), and region 1, the fewest (5.5 percent). While the number of significant trends slightly exceeds that expected by chance, the trends are not predominately either positive or negative. The slight excess of significant trends is attributed to the fluctuations discussed in the previous section.

The 27 gaging stations with significant trends were examined to determine if the trends were the result of physical changes in the associated watersheds. Because no physical cause could be determined for any of the trends, the trends

Table E-3. Trend direction and number of significant trends as a function of record length.

Record length (years)	Number of observations	Trend direction				Significant trends	
		Positive	Negative	Zero	% Positive	Number	Percent
10	6,761	3,332	3,361	68	49.3	289	4.3
20	3,794	1,777	1,936	81	46.8	161	4.2
30	2,184	1,083	1,087	14	49.6	149	6.8
40	1,214	614	592	8	50.6	161	13.3
50	641	375	265	1	58.5	109	17.0
60	285	186	98	1	65.3	59	20.7
70	96	71	25	0	74.0	35	36.5
80	30	28	2	0	93.3	13	43.3

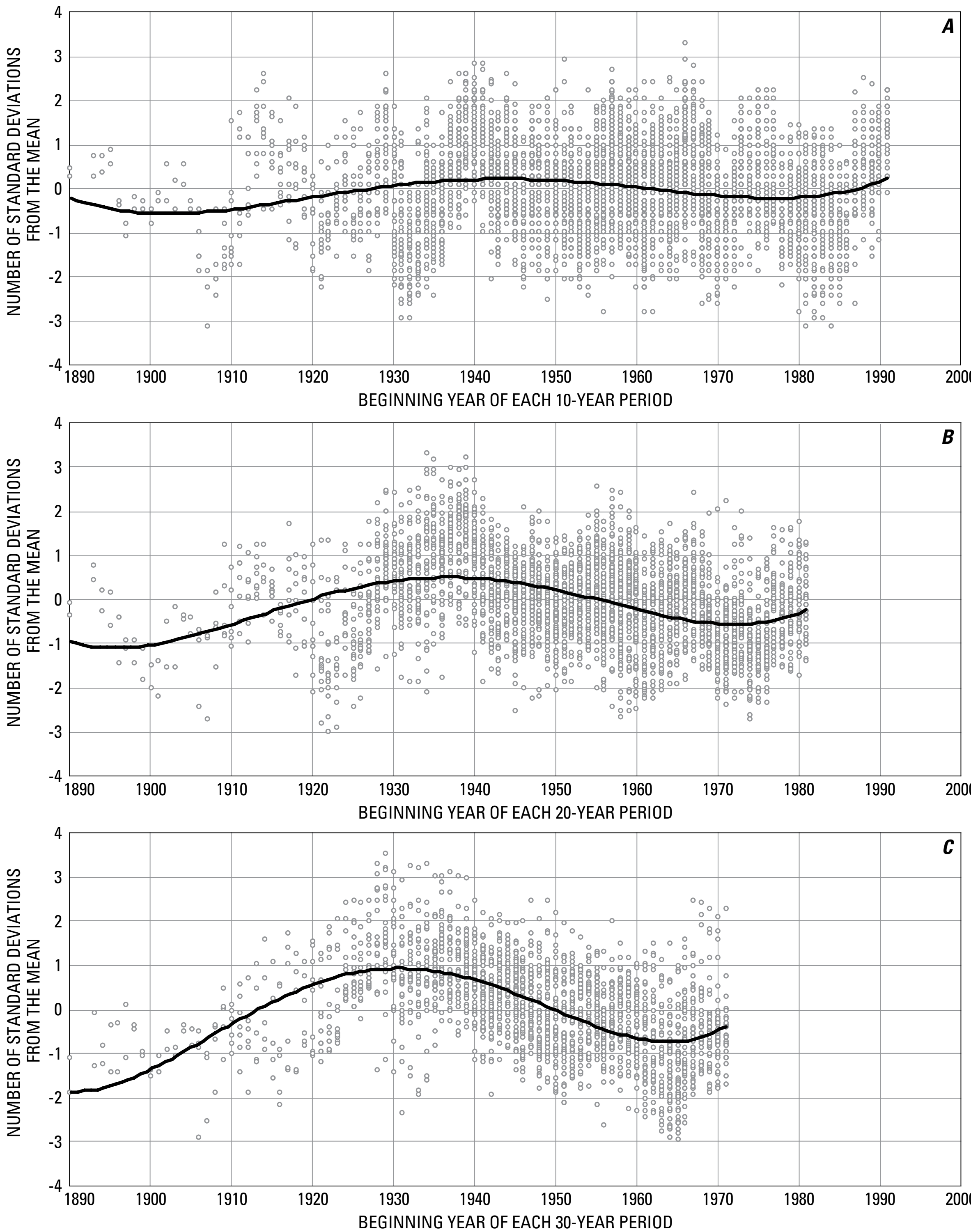

Figure E–2. These graphs show how Kendall's tau varies in time and as a function of the length of the period of record. The number of standard deviations Kendall's tau departs from the mean (i.e., its z score) for the specified periods of record are plotted against the beginning year of each period. Plotted in this way, tau gives the direction of the trend, and is proportional to its statistical significance, for the period of record that follows its plotted position. The solid line on each graph is a fourth order polynomial fitted to the plotted points. The graphs are for uniform periods of record of (A) 10 years, (B) 20 years, (C) 30 years, (D) 40 years, (E) 50 years, and (F) 60 years.

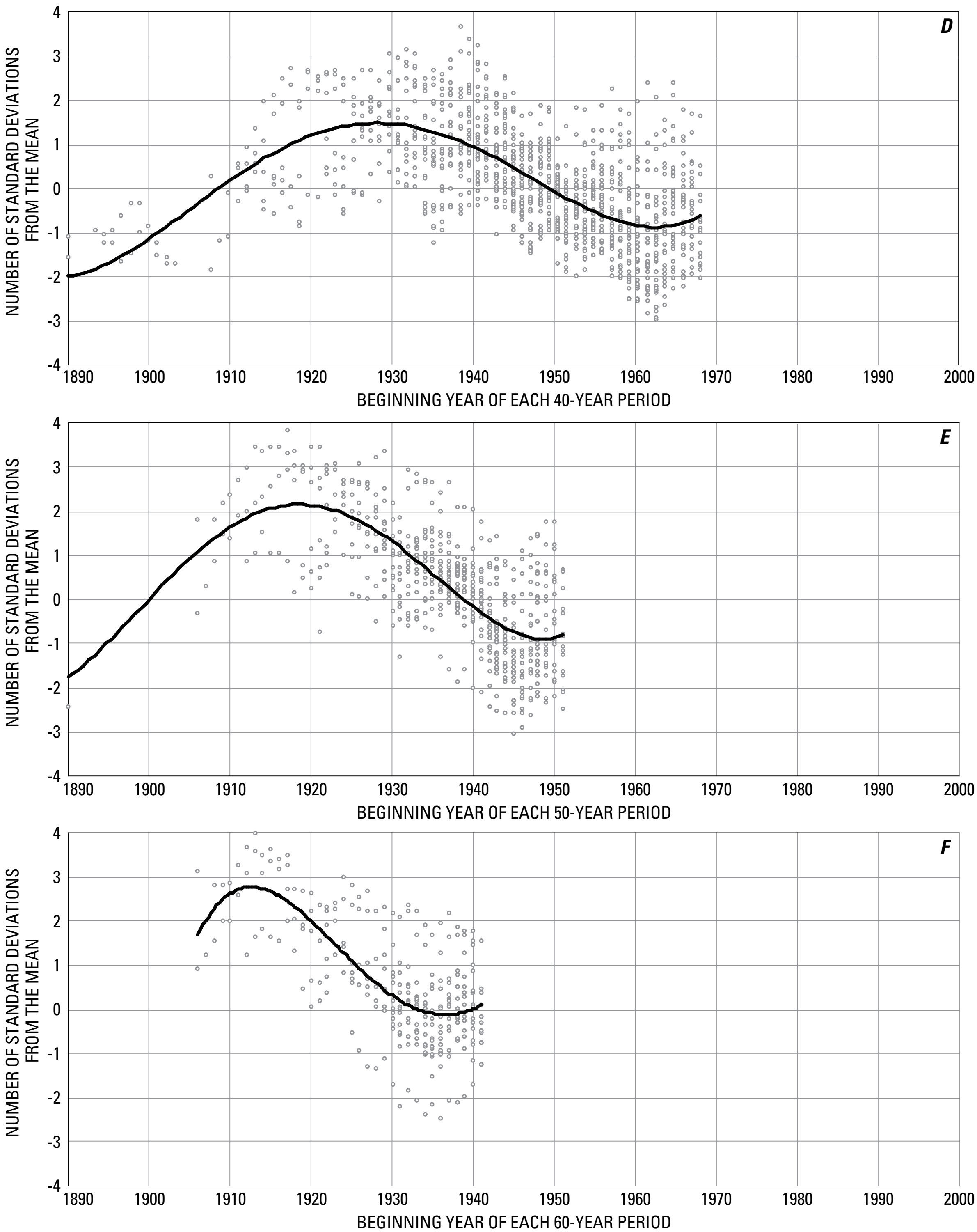

Figure E–2.—Continued.

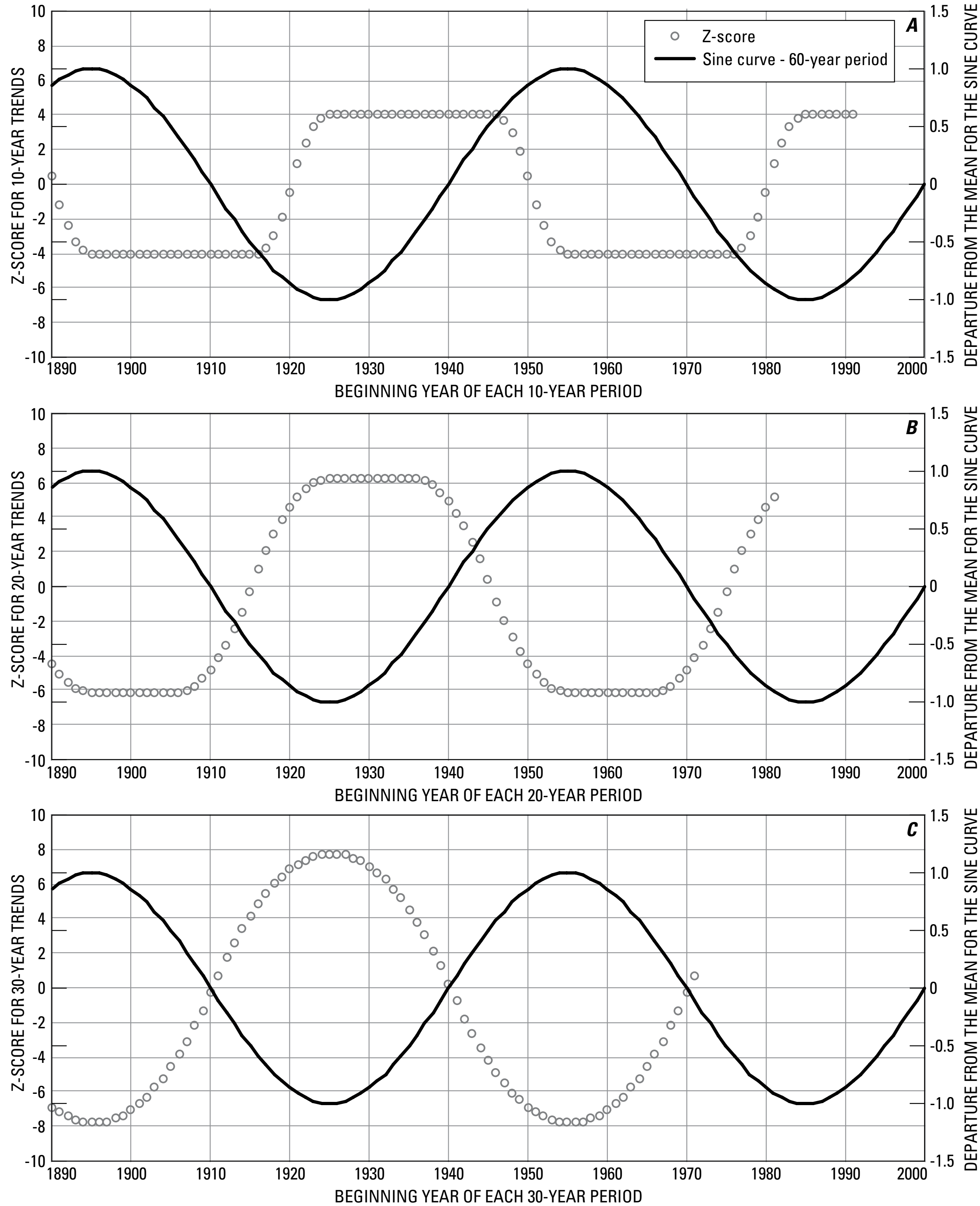

Figure E–3. Kendall's tau was calculated for samples of specified length taken from a population based on a sine curve with a period of 60 years and beginning in 1880 (solid line). The values of the population represent departures from a mean of zero. Z scores for the tau values are shown plotted against time. These z scores exhibit behavior similar to the z scores in figure E–2. Note that when the length of the sample is half the period of the sine curve, the two curves are 180 degrees out of phase. The graphs are for uniform periods of record of (A) 10 years, (B) 20 years, (C) 30 years, (D) 40 years, (E) 50 years, and (F) 60 years.

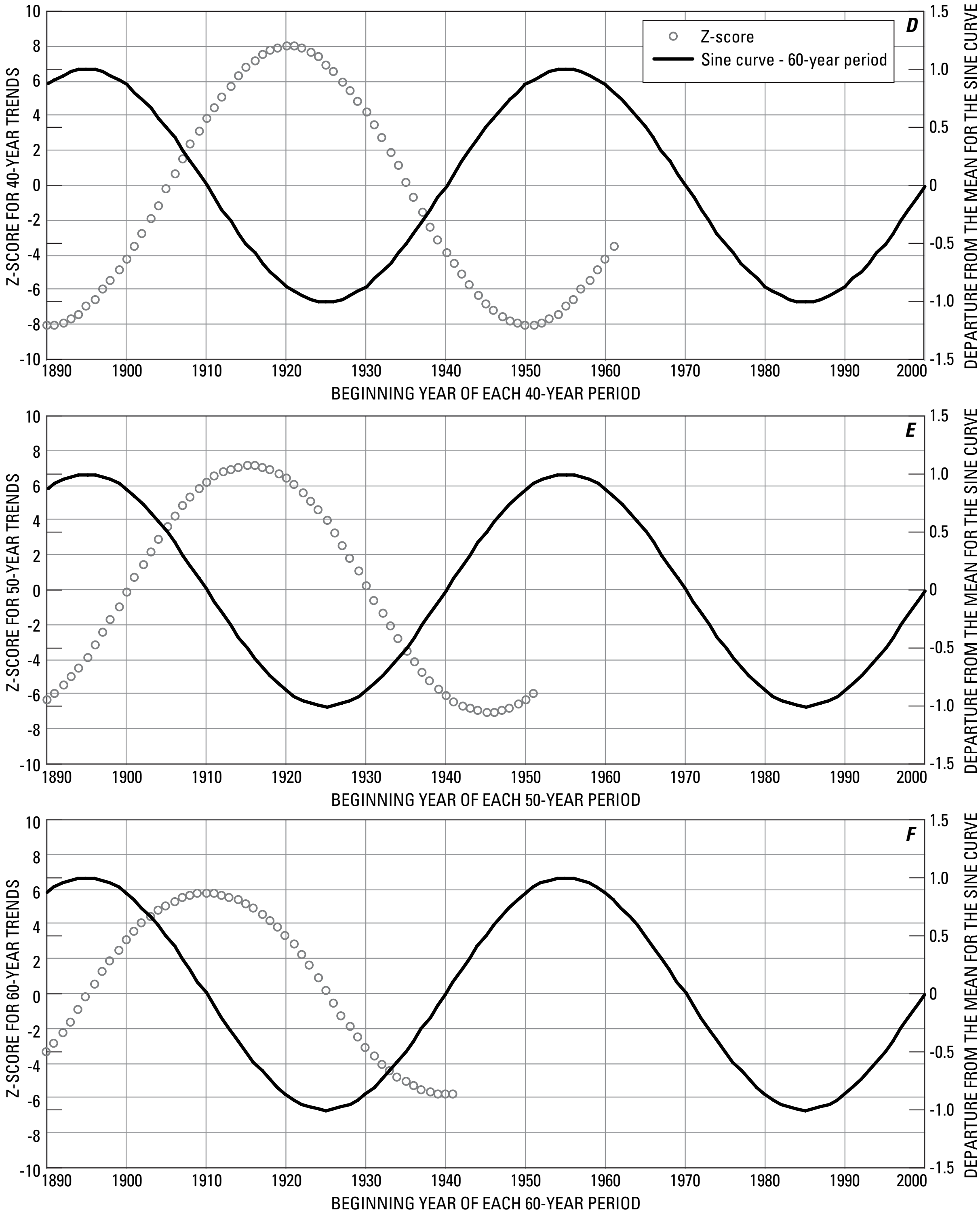

Figure E–3.—Continued.

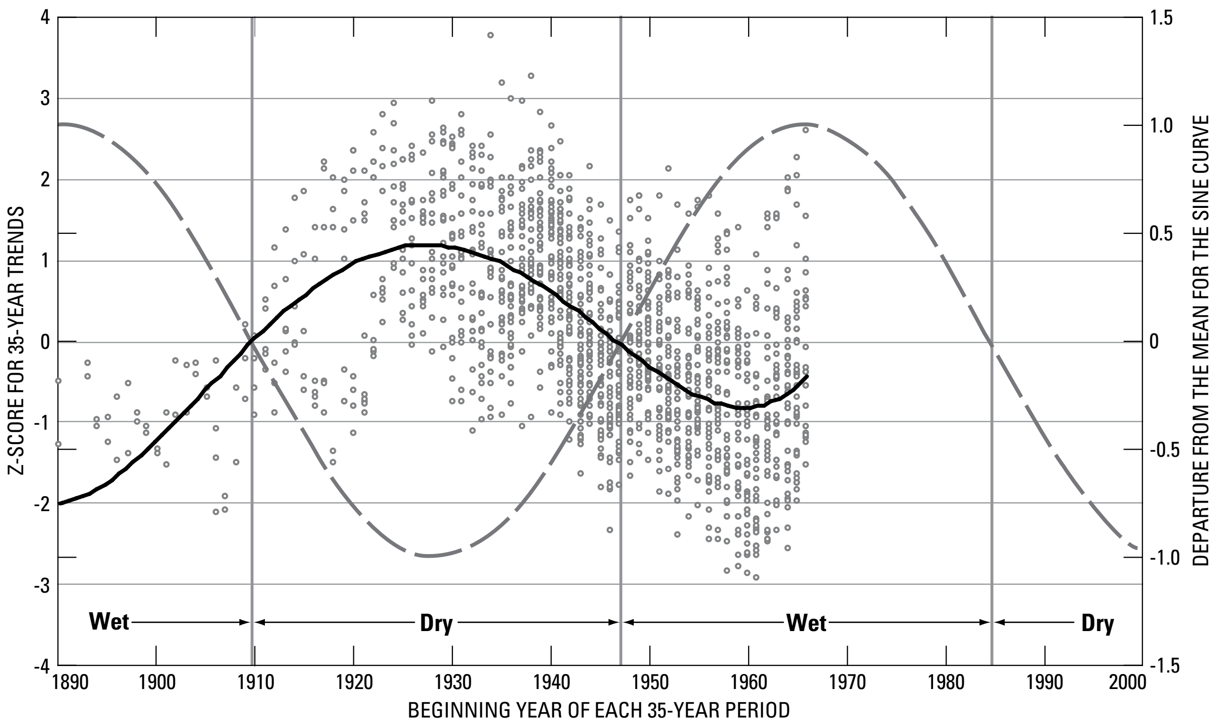

Figure E–4. Z scores for Kendall's tau calculated for all possible periods of 35 years are plotted against the beginning year of each period. The solid black curved line is a fourth-order polynomial fitted to the plotted points. The dashed line is a sine curve with a period of 75 years and beginning in 1872. The parameters of the sine curve and the length of record were selected so that the two curves were 180 degrees out of phase. The boundaries of the wet and dry periods are located where the two curves cross each other and zero.

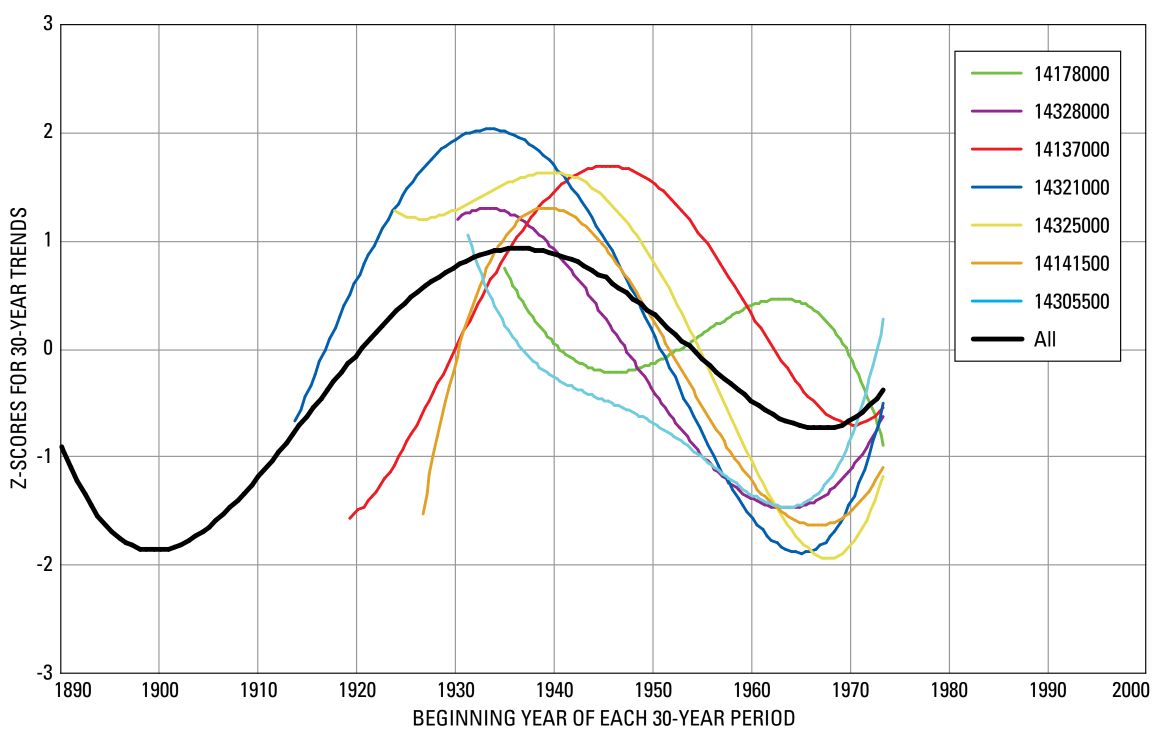

Figure E–5. Trend line of z scores for the seven gaging stations with the longest periods of record compared to the trend line for z scores of all gaging stations.

Table E-4. Trends in annual series of peak discharges by region for all gaging stations.

Region	Total number of stations	Positive trend		Negative trend		No Trend	
		Number of stations	Percent of total	Number of stations	Percent of total	Number of stations	Percent of total
1	91	3	3.3	2	2.2	86	94.5
2A	107	5	4.7	3	2.8	99	92.5
2B	178	6	3.4	8	4.5	164	92.1
All	376	14	3.7	13	3.6	349	92.7

were assumed to be due to chance alone, and the 27 gaging stations were retained in the analysis.

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