Streamflow and La Niña Event Relationships in the ENSO-Streamflow Core Areas

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The high index phase of the Southern Oscillation (SO), La Niña, has not been given as much attention as its counterpart, the low index phase of the SO, El Niño. One reason may be related to the fact that many similarities exist among El Niño events but not among La Niña events. Thus, the literature mostly contains studies based on composite analysis for El Niño episodes (Philander 1990).

In a global-scale study, Ropelewski and Halpert (1989) found that relationships between the high SO index phase and precipitation anomaly are opposite in sign to the low index phase of the SO relationships. Their study included two regions (the Gulf-northern Mexico and the Great Basin) based on the study of Ropelewski and Halpert (1986) in North America. In a hydrologic perspective, Kahya and Dracup (1993) (hereafter abbreviated as "KD") identified four El Niño/Southern Oscillation (ENSO)-Streamflow core core areas (Gulf of Mexico, North East, North Central, and Pacific Northwest) that exhibit a reliable and coherent ENSO/streamflow association (Figure 1). In this study, we focus on the influences of La Niña phenomena on streamflow anomalies in these four areas to explore the SO-related signal over the United States.

Data Set and Methodology

Monthly virgin streamflow volumes compiled by Wallis *et al* (1991) in the form of CD-ROM are used in this investigation. The data set contains 1,009 high-quality stream gauge records in the United States, each with 41 years of observation (1948-1988). Each record contains nine La Niña events. In determining the relationship between streamflows in the core areas and La Niña events, the following analysis procedures were performed using six event years (1950, 1955, 1964, 1970, 1973, and 1975). In the two cases of two successive La Niña years, only the first year is used for the individual station composite; however, the second years (1956, 1971) and 1988 (if possible) are marked in the index time series.

In our earlier study (KD), the monthly streamflow values were initially expressed in terms of percentiles based on the appropriate log-normal distribution for each month at each station. The ENSO streamflow composite at each station was formed for a idealized 2-year period to make our results comparable to those of Ropelewski and Halpert (1989).

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However, the length of the composites was changed to three years when detecting a seasonal signal. (This was especially important in the PNW area.) The episode year in which maximum sea surface temperature anomalies related to El Niño (or La Niña in this study) generally occur in the central and eastern Pacific Ocean was designated by (0); the year that precedes the episode year is designated by (−) and the year that follows is designated by (+). In this convention, ENSO composites of the log-normal streamflow percentiles were constructed for the 24-month period starting with the July preceding the episode, July(−), and continuing through the June following the episode, June(+). These composites were subjected to the fit of the first harmonic. The phase of the first harmonics was assumed to represent the time of maximum relationship between streamflow and ENSO events. The amplitude of the first harmonics represents the magnitude of the relationship. Both quantities were combined into one as a vector and plotted on a map (Figure 1) in order to identify regions that have spatial coherence in terms of timing and magnitude for the streamflow response to the tropical thermal forcing.

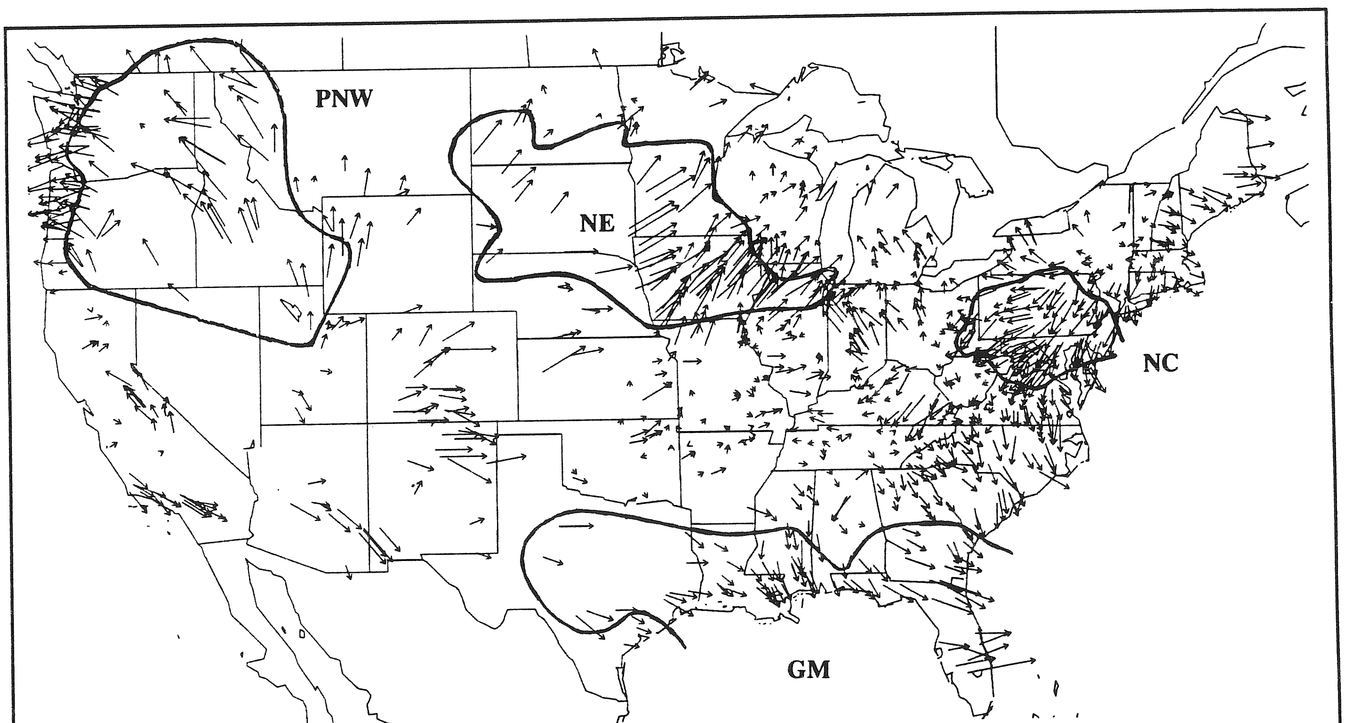

Figure 1. Streamflow station vectors based on the 24-month harmonic fitted to ENSO streamflow composites.
Outlined regions of coherent streamflow responses are the core areas. For the direction of arrows, south refers to July(−), north corresponds to June(0), and so on. For the magnitude of arrows, the harmonic arrow belonging to southernmost Florida has a magnitude of 21.6 percent and a phase of December(0), for example. (Adapted from Kahya and Dracup 1992.)

Analysis steps in this study start with those streamflows included in the four core areas. An aggregate La Niña composite for each area is obtained by averaging individual station composites based on three years to detect subjectively a single season. The index time series (ITS) for the region is plotted against the detected season. Finally, ITS is examined for temporal consistency to see whether the La Niña-related streamflow signal is reliable.

Results and Discussion

In this section, results are summarized for each of the four areas. Specific information for an area, such as number of stations included, coherence of the first harmonics, and general regional climate, are available in KD.

Since the phenomena of El Niño and La Niña are known to be the extreme state of climate in the equatorial Pacific, it may be plausible to expect their influences on the surface hydroclimatic parameters at middle latitudes to be extreme. It would be advantageous if water resources managers could understand the causes of extreme conditions such as floods and droughts. Therefore, we intend to determine the number of extreme streamflow conditions that were coincident with the occurrence of La Niña events.

The values of an ITS (numbered as a total of 41) are basically the average of log-normal percentiles for months that are included in the corresponding season for each year. Since these index values constitute a distinct population for different seasons, limits for the lowest and the highest will depend on the season and the ITS under consideration. Thus, in this study, the values of an ITS that are lower than 30 percent or higher than 70 percent are not specified as a driest or wettest season average. For that, we found the cumulative distribution of the values of an ITS and calculated the limiting index values for the 10 percent (for the driest conditions) and the 90 percent (for the wettest conditions). In our case, there are always four ITS values that fall below 10 percent and another four that fall above 90 percent.

This analysis attempts to identify a coherent and systematic hydrologic response to the equatorial cold events in the ENSO-streamflow core areas, but the streamflow response to La Niña events may exist elsewhere. Also, the sizes and locations of the core areas may not be right to look for the La Niña-related streamflow response. This may be checked by performing the entire analysis initially based on the La Niña composite.

Gulf of Mexico (GM)

In the La Niña aggregate composite for the GM area (Figure 2), the 9-month dry period from December(0) to August(+) has been selected as a season with strong La Niña/streamflow relationship. This seasonal signal has similar timing and magnitude with that of ENSO (wet December(0) to April(+) in KD), but has opposite sign. This season also appeared as a dry period in the ENSO aggregate composite (see KD) for the GM. The ITS based on this season is depicted in Figure 3. Seven out of eight episodes affirmed the detected dry season and only one appeared to be extremely dry.

Similarly Ropelewski and Halpert (1989) found that regional precipitation response to La Niña events in the Gulf-northern Mexico region was in the form of dry season, with 16 out of 19 confirmed cases in their 101-year record. In the GM area, Kiladis and Diaz (1989) found a tendency for dry conditions during fall of (-) year that later turns out to be a weak dry signal during winter of (0) year. In the fall of (0) year, the SO-related signal reverses sign, appearing as weak precipitation anomalies. Approaching winter and spring of (+) year, strong wet anomalies dominate the region. These findings refer to El Niño; the opposite is true for La Niña events. Moreover, composite 700-mb height anomalies for six winters (three of

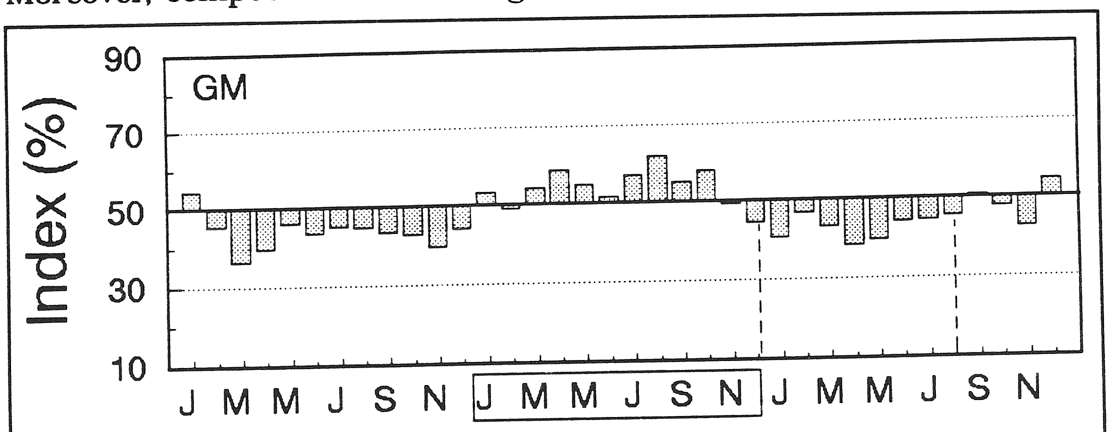

Figure 2. Aggregate La Niña composite based on percentiles of log-normal distribution for the Gulf of Mexico area.
Dashed lines delineate the season of possible La Niña-related streamflow responses. Months in the box refer to La Niña or (0) year.

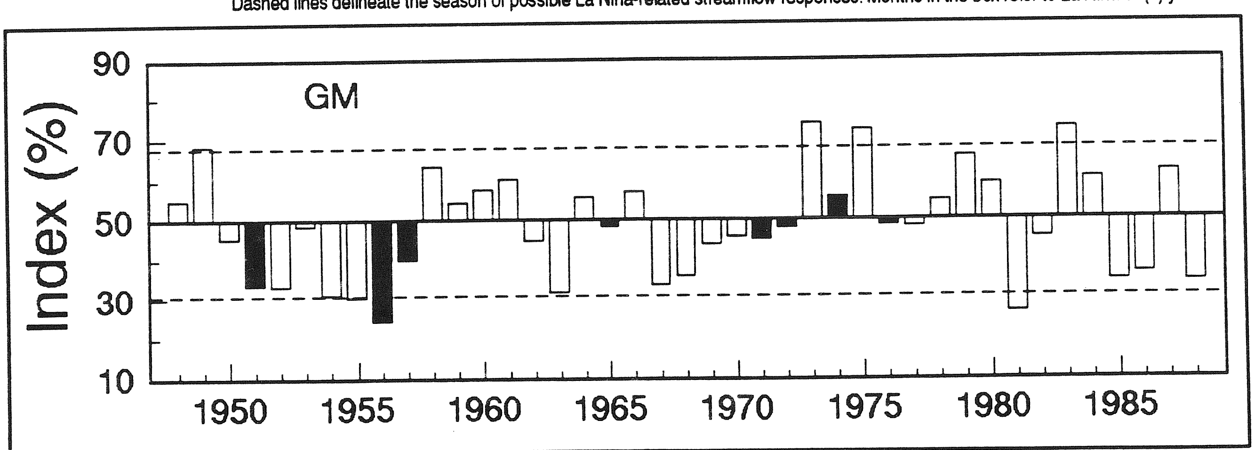

Figure 3. Index time series of streamflow percentiles based on the season chosen in Figure 2 for the Gulf of Mexico area.
Signal years are shown by dark bars. Dotted lines indicate the limit for the wettest and driest values.

those indicated as La Niña winters in this study) following dry autumns in the equatorial Pacific (Douglas and Englehart 1981) suggest decreased storm activity in the Gulf of Mexico due to a weakened East Coast trough. This circulation pattern generally bears a warm, dry winter in Florida.

North East (NE)

The wet August(0) to February(+) season is an apparent period for the signal timing in the aggregate composite of the North East area (Figure 4). The seasonal ENSO signal with negative anomalies has been previously found during the August(0) to February(+) season in the NE (see KD). The relevant ITS for this area (Figure 5) indicates an acceptable level of consistency, since six of eight cases had above-normal values, one almost neutral, and one major failure case. Two of four extremely wet seasons occurred during La Niña events.

Kiladis and Diaz (1989) indicate a significant SO-related signal for dry conditions for ENSO events (wet conditions for La Niña events) over the North East during summer of (0) year, which is the start of wet streamflow season mentioned above. Their analysis also indicates dry precipitation anomalies during the mature phase. This is in agreement with our results.

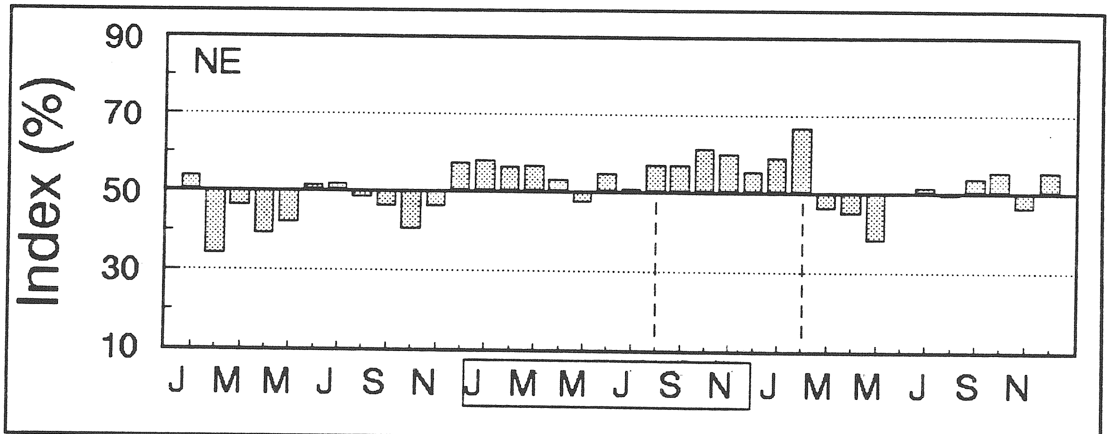

Figure 4. Aggregate La Niña composite based on percentiles of log-normal distribution for the North East area. Dashed lines delineate the season of possible La Niña-related streamflow responses. Months in the box refer to El Niño or (0) year.

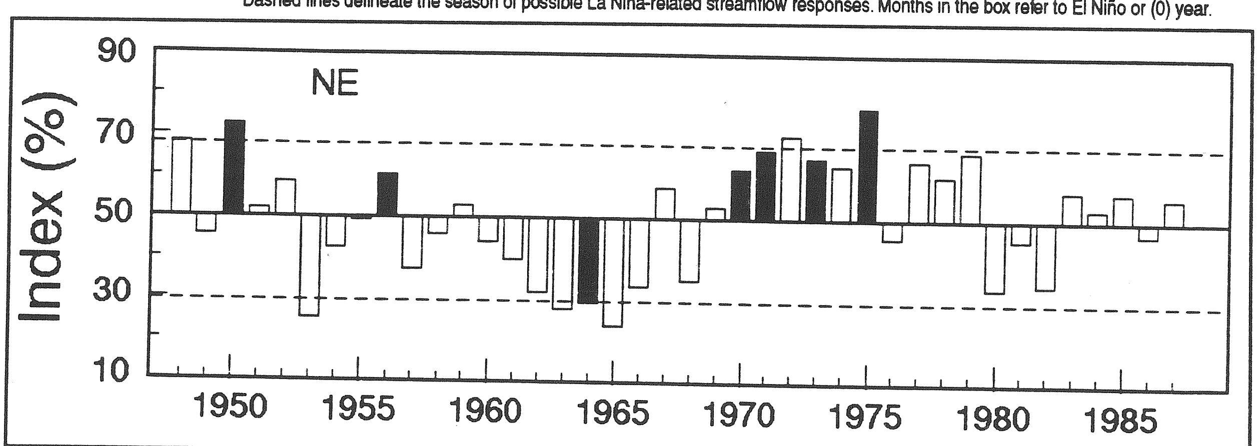

Figure 5. Index time series of streamflow percentiles based on the season chosen in Figure 4 for the North East area. Signal years are shown by dark bars. Dotted lines indicate the limit for the wettest and driest values.

North Central (NC)

Figure 6 illustrates typical streamflow anomalies in the evolution period of La Niña phenomena. The sequence of below-average anomalies between July(0) and January(+) has been considered as the response of streamflows in the NC to the tropical cold events. Comparison of this season with the wet April(0) to January(+) season for ENSO events (see KD) shows that initiation of this season was delayed by 3 months and signs of anomalies were reversed. The persistent negative anomalies from January(−) to January(0) in the ENSO composite (see KD) were almost the same as this NC dry season associated with La Niña events. Figure 7 shows the relevant ITS with two positive departures from the median (out of 9 La Niña episodes), confirming the signal by a 0.78 level of consistency. In the study period, three of the four driest seasons occurred during the La Niña years. From a perspective of the occurrence of extreme streamflow conditions, this signal is highly significant.

The results of Kiladis and Diaz (1989) for the NC area indicates dry conditions in the southeastern NC during winter of (+) year and wet conditions in the southwestern NC during spring of (+) year.

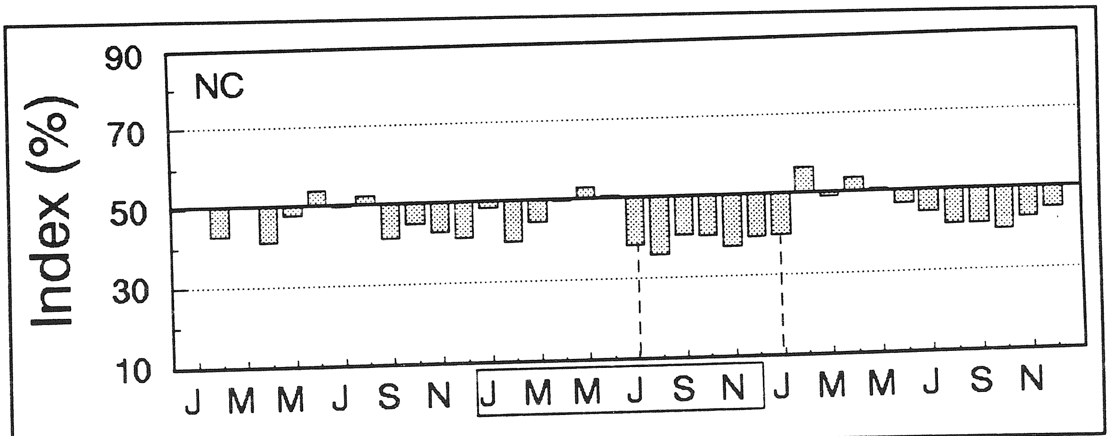

Figure 6. Aggregate La Niña composite based on percentiles of log-normal distribution for the North Central area.
Dashed lines delineate the season of possible La Niña-related streamflow responses. Months in the box refer to La Niña or (0) year.

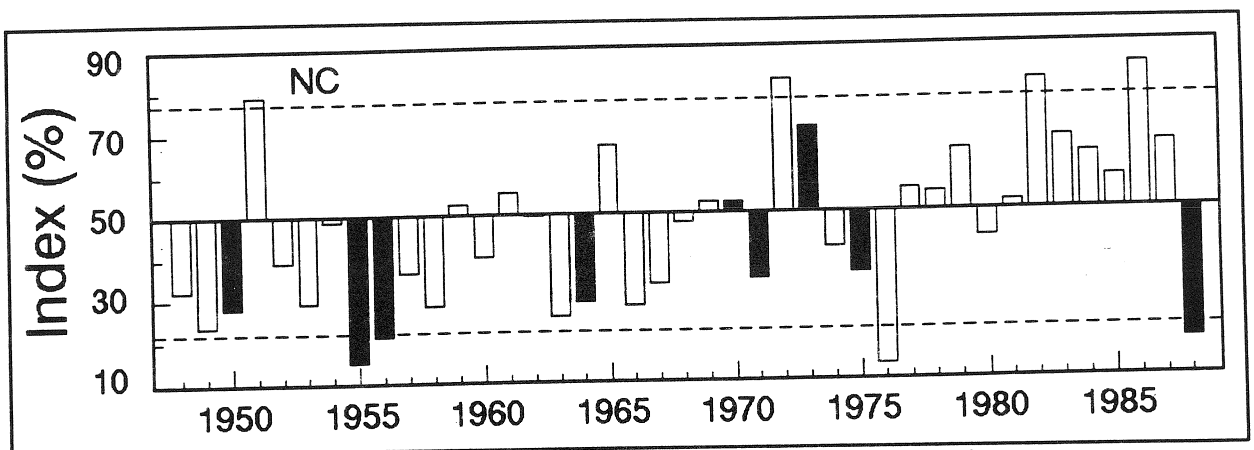

Figure 7. Index time series of streamflow percentiles based on the season chosen in Figure 6 for the North Central area.
Signal years are shown by dark bars. Dotted lines indicate the limit for the wettest and driest values.

Pacific Northwest (PNW)

In the aggregate La Niña composite for the PNW area (Figure 8), the October(0) to August(+) season has been selected from among several alternatives as a period when the La Niña/streamflow relationship is possibly strong and coherent. In the plot of ITS for this season, all seasonal averages associated with La Niña events show an above-normal departure, indicating a highly consistent relationship. All of four extremely wet streamflow occurrences for this season coincided with a La Niña event. Two obvious seasons — October(0) to February(+) and April(+) to August(+) — that could be selected as a response period in Figure 8 revealed reasonable results. The ITS for October-February season (not shown) indicated a high degree of consistency, except one small negative departure (1.7 percent), and the occurrence of two extreme cases. The ITS for the April-August season (not shown) also had eight positive departures out of nine and three extremely wet seasonal occurrences. Redmond and Koch (1991) also found that anomalies of the surface climatic parameters in the PNW region during La Niña events were equally as pronounced as those for ENSO years. The map of Kiladis and Diaz (1989) for the American sector offers some clues for below-normal precipitation in the PNW during the (+) year.

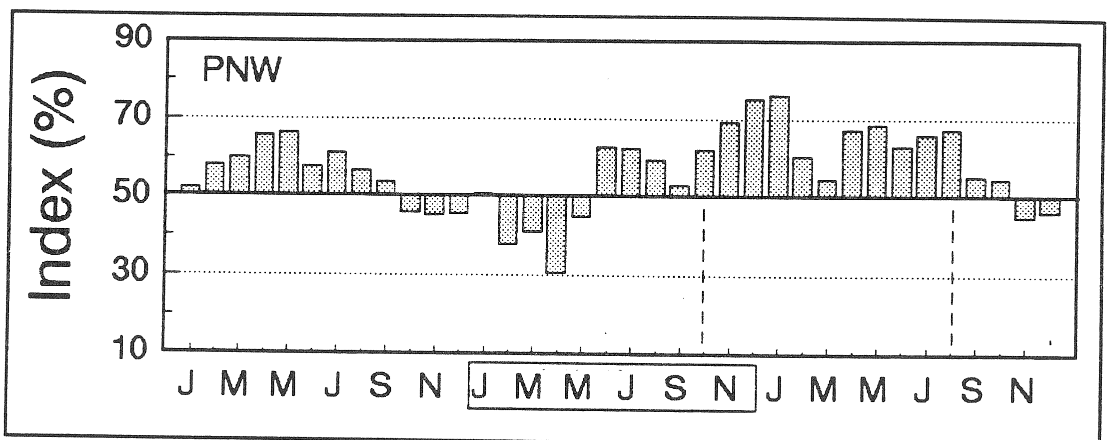

Figure 8. Aggregate La Niña composite based on percentiles of log-normal distribution for the Pacific Northwest area. Dashed lines delineate the season of possible La Niña-related streamflow responses. Months in the box refer to La Niña or (0) year.

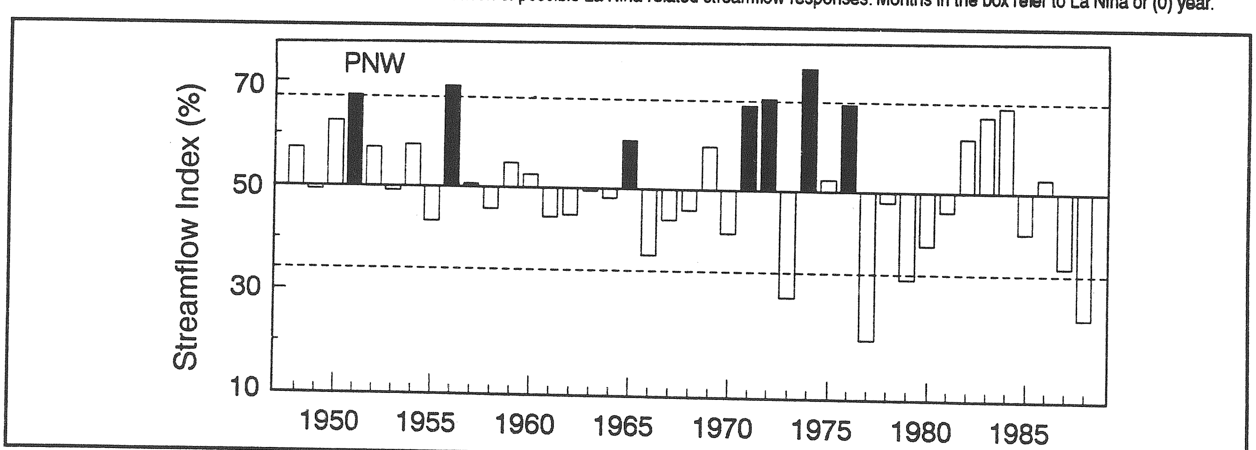

Figure 9. Index time series of streamflow percentiles based on the season chosen in Figure 8 for the Pacific Northwest area. Signal years are shown by dark bars. Dotted lines indicate the limit for the wettest and driest values.

Conclusion

Identification of possible core areas is a major step in seeking predictive utilities for long-range streamflow forecasting in the United States. The core areas that may have had streamflow anomalies associated with ENSO events have been shown to have the same degree of association with La Niña events. The season that reveals the sign and magnitude of the La Niña-related streamflow signal has been detected for each ENSO-streamflow core area. In general, these seasons have almost the same timing, length, and magnitude as those for ENSO events, but the signs of anomalies are reversed.

We have implied the existence of significant mid-latitude streamflow responses to the colder-than-normal sea surface anomalies in the eastern Pacific. Results of this study confirmed the previous climatic studies on the subject from a hydrologic perspective and offered a basis to check the outcomes of atmospheric and hydrologic modeling studies. Since the extremes of the SO have occurred 18 of the 41 years of this study period (44 percent), the relationships specified here and the earlier studies provide some insight for a crude long-range seasonal prediction of streamflow for several regions in the United States.

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