Drought and the 2002-2003 El Niño in the Southwest U.S.

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Abstract

The southwest United States is currently experiencing three years of drought causing water shortages and low lake levels, and now an El Niño event is occurring. This study first assesses the current drought in the southwest United States, and then evaluates whether anticipated hydrologic impacts from the El Niño event are sufficient to end drought conditions. Drought conditions for the Colorado River basin are evaluated using 80 years (1923-2002) of streamflow data from two United States Geological Survey (USGS) stations located in the Upper Colorado River Basin (the Colorado River near Cisco, Utah and the Green River near Green River, Utah). Comparisons of historical cumulative streamflow deficits for droughts during this timeframe are examined. The current El Niño event is forecasted to persist through the end of 2002 and into early 2003 and the anticipated impacts for the Colorado River basin are less than the last El Niño event in 1997-1998. The observed streamflow for water years following the 11 identified El Nino events during 1923-2002 are evaluated to determine if current conditions would be sufficient to end the current drought. The Pacific Decadal Oscillation (PDO) is another factor that affects the hydrologic impacts of an El Niño event. The hydrologic impacts during the different phases of PDO and El Niño events will be evaluated to determine the likelihood of enhanced hydrologic impacts in the next year. The results of this research provide insight to the role of climate variability on drought in the southwest United States.

Introduction

The most well understood atmospheric/oceanic patterns relevant to climate variability in the western United States include the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). ENSO refers to the interaction of El Niño, defined as the periodic large scale warming of the central-eastern equatorial Pacific Ocean, with the Southern Oscillation, the large scale climate variations existing in the tropical Pacific. ENSO phenomenon causes, simultaneously, droughts in Australia, New Zealand, and Southern Africa and devastating floods in North America, Peru, and Ecuador (Ropelewski and Halpert 1987). The PDO is the oscillation of the North Pacific Ocean with a periodicity of approximately 50 years (Mantua and Hare, 2002). Recent research has show that the PDO can both enhance and dampen the hydrologic impacts during ENSO conditions (Hamlet and Lettenmaier, 1999).

In the western United States, El Niño events are associated with below-normal streamflow in the Pacific Northwest, while at the same time there is above-normal streamflow in the southwest (e.g., Cayan and Peterson, 1989; Redmond and Koch, 1991; Piechota and Dracup, 1996).

Hydrologic drought in the Colorado River Basin has been extensively studied by researchers using recorded streamflow, and streamflow reconstructions from tree ring data (e.g., Meko et al., 1995; Tarboton, 1995, Hidalgo et al., 2000). The variability of the snowpack in the Colorado River Basin during El Niño and La Niña years has been investigated by Clark et al. (2001) and McCabe and Dettinger (2002). Clark et al. (2001) found mixed signals where the Upper Basin had slightly below-normal snow pack during El Niño years and Lower Basin rivers had above-normal streamflow. The opposite conditions were observed for La Niña years.

The study presented here focuses on influence of climate variability on drought in the Colorado River basin. The southwest United States is currently experiencing three years of drought causing water shortages and low lake levels. In addition, an El Niño event is occurring and could have an impact on drought conditions in the Colorado River basin. This study first assesses the current drought in the basin, and then evaluates whether anticipated hydrologic impacts from the El Niño event are sufficient to end drought conditions.

Historical Droughts of the Upper Colorado River Basin

Average monthly streamflow data (cubic feet per second - cfs) from 1923-2001 (79 years) was obtained from the U.S. Geological Survey (USGS) NWISWeb Data retrieval (http://waterdata.usgs.gov/nwis/) for two stations located in the Upper Colorado River basin (see Table 1 and Figure 1). The average monthly rate was averaged for the water year (October through September) and converted to volume (acre feet). The average yearly flow for the Colorado River station (Cisco) was 5.22 million acre feet and for the Green River station (Green) was 4.18 million acre feet.

Streamflow data for water year 2002 was not available. Therefore, National Resources Conservation Service 2002 Water Supply Outlook for the Western United States (NRCS, 2002) June 1, 2002 forecast was obtained from the website (http://lasal.cbrfc.noaa.gov/product/westwide/). The most probable forecast estimates that the Cisco station will be at 23% (1.20 million acre feet) of average and that the Green station will be at 27% (1.13 million acre feet) of average for the 2002 water year. Using these values, the average (water) yearly flow from 1923-2002 is 5.17 million acre feet for Cisco and 4.14 million acre feet for Green. These averages are used to determine yearly deficits or surpluses by taking the water year value for each year (1923-2002) and subtracting the average. A positive difference represents an above average streamflow year. A negative difference represents a below average streamflow year. For the purposes of this study, a drought is defined as two or more consecutive years of negative (below average streamflow).

Table 1: List of USGS stations with unimpaired streamflow data.

River Basin	Site Name	USGS Site #	Years of Record
Green	Green River near Green River, Utah	09315000	1923-2001 (2002 forecast)
Colorado	Colorado River near Cisco, Utah	09180500	1923-2001 (2002 forecast)

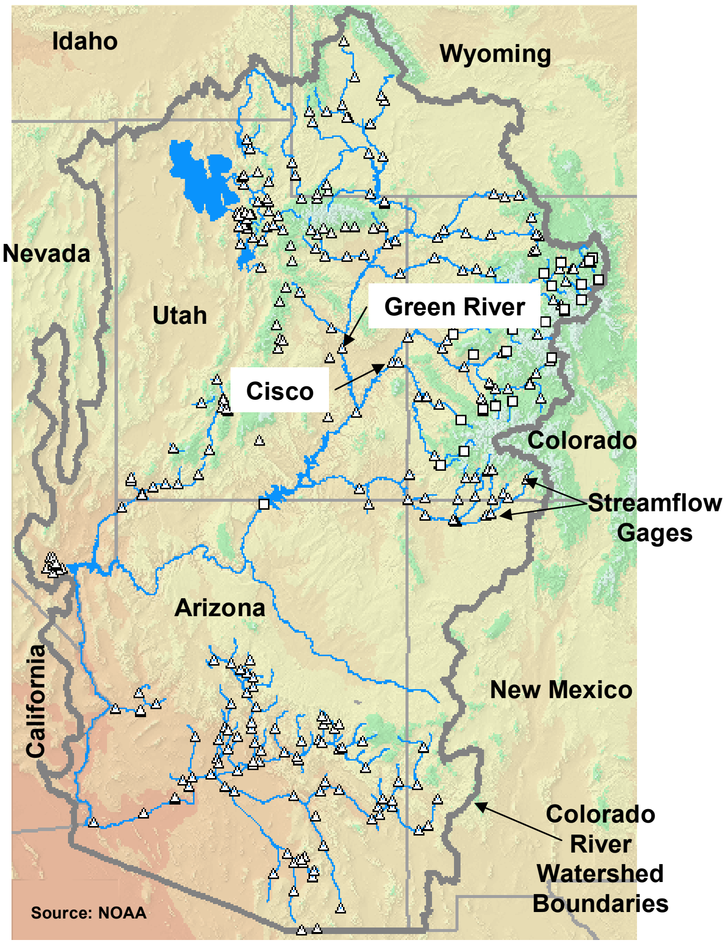
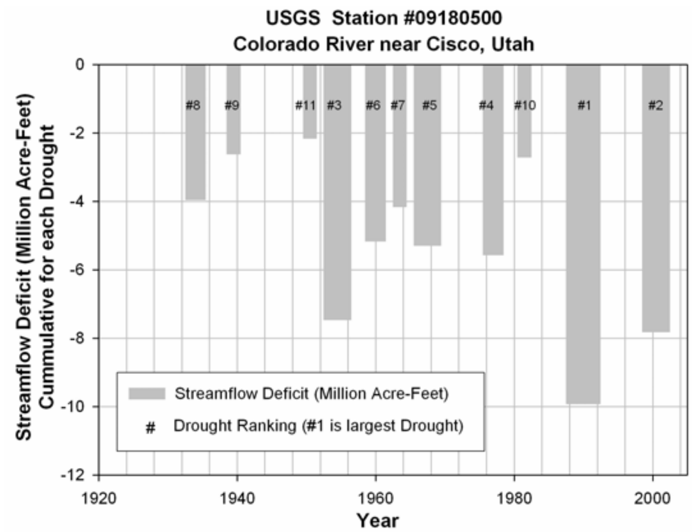


Figure 1: Select USGS streamflow stations for Upper Colorado River. These stations have unimpaired streamflow data.

Figure 2 presents the number, magnitude and ranking of droughts at the two stations (Cisco and Green). For the time period 1923 – 2002, the Cisco station displayed 11 droughts while the Green station displayed 10 droughts. The magnitude of the droughts varied, however, it should be noted that for both stations, the two largest droughts occurred during the late 1980's / early 1990's and the current drought which began in 1999/2000 is the next largest. The cumulative deficit of these two droughts is approximately 18 million acre feet (or three and one-half average years of streamflow) for Cisco and 16 million acre feet (or four average years of streamflow) for Green.



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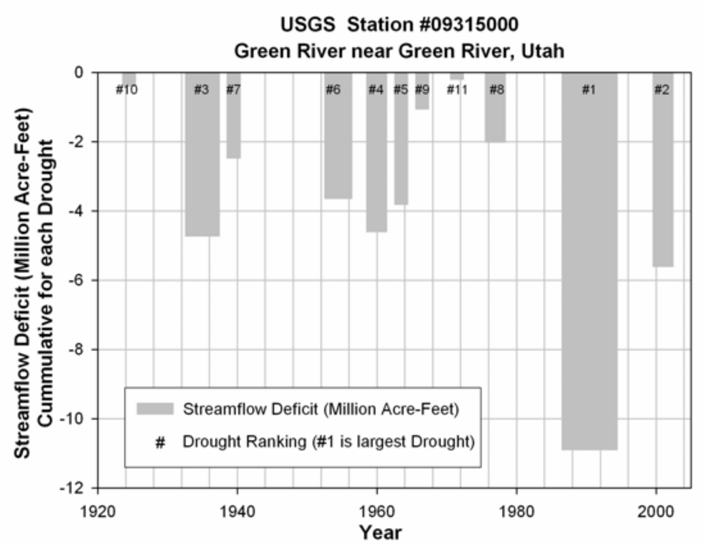

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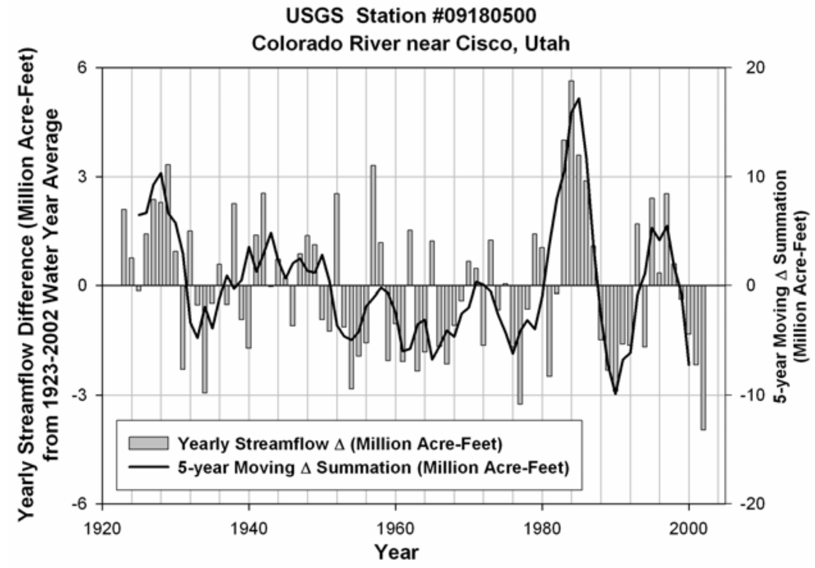
Figure 2: Drought rankings and magnitude for (a) Colorado River near Cisco, Utah and (b) Green River near Green River, Utah

Figure 3 presents the yearly streamflow differences (surpluses or deficits) and a five-year moving summation of surpluses and/or deficits. The 1950’s and 1960’s were a period of below normal streamflow for both stations. For the Cisco station, 15 out of 20 years had streamflow below normal between 1950 and 1969. The five-year moving summation remains negative for the Cisco station from 1952 through 1980, with the exception of two slightly positive years (1971 and 1972). From approximately 1983 to 1987, both stations experienced tremendous streamflow surpluses. However, these surpluses were followed by the previously discussed large drought of the late 1980’s / early 1990’s. The current three-year drought has moved the five-year average (1998-2002) to a negative value. For the Cisco station, the five-year deficit is approaching historical low values.



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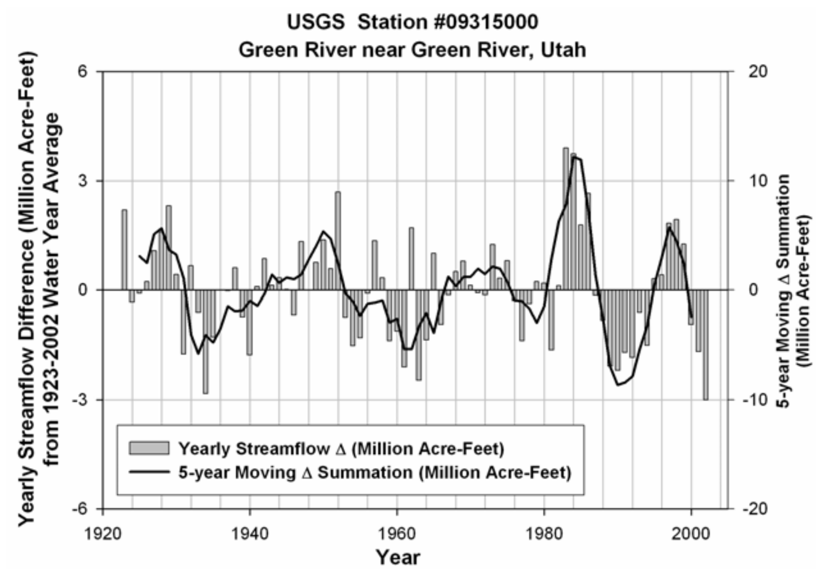

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Figure 3: Yearly streamflow difference and 5-year moving summation for (a) Colorado River near Cisco, Utah (b) Green River near Green River, Utah

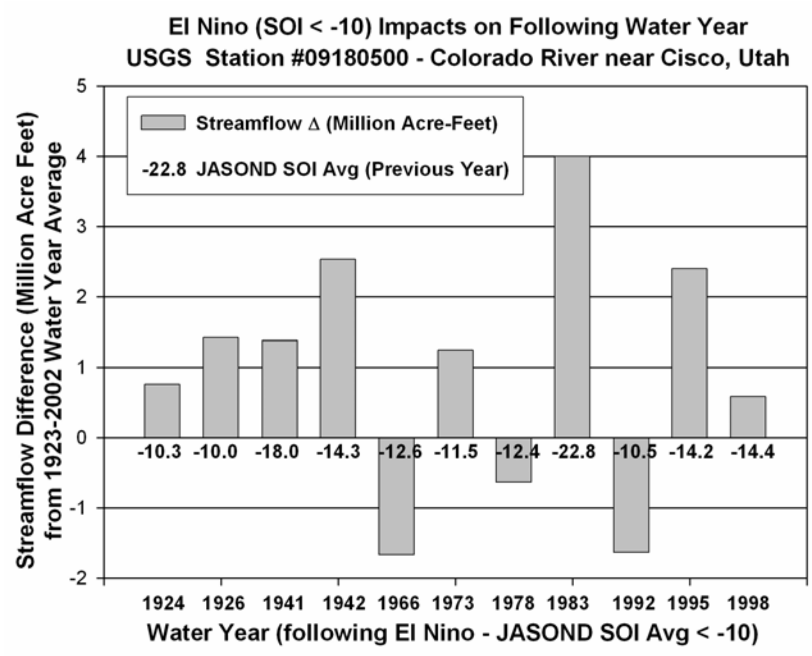
Drought and Climate Variability

A common measure of the strength or weakness of ENSO is the Southern Oscillation Index (SOI). The Troup SOI used by the Australian Bureau of Meteorology (ABoM) was selected for use in this study. The Troup SOI is the standardized anomaly of the Mean Sea Level Pressure difference between Tahiti and Darwin. The SOI ranges from about –35 to about +35, where a negative SOI value represents an El Niño occurrence, while a positive SOI value represents a La Niña occurrence.

Monthly SOI values were obtained from the ABoM website (www.bom.gov.au). The monthly SOI values were then averaged for the months of July, August, September, October, November and December (JASOND), the typical timeframe for the occurrence of a El Niño / La Niña. For this paper, an El Niño event is defined as when the JASOND SOI average value for a particular year is less than or equal to –10. Based on this definition, 11 El Niño events occurred between 1923 and 2002 (1923, 1925, 1940, 1941, 1965, 1972, 1977, 1982, 1991, 1994 and 1997). Figure 4 presents previous year's JASOND average SOI and the magnitude of the streamflow difference for the water year immediately following the El Niño. For the Cisco station, 8 of 11 positive (above average) streamflow events occurred after an El Niño event while, for the Green station, 7 of 11 positive streamflow events occurred after an El Niño event. It should be noted that the largest El Niño (most negative JASOND SOI average value) for this study was –22.8 and it occurred in 1982. The largest positive streamflow occurred in 1983, the year following this event (See Figure 4). Also, as previously noted and presented in Figure 3, the years following this extreme El Niño represented several of the largest positive streamflow years in the record.

The Pacific Decadal Oscillation (PDO) (Mantua et al., 1997), is a climate phenomena associated with persistent, bimodal climate patterns in the North Pacific Ocean that oscillate with a characteristic period on the order of 50 years (a particular phase of the PDO will typically persist for about 25 years). The PDO also refers to a numerical climate index based on sea surface temperatures in a particular region of the North Pacific (Mantua et al., 1997), which has an interannual signal. The warm phase of the PDO has a positive numerical index value while the cold phase has a negative numerical value.

PDO values were obtained from the Joint Institute for the Study of the Atmosphere and Ocean, University of Washington (http://tao.atmos.washington.edu/pdo/) for the period of 1923 to 2002. The average monthly values were converted to average water year values. Figure 5 presents the average water year PDO values versus the 5-year moving summation of streamflow differences. There is a tendency for positive correlation between the PDO and streamflow (i.e., positive PDO results in above average or positive streamflow, and vice versa). Figure 6 more closely examines this trend. For the Cisco station, 28 of 39 (72%) negative PDO values resulted in negative streamflow while 27 of 41 (66%) positive PDO resulted in positive streamflow. For the Green station, the PDO signal strength was not as well defined – 23 of 39 (59%) negative PDO values resulted in negative streamflow while 24 of 41 (59%) positive PDO resulted in positive streamflow.



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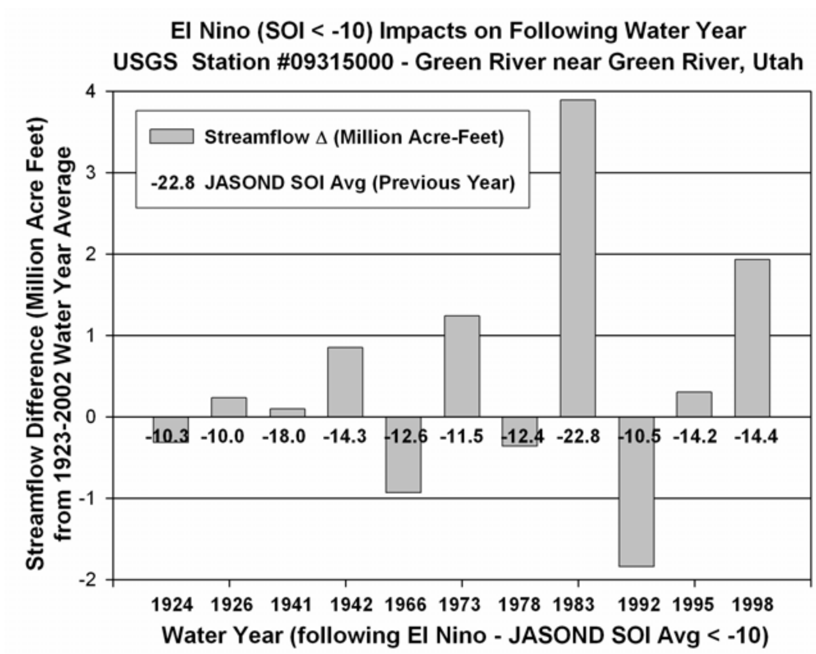

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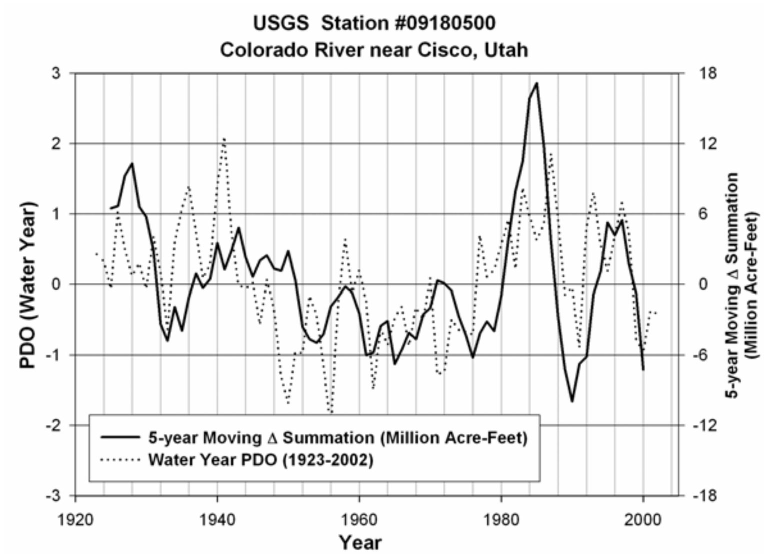
Figure 4: Yearly Streamflow Difference for Water Years following JASOND El Nino for (a) Colorado River near Cisco, Utah (b) Green River near Green River, Utah



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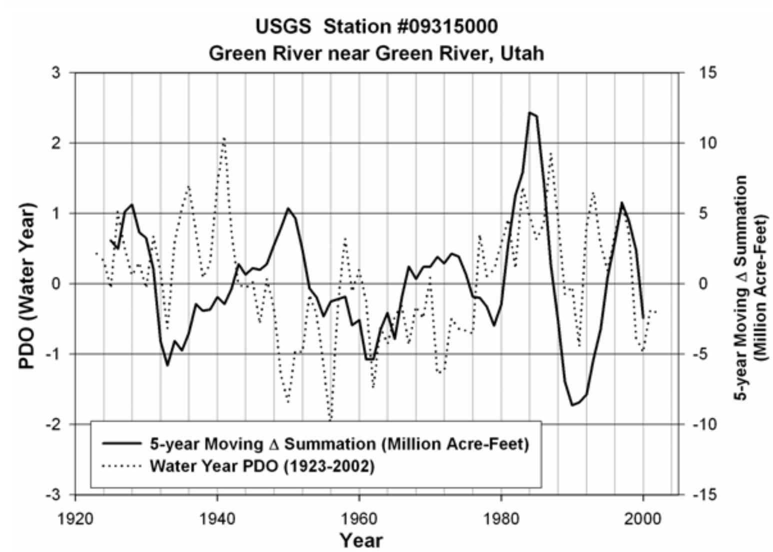

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Figure 5: **Yearly PDO for Water Years versus 5-year Moving Difference Summation for (a) Colorado River near Cisco, Utah (b) Green River near Green River, Utah**

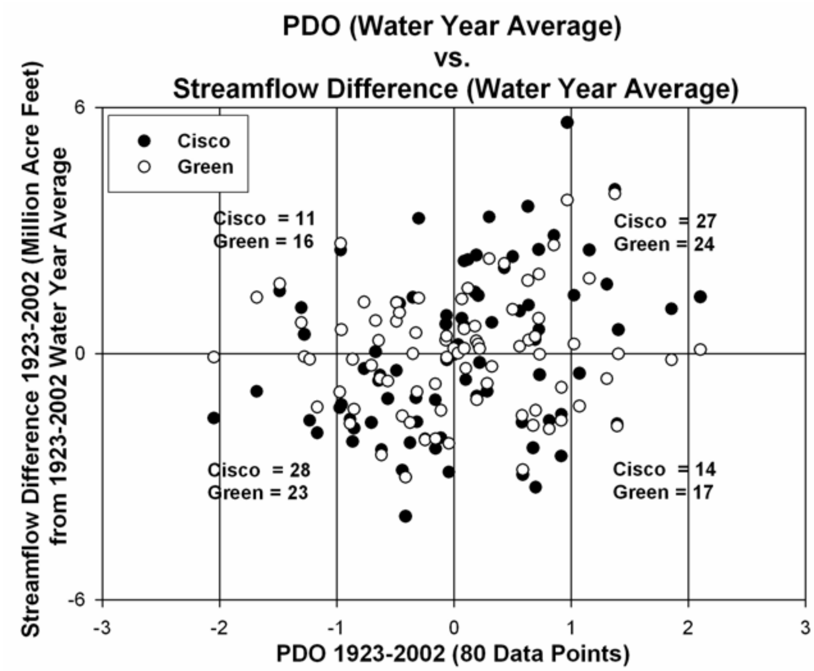

Figure 6: Yearly PDO for Water Years versus Streamflow Difference for the Colorado River near Cisco, Utah and the Green River near Green River, Utah

Conclusions

There are several noteworthy observations from the study presented here.

- The two most recent droughts are the largest recorded in the past 80 years.
- The current El Niño event is weak (SOI = -10) and will probably not have a large impact on streamflow in the Upper Colorado River basin for the current water year.
- In the year following El Niño events, streamflow is on average 10-15% higher in the Upper Colorado River basin. This is not sufficient to bring the Upper Colorado River basin out of the current drought.
- There is a tendency for Upper Colorado River basin streamflow to be in phase with the PDO. For instance, the largest droughts in the Colorado River at Cisco correspond to periods of negative PDO values.

Acknowledgements

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