Climate Variability and Water Supply of the Colorado River Basin

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Abstract

This study investigates the implications of climate variability and long range forecasting to the water resources of the western United States. More specifically, the usefulness of this information to water agencies in the Colorado River Basin is studied. Streamflow data from select stations are evaluated for a relationship with the climate indices: (1) the Southern Oscillation Index (SOI); (2) the Pacific Decadal Oscillation (PDO); and (3) the North Pacific (NP). Results indicate that the Lower Colorado River Basin has a significant correlation with the SOI and PDO. The SOI and PDO can serve as indicators of the upcoming water year (Oct – Sept) streamflow conditions for the Lower Colorado River Basin. The results are not as encouraging for the Upper Colorado River Basin where the strength of the relationship is weak. Further studies should investigate the potential of utilizing climate indices for long-range streamflow forecasting prior to the beginning of the water year.

Introduction

Climate change and climate variability has received considerable attention from the scientific community in the past decades, and now policy and decision makers want to know how the past research may be beneficial to the public. This study investigates the implications of climate variability and long range forecasting to the water resources of the western United States. More specifically, the usefulness of this information to water agencies in the Colorado River Basin is studied. The majority of the runoff in the Colorado River Basin is generated from snowmelt in the Upper Basin, so it is logical to investigate changes in the climate and hydrology of the Upper Basin. Climate variability and climate change have global impacts, so it is also necessary to identify the broader regional impacts (e.g., the southwest U.S.) and how this information is scaled down to a region such as Southern Nevada.

This study summarizes the current state of long-range hydrologic forecasting as relevant for water supply purposes; however, the state of flood forecasting will not be discussed here. The impact of climate variability and effects on water resources is then discussed. Particular emphasis is placed on identifying climate indices that may be useful for long range hydrologic prediction. Lastly, the implications of climate variability and droughts are analyzed and discussed.

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Long Range Hydrologic Forecasting

Research on long range seasonal hydrologic forecasting is not as well coordinated as climate forecasting. The National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC) is responsible for issuing long range climate forecasts. The lack of a coordinating agency for hydrologic forecasts has limited the transfer of new research into operational hydrology. The National Weather Service (NWS) does have River Forecast Centers (RFCs) that issue short term hydrologic forecasts on the order of hours to days in advance; however, these forecasts are more relevant to protecting the public from floods. Water agencies are interested in the forecasting of water supply for the upcoming seasons.

For the western U.S., there are two main agencies that provide operational long range hydrologic forecasts — the Natural Resources Conservation Service (NRCS) and the Colorado Basin River Forecast Center (CBRFC). These forecasts are usually in the form of a runoff volume –an important variable for water supply purposes.

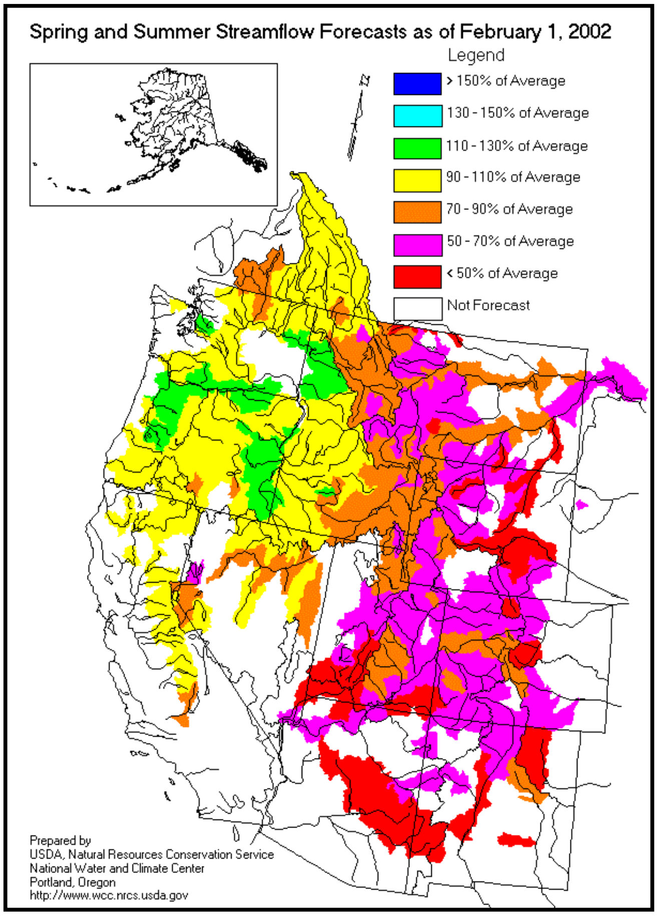

Figure 1: NRCS Spring - Summer 2002 streamflow forecast based on observed snowpack conditions on February 1, 2002. (Source: NRCS)

Natural Resources Conservation Service (NRCS)

The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) is responsible for continuously monitoring snowpack data in the western U.S. and producing the water supply forecasts for many rivers. The National Water and Climate Center provides information to the NRCS for producing the water supply forecasts (http://www.wcc.nrcs.usda.gov/). The "Water Supply Outlook for the Western United States," issued by the NRCS, provides streamflow predictions for the snowmelt and summer runoff periods of April through July (NRCS, 2001). In addition to streamflow forecasts, the outlook provides a summary of snow accumulation to date, and storage in large reservoirs.

Figure 1 presents the Spring – Summer 2002 streamflow forecasts for the western U.S. based on observed snowpack on February 2002. Spring – summer runoff forecasts are important since this is the time of highest flow, due to snowmelt runoff, and this also corresponds to the period of highest water demand. These forecasts are first issued in January and then updated monthly based on recent snow survey data. The last update is issued in May.

Colorado Basin River Forecast Center (CBRFC)

The Colorado Basin River Forecast Center (CBRFC) is one of the five river forecast centers operated by the NWS (http://www.cbrfc.noaa.gov/). The CBRFC issues short term hydrologic predictions such as river stages for flooding purposes, long term forecasts of water supply, and timing of spring-summer flood peaks. The forecasts issued by CBRFC are done so in conjunction with NRCS, so there is consistency in the water supply outlook. The difference for the Colorado River Basin is that the Advanced Hydrologic Prediction System (AHPS) is used instead of the statistical forecast that NRCS uses for the remaining rivers in the west.

The AHPS produces simulated flow scenarios that may occur in the future based on historical climate data. The scenarios can also utilize information, such as El Niño, to condition the forecast (i.e., only use information from past El Niño years). These various simulations are called traces and statistical analysis can be performed on the data to obtain exceedance probabilities. Figure 2 is an example of the traces produced for the Green River streamflow forecast over the next three months.

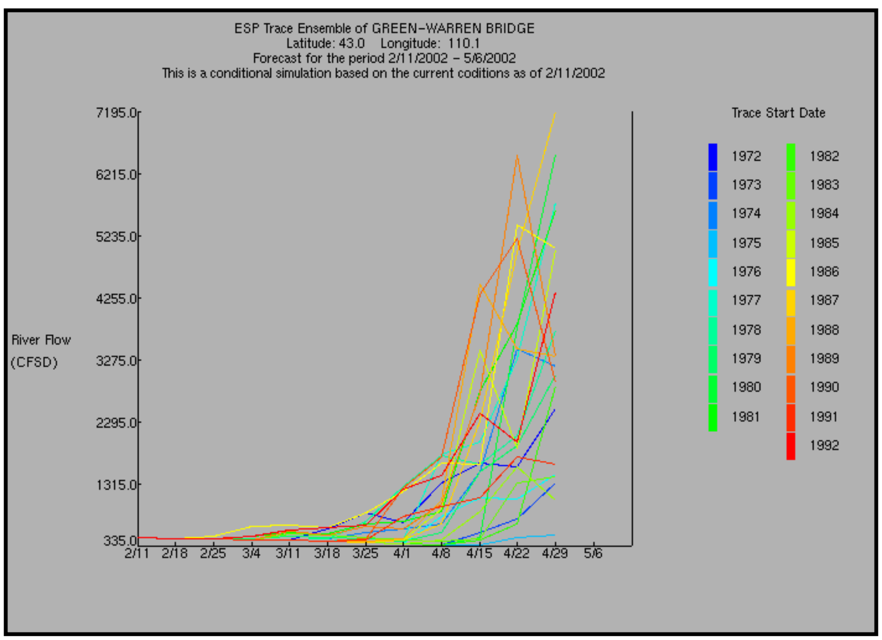

Figure 2: CBRFC streamflow forecast for the Green River at Warren Bridge for February – April 2002 using the AHPS.

Climate Variability and Western U.S. Water Supply

The relationship between climate indices and streamflow variability has long been investigated using variables such as the Southern Oscillation Index (SOI) which is a broad measure of the El Niño – Southern Oscillation. Recently, new climate indices have been developed that measure large scale (in time and space) atmospheric phenomena. These include the Pacific Decadal Oscillation (PDO) (Mantua et al., 1997) and the North Pacific (NP) (Trenberth and Hurrell, 1994) which measure atmospheric pressure and sea surface temperature variations in the northern Pacific Ocean.

Table 1: List of USGS stations with unimpaired streamflow data. The NRCS currently provides water supply forecasts for these stations. The Lee's Ferry data has been adjusted to represent natural flows.

River Basin	Site Name	USGS Site #	Years of Record
Truckee	Truckee River at Farad	10346000	1909-2000
Walker	East Walker at Bridgeport	10293000	1921-2000
Colorado	Lee's Ferry		1906-2000
Colorado	Whiterocks River near Whiterock	09299500	1909-2000
Colorado	Virgin River near Littlefield	09415000	1929-2000

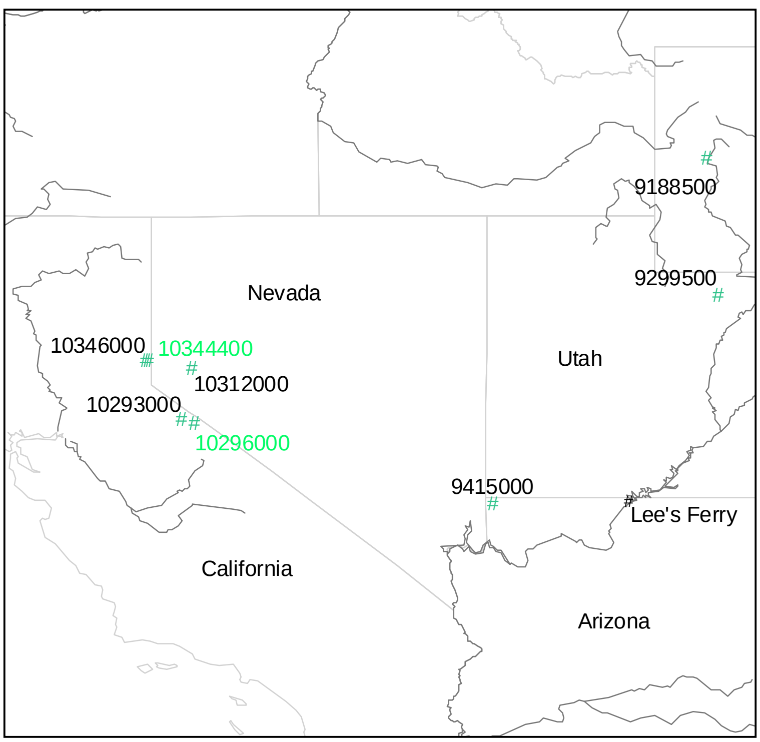

Figure 3: Select USGS streamflow stations for rivers supplying surface water for Nevada. These stations have unimpaired streamflow data and are locations that the NRCS forecasts spring-summer runoff.

In this study, streamflow in the Colorado River Basin and the eastern slopes of the Sierra Nevada are related to the three indices (SOI, PDO, and NP). The purpose is to determine whether these indices provide information for long range water supply forecasting. Therefore, the streamflow is expressed as Water Year (October – September) values. Figure 3 and Table 1 present the locations of the stations used in this study. The data for these streamflow stations was obtained from the U.S. Geological Survey (USGS) National Water Information System (NWISWeb), which is a network of relatively unimpaired streamflow data. It is important to use stations that have relatively minor upstream impairment since the study is evaluating the true climate signal in streamflow data. The Lee's Ferry data is from the U.S. Bureau of Reclamation that has adjusted the flows to account for reservoir operations. All of these stations are ones that the NRCS forecasts spring-summer runoff and the results from this study would represent a direct benefits to the users of the forecasts.

Table 2: Correlation table between Water Year streamflow and seasonal climate indices (PDO, NP, and SOI). The first three seasons [JFM(-), AMJ(-), and JAS(-)] are all prior to the water year [OND(-), JFM, AMJ, JAS]. The light shaded boxes are correlations significant at the 95% confidence level. The dark shaded boxes are significant at the 99% level.

				Water Year (Oct-Sept)			
Station/Index	**JFM(-)**	**AMJ(-)**	**JAS(-)**	**OND(-)**	**JFM**	**AMJ**	**JAS**
Lee's Ferry							
PDO							
NP							
SOI							
Virgin River							
PDO							
NP							
SOI							
White River							
PDO							
NP							
SOI							
Truckee River							
PDO							
NP							
SOI							
East Walker							
PDO							
NP							
SOI							

Table 2 summarizes the relationship between streamflow variability and climate indices for preceding periods for the stations listed in Table 1. For all cases, the Water Year (WY) streamflow is related to the seasonal climate index from the previous calendar year (-) and the three seasons of the current calendar year. Thus, the first three seasons in the previous calendar year [JFM(-), AMJ(-), JAS(-)] act as predictor variables for the upcoming WY streamflow at each station. The remaining seasons are also predictors of WY streamflow since they are predicting the remainder of the WY flows. There are several noteworthy results from Table 2:

- Lee's Ferry streamflow is not highly correlated with any of the climate indices. Lee's Ferry represents the flow from the Upper Colorado River basin which has not been as closely linked to climate variability such as ENSO.

- The Virgin River, in the Lower Colorado River Basin, is highly correlated with the SOI and PDO. Moreover, the correlation between streamflow and the SOI is strongest during the early predictor periods (i.e., the WY streamflow can be predicted with the SOI during the JAS(-), OND(-), and JFM periods). The PDO has similar predictive qualities.
- There is a slight correlation between the White River, in the Upper Colorado River Basin, and the SOI. It is encouraging that the strongest correlations for this station are for the early predictor periods.

Drought and Climate Variability

Drought is a major concern in the Colorado River Basin where the water resources are over allocated among the states. Currently, the basin has experienced three consecutive years of below normal precipitation and could be entering a drought period. The relationship between the climate indices is investigated by evaluating the upper, middle, and lower terciles of the streamflow data and the corresponding climate indices during these periods. Figure 4 presents the shift in the climate indices associated with the different streamflow periods at the Virgin River station in the Lower Colorado River Basin.

There are clear shifts in the distribution of the PDO and SOI data during the three streamflow periods. During drought periods (lower tercile streamflow), the SOI is generally higher reflecting La Niña conditions, and the PDO is generally lower. The opposite response in both the PDO and SOI is observed during wet periods (upper tercile streamflow).

Conclusions

The preliminary results of this research suggest that the PDO and SOI may be important for making long-range water supply forecasts in the Lower Colorado River Basin. For example, the observed PDO and the SOI at the beginning of the water year may be good predictors of the total water supply for the year. This is valuable information since current methods only allow water supply forecasts to be made starting in January of the water year. The weak signal in the Upper basin was also noted by Clark et al. (2000) who studied the snow pack in the Colorado River Basin during El Niño and La Niña years. There was a mixed signal 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. Piechota et al. (1997) also noted the weak signal in the Upper Basin and stronger signal in the Lower Basin.

Future studies should evaluate the linkage between the PDO and SOI. Researchers have noted the linkage between ENSO and PDO (Gershunov and Barnett, 1998). Strong and consistent El Niño patterns were found on U.S. climatic variables only during the positive phase of the PDO, while the patterns typical of La Niña winters are strong and consistent during the negative phase of the PDO. Thus, it would be prudent to investigate how streamflow varies in relation to the PDO and identify how this information might be useful as a predictor variable.

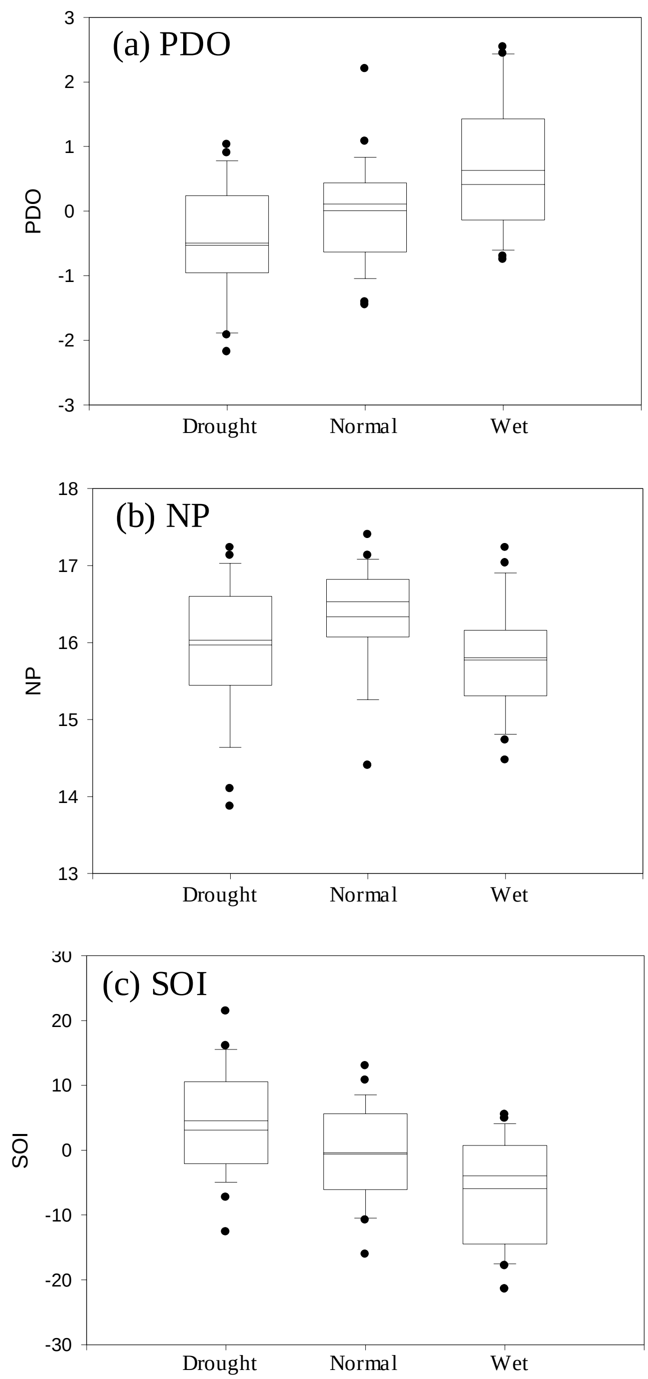

Figure 4: Box plots of (a) PDO, (b) NP, and (c) SOI indices when divided into terciles based on Virgin River water year streamflow. The top and bottom whiskers represent the 90^{th} and 10^{th} percentiles, respectively. The top and bottom of the box represent the 75^{th} and 25^{th} percentiles, respectively.

Acknowledgements

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