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Editorial

Building Bridges in Nevada

By Michael Strobel, PhD, Chief Editor, Journal of the Nevada Water Resources Association and Associate District Chief, Nevada District, U.S. Geological Survey

To begin, I would like to welcome you to the first edition of the Journal of the Nevada Water Resources Association (JNWRA). Our goals are to produce a quality web-based science journal that addresses water issues important to Nevadans, provide an outlet for research reports that are of local or regional interest, present student papers in a peer-reviewed publication, and keep readers abreast of recent developments in scientific, political, and public-opinion directions that potentially affect present and future water management in the State. We will try to accomplish this by publishing the JNWRA twice yearly. The success of the journal depends on the scientific contributions from a broad range of researchers in Nevada. I encourage each of you to consider using the JNWRA to share your research with your colleagues in Nevada.

A journal would not be possible without huge efforts from many people. I would like to thank the NWRA Board of Directors for agreeing to pursue this endeavor, and especially the Executive Director, Donna Bloom, for all her support, efforts, and perseverance to seeing this develop from an idea into a true publication. The Assistant Editors, Chris Benedict, Dave Berger, Terry Katzer, and Mike Widmer, reviewed the manuscripts, provided valuable technical comments, and spent much time and effort to make sure this first edition of the JNWRA is both interesting and technically sound. Anne Jeton, USGS, provided technical review of one of the manuscripts. These contributions are greatly appreciated. Future editions will rely more heavily on the peer reviews of our Associate Editors. If you are interested in serving as an Associate Editor, please provide a letter of intent and a brief resume and bibliography.

As the title of this editorial suggests, I would like to discuss the concept of building bridges. Nevada, being the driest State in the United States, often isn't the focus of discussion when one thinks about bridges. Why build bridges when you don't even have streams to cross? But it's because we are so dry that we need to consider how to build bridges.

The bridges I refer to are those between the various water groups representing the needs and interests of various parts of our population in Nevada. We have some critical issues to address in Nevada when we talk about water. Rapid growth in population in some of our urban areas is putting stresses on the water resources readily available to these areas, and results in expanding the search for additional water resources into the rural parts of Nevada. Water rights, water importation, and potential changes in the way-of-life in many parts of Nevada are possibly the most discussed and potentially controversial issues we face at this time. The enduring drought in the western Unite States only adds to the stress of our water resources and contributes even more urgency for the need to explore and utilize other options for water supply. Water quantity isn't the only concern we face. Potential water-quality degradation from contamination in Lake Mead, declines in water clarity in Lake Tahoe, effects of mining on stream and ground-water quality, and meeting the new Federal standards for arsenic levels in drinking water are just some of the difficult issues that need to be resolved. Water managers and political decision-makers, and society in general, are expecting scientists to provide some answers and some guidance for addressing these issues. The reality is that the burden falls on us as water scientists to look at the data, understand the natural environment and the potential impacts from various stresses, and provide conclusions on how to proceed with the benefit of Nevada in mind. This certainly is a huge responsibility for all of us.

The problem is that every scientist has their own opinion on how to proceed. We are, after all, human, and although we would like to believe that science is pure and unbiased, there is a large degree of what we refer to as "scientific judgment" with each conclusion we make. Every scientific study has some degree of uncertainty, which we often qualify with error bars around the data points. How we draw conclusions while considering the uncertainty often depends on our perspective on things. A scientist looking for water resources to increase water supplies for a growing city might focus on positive aspects of the data and conclude higher values of available water for a basin. A scientist looking at limiting human impacts on water resources to a minimum might focus on the lower range of data values and make different conclusions. Because with any earth science, there are always large numbers of unknowns, which make it a necessity to make scientific judgments. This is why every science paper and presentation comes with its share of disagreement and counter-arguments. This also is why the State Engineer can hold week-long hearings to discuss water appropriations and hear two different views from prominent scientists concerning the same topic. I always find humor when hearing news reports that because one group of scientists disagree with the findings of another group of scientists, for example the discussions over global warming, the media headlines the story with "scientists disagree on subject." Well, no kidding. And this makes headlines because society believes science should be exact, unquestionable, and all scientists should see the data and be in complete agreement. We all know this is never the case.

This brings me to the title of this article. If we can build bridges of interaction and communication between the various science groups in Nevada, it will benefit everyone involved. Instead of separating into different camps of differing opinions, we need to consider how to work together to find common solutions for the people of Nevada. It is imperative that scientists share data, observations, and conclusions with each other and offer their findings for discussion, scrutiny, and possibly either general acceptance or refutation. I truly believe that each of us want to do what is best for Nevada. I also believe that each of us have our own opinions on what that might be, whether concerning water supply, urban growth, water quality, Yucca Mountain, or any other issue. It is important for the science and for the people of Nevada that the science community interact, share ideas, share data, discuss and debate (even argue), and find common conclusions. Building bridges between the many science groups can only improve the quality of our science, reduce costs by sharing data, expertise, and technology, and result in viable recommendations for managers and politicians in deciding the future for Nevada. It is my hope that this journal will serve as one mechanism for helping to build those bridges.

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Evaluation of Climate Factors to Forecast Streamflow of the Upper Truckee River

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ABSTRACT

Rapid development in eastern California and the Truckee Meadows (Reno) region of Nevada has resulted in an increased need for water. The primary water supply for the region is the Truckee River, which originates in the Sierra Mountains of California and Nevada and flows east until its terminus into Pyramid Lake. The Upper Truckee River Basin contributes the majority of runoff to the Truckee River. This is primarily due to higher precipitation (snowfall) in the Sierra Mountains and the resulting snowmelt during the spring-summer season. Currently, a spring-summer (April, May, June and July) forecast is provided by the Natural Resources Conservation Service for the Upper Truckee River station at Farad, California, considered the terminus (lower or downstream boundary) of the Upper Truckee River Basin. Water planners rely on this forecast, as well as other forecast models, to assist with water supply decisions. Cyclonic (frontal) storms that originate in the Pacific Ocean and move eastward account for the majority of wintertime precipitation (snowfall) in the western United States and the resulting spring-summer runoff. Seasonal averages of (a) persistence (previous season's streamflow); (b) Pacific Ocean climate indices for climate patterns such as the El Niño-Southern Oscillation, the Pacific Decadal Oscillation and the Pacific – North American index; and, (c) Pacific Ocean sea surface temperatures will be examined for long lead-times (3 to 9 months in advance) and correlated with the spring-summer streamflow for the Truckee River at Farad, California. Based on the results of this analysis, the more highly correlated "predictors" will be used in a statistically based streamflow forecast methodology previously applied to watersheds in Australia and the United States.

INTRODUCTION

The Truckee River provides a vital water supply to the Truckee Meadows region of Nevada including the major population centers of Reno and Sparks, Nevada. The Truckee River has numerous decrees, agreements and laws that effect the operation of the river (USGS, 1998). The Truckee River Operating Agreement (TROA) provides a foundation for improving water management and for negotiating and developing operating criteria to balance interstate and interbasin allocation of water rights (among the many competing interests). The TROA preferred instream flows are seasonal goals downstream of the reservoirs on both the Truckee and Little Truckee River.

Water supply forecasts for the spring-summer season are released monthly, beginning in January and ending in May. These exceedance probability forecasts of seasonal streamflow represent a coordinated effort between the National Weather Service and the Natural Resources

Conservation Service (NRCS) (http://www.wcc.nrcs.usda.gov/wsf/). Hydrologic data for these forecasts are obtained from numerous entities including the U.S. Bureau of Reclamation, U.S. Geological Survey, and local water district managers. Currently, an NRCS forecast is provided for two locations on the Truckee River. These locations are the outlet from Lake Tahoe (a stage rise forecast is provided) and the Truckee River at Farad (a streamflow forecast is provided for the spring-summer (April-May-June-July) season). A spring-summer forecast (percentage of average spring-summer streamflow) is provided on the 1st of the month beginning in January and ending in June of the current year.

The spring-summer streamflow season is selected since this is traditionally when the majority of the runoff occurs due to snowmelt, and this is the period of highest water demand. The challenge for some water resource managers is the small lead time prior to the spring-summer streamflow. The first official forecast by water agencies is provided on January 1st, three months before the beginning of the spring-summer streamflow and three months after the beginning of the water year, October 1st. The ability to provide a long range (3 to 9 month) forecast of the spring-summer streamflow for the Upper Truckee River Basin could be of value for managing the water resource system (e.g., reservoir releases). To potentially increase the lead time of a forecast, it is necessary to evaluate the influence on regional hydrology of: (1) Persistence [streamflow for a period (season) prior to the period of interest], (2) Large-scale oceanic and climate variability, and, (3) Pacific Ocean sea surface temperatures.

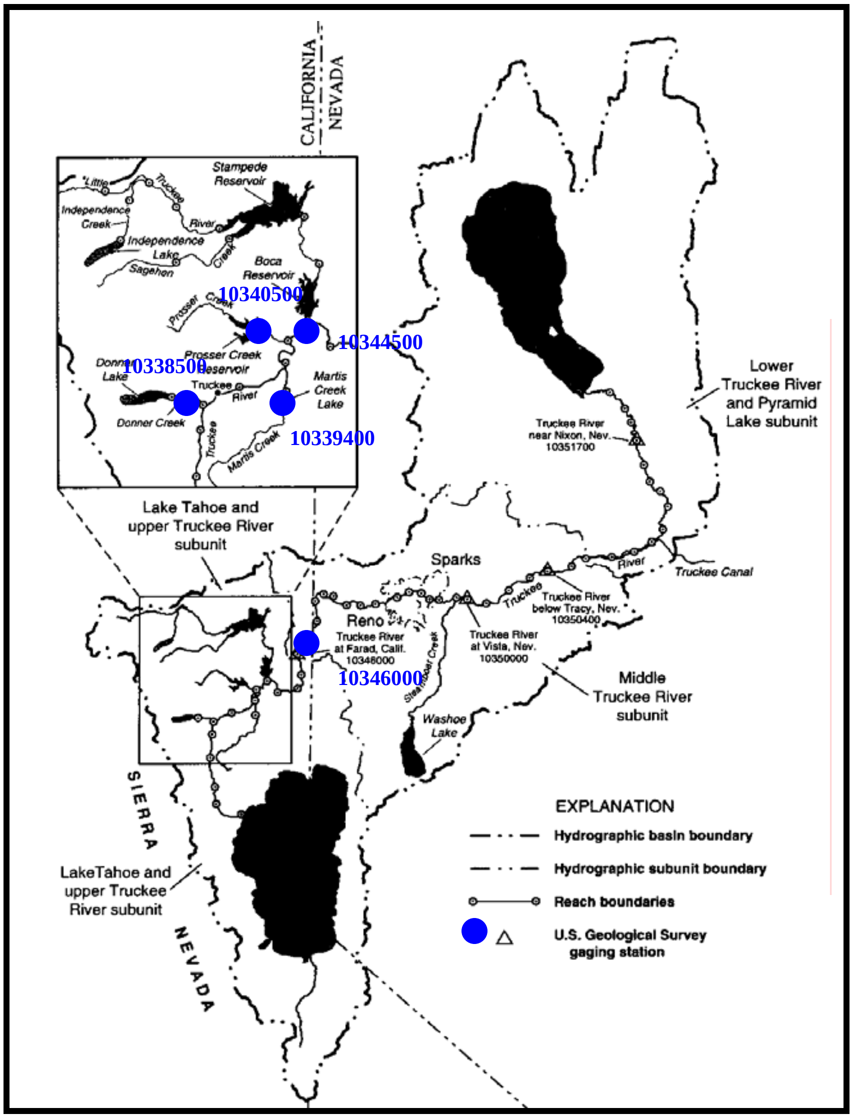
The most widely understood oceanic and atmospheric phenomenon is the El Niño-Southern Oscillation (ENSO) (Ropelewski and Halpert 1987) that describes the warm phase of a naturally occurring sea surface temperature oscillation in the equatorial Pacific Ocean while the Southern Oscillation refers to a shift in surface air pressure at Darwin, Australia and Tahiti. Other large scale climate occurrences include the Pacific Decadal Oscillation (PDO) (Mantua and Hare, 2002) and the Pacific / North American (PNA) index (Wallace and Gutzler, 1981) that are long-term ocean temperature fluctuations of the Pacific Ocean. Pacific Ocean sea surface temperature (SSTs) data consists of average monthly values for a 2^{o} by 2^{o} grid cell (Smith and Reynolds, 2002).

The research presented focuses on identifying the best climate predictors for long lead-time (3 to 9 month) forecasting of Truckee River spring-summer streamflow. The best climate predictors are used to develop a statistically based exceedance probability forecast for the spring-summer season of streamflow for the Truckee River. The significance of this work is the identification of long lead-time (3 to 9 month) predictors of spring-summer streamflow with the goal of providing a spring-summer streamflow forecast at (or prior to) the beginning of the water year (October 1st).

WATERSHED DESCRIPTION

The Truckee River (Figure 1) originates at the downstream outlet of the Lake Tahoe dam in the Sierra Nevada mountains of California. The headwaters of the river exceed elevations of 3,000 meters while the terminus of the river, Pyramid Lake, is at elevation 1,158 meters. The river has a total length of 183 kilometers and approximately 3,700 square kilometers of land area directly contribute to the river.

Figure 1. Location Map (USGS, 1998)



DATA

The major datasets used to develop the relationships between climate variability and streamflow are historical streamflow data for the Upper Truckee River, persistence (previous seasons streamflow) and historical climate / oceanic data for the Pacific Ocean.

Streamflow Data

Streamflow data were obtained from the U.S. Geological Survey (USGS) NWISWeb Data retrieval (http://waterdata.usgs.gov/nwis/) (Figure 1 and Table 1).

Table 1. List of USGS stations with streamflow data

River Basin	Site Name	USGS Site #	Study Period
Truckee River	Donner Creek	10338500	1959 to 1990
Truckee River	Martis Creek	10339400	1959 to 1990
Truckee River	Prosser Creek	10340500	1959 to 1990
Little Truckee River	Little Truckee River below Boca Reservoir	10344500	1959 to 1990
Truckee River	Truckee River at Farad	10346000	1959 to 1990

Identifying records of streamflow for long, uninterrupted periods of time proves challenging. Additionally, most streamflow data does not represent naturalized (or unimpaired) flow due to impoundments by dams and upstream diversions. The spring-summer runoff is considered the most important season for water supply due to the melting of winter accumulated snowfall. The spring-summer season is assumed to be April-May-June-July (AMJJ) for this study. Average monthly runoff rates in cubic feet per second (cfs) were obtained from the USGS NWISWeb for these months (for the period of study) for each of the five streamflow stations. The rate of runoff is then converted to monthly volume cubic kilometers (km^3) of runoff. The four months are then summed to determine the yearly AMJJ runoff volume (km^3) for each of the five stations. For the predictand (spring-summer streamflow), the (0) notation [i.e. AMJJ(0)] represents the current year. Linear correlation of the yearly AMJJ runoff volume for the five stations (Table 2) shows that, despite impoundments, spring-summer runoff is highly correlated between the stations. Given this high correlation, streamflow data for the Truckee River at Farad station is selected for the linear correlation analysis of persistence, Pacific Ocean climate indices and sea surface temperatures. The period of record for the Truckee River at Farad station will be expanded to 1953 to 2002 (50 years) and a forecast will be developed.

Table 2. Linear correlation values of yearly (1959-1990) spring-summer (AMJJ) runoff volume (cubic kilometers) for selected USGS stations.

	Donner Creek	Martis Creek	Prosser Creek	Little Truckee River below Boca Reservoir
Martis Creek	0.91			
Prosser Creek	0.93	0.93		
Little Truckee River below Boca Reservoir	0.75	0.85	0.78	
Truckee River at Farad	0.88	0.96	0.92	0.91

Persistence and Climate / Oceanic Data of the Pacific Ocean

Like the predictand (streamflow), average monthly values of persistence, the Southern Oscillation Index, the Pacific Decadal Oscillation index, the Pacific-North America Oscillation index and Pacific Ocean sea surface temperatures are averaged for each season: April-May-June (AMJ - spring season), July-August-September (JAS – summer season) and October-November-

December (OND – fall season). The (-1) notation [i.e. JAS(-1)] represents the previous year. The study period for all predictors is 1952 to 2001 (Figure 2).

Persistence

Persistence (streamflow volume from previous seasons) is determined by the same methods used to determine the spring-summer runoff volume. Average monthly runoff rates (cfs) were obtained from the USGS NWISWeb and then converted to seasonal volume (km^3).

Southern Oscillation Index (SOI)

The SOI is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. Sustained negative values of the SOI often indicate El Niño episodes. These negative values are usually accompanied by sustained warming of the central and eastern tropical Pacific Ocean, a decrease in the strength of the Pacific Trade Winds, and a reduction in rainfall over eastern and northern Australia (Philander, 1990). The most recent strong El Niño was in 1997/98. Positive values of the SOI are associated with stronger Pacific trade winds and warmer sea temperatures to the north of Australia, popularly known as a La Niña episode. Waters in the central and eastern tropical Pacific Ocean become cooler during this time. These events are typically on the order of 6 to 18 months in length.

There are two commonly used methods to calculate the SOI. The United States method (Ropelweski and Jones, 1987) is based on the difference in the standardized pressures at Tahiti and Darwin. The method used by the Australian Bureau of Meteorology (ABOM) is the Troup SOI (Troup, 1965) which is the standardized anomaly of the mean sea level pressure difference between Tahiti and Darwin. The Australian SOI was used for this study and data were obtained from the ABOM (http://www.bom.gov.au/climate/current/soi2.shtml).

Pacific Decadal Oscillation (PDO)

The PDO describes an oscillation in northern Pacific Ocean sea surface temperatures. Unlike ENSO events (which typically persist for 6 to 18 months and are located in the equatorial region of the Pacific ocean), the PDO cycle is 20 to 30 years in length. The PDO index is defined as the leading principal component of North Pacific monthly sea surface temperature variability (Mantua and Hare, 2002). Positive values of the index indicate warm phases of PDO, while negative values of the index indicate cool phases of PDO. The warm phase of the PDO tends to result in El Niño like weather patterns in the United States while the cool phase tends to result in La Niña like weather patterns (Mantua and Hare, 2002). PDO values were obtained from the University of Washington, Joint Institute for the Study of the Atmosphere and Ocean (JISAO) website (http://jisao.washington.edu/pdo/PDO.latest).

Pacific-North America Index (PNA)

The PNA index measures pressure / height differences at four points across the Pacific and North America for the months December, January and February. When surface pressures and temperatures are low over the northern Pacific Ocean, the same occurs in the southeastern United States while the opposite occurs over the northwest U.S. (Horel and Wallace, 1981). The PNA index is derived from the formula in Wallace and Gutzler (1981) and PNA values were obtained from the JISAO website (http://tao.atmos.washington.edu/data_sets/pna/).

Pacific Ocean Sea Surface Temperatures (SSTs)

SST data consists of average monthly values for a 2^{o} by 2^{o} grid cell (Smith and Reynolds, 2002). The range of Pacific Ocean SST data used for the analysis was Longitude 120^{o} West to Longitude 80^{o} East and Latitude 70^{o} South to Latitude 70^{o} North. This results in a grid with 81 cells in the x-direction and 71 cells in the y-direction. Pacific Ocean SST data were obtained from the National Climatic Data Center website (http://lwf.ncdc.noaa.gov/).

METHODOLOGY

Linear correlations were performed between the seasonal [AMJ(-1), JAS(-1) and OND(-1)] predictors (Persistence, SOI, PDO, PNA and Pacific Ocean SSTs) and the spring-summer [AMJJ(0)] runoff volume in cubic meters (Figure 2 and Table 3).

Figure 2. Seasonal predictors (Persistence, SOI, PDO, PNA & SSTs) and predictand (Streamflow).

PREDICTORS 1952-2001		
AMJ(-1)	JAS(-1)	OND(-1)
SPRING	SUMMER	FALL
PERSISTENCE, SOI, PDO, PNA & SSTS		

PREDICTAND 1953-2002
AMJJ(0)
SPRING-SUMMER
STREAMFLOW

Table 3. Correlation values of seasonal [AMJ(-1), JAS(-1) and OND(-1)] predictors to Truckee River at Farad AMJJ(0) streamflow. **Highlighted** predictors are those selected for model input.

	AMJ(-1) Spring	**JAS(-1) Summer**	**OND(-1) Fall**
Persistence	0.11	0.09	**0.37**
SOI	-0.10	-0.06	-0.20
PDO	0.05	0.11	-0.07
PNA	0.10	0.19	-0.04
SST Positive Region	**0.33**	**0.24**	**0.30**
SST Negative Region	**-0.27**	**-0.24**	**-0.28**

The “best” (highest correlation) predictors are input into an exceedance probability forecast model. The Student’s distribution (Fisher and Yates, 1938) was used to test the significance (confidence level). For this study, a predictor must exceed a 95% confidence level to be used in the forecast model. For a sample size of 50, the linear correlation value (R) must be great than 0.23 or less than -0.23 to achieve a 95% confidence level. For example (Table 3), for the OND(-1) predictor period, persistence, SST positive and SST negative all exceed the minimum 95% confidence level R value of +/- 0.23 and are therefore input into the forecast model.

The SST regions (Figures 3 – 5) represent areas in which the confidence level exceeded 95%. Blue regions represent regions that are positively correlated while red regions represent regions that are negatively correlated. The single “best” (highest correlation) SST region for both positive and negative correlations for each season are selected for input into the model. The region selected as the predictor used in the exceedance probability model is identified in the figure.

Figure 3. AMJ (-1) SST ranges as predictors of spring-summer [AMJJ(0)] streamflow for the Truckee River at Farad.

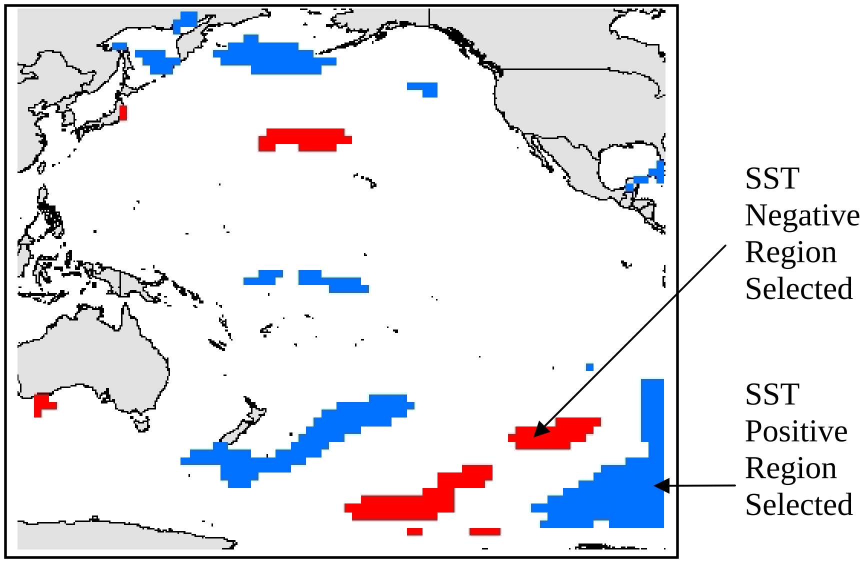


Figure 4. JAS(-1) SST ranges as predictors of spring-summer [AMJJ(0)] streamflow for the Truckee River at Farad.

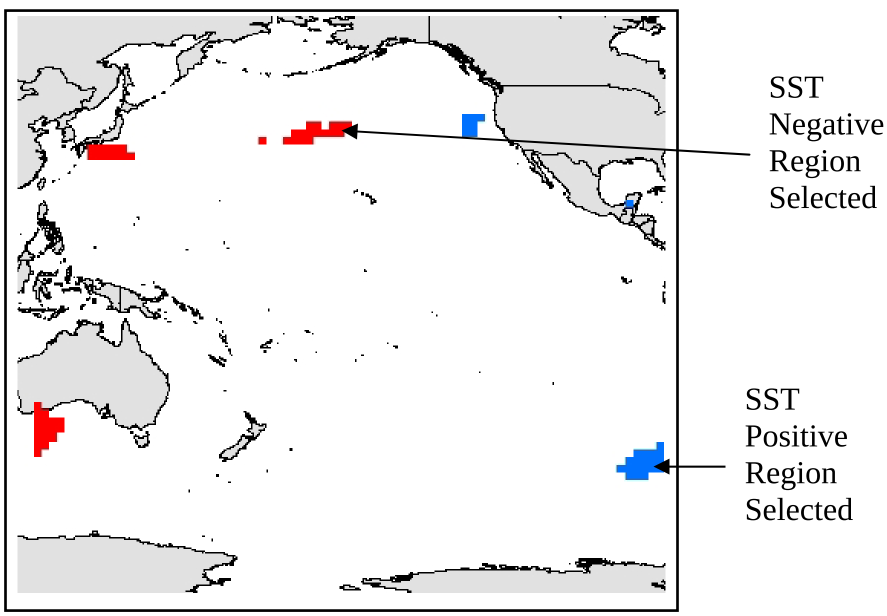
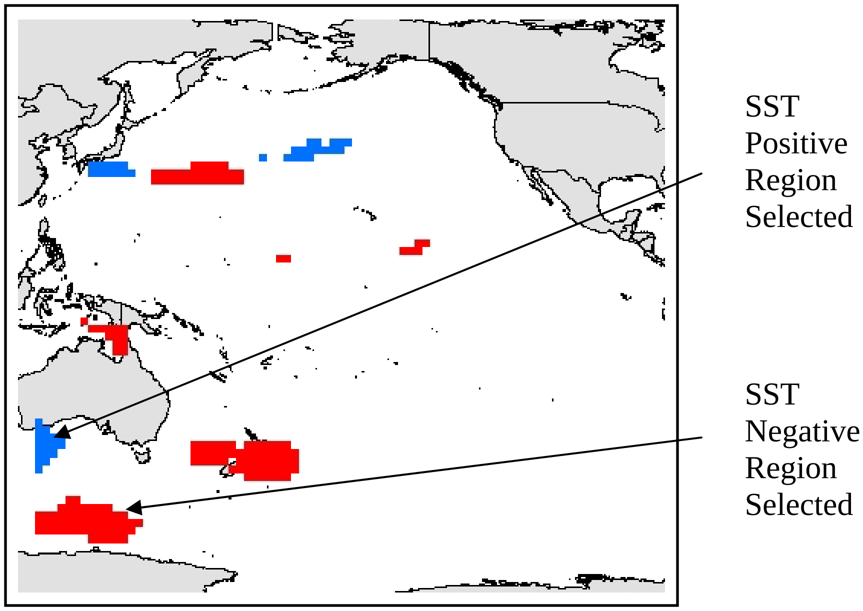


Figure 5. OND(-1) SST ranges as predictors of spring-summer [AMJJ(0)] streamflow for the Truckee River at Farad.



The streamflow forecast developed is a continuous exceedance probability curve that can be used for any assumed risk level and was developed by Piechota et. al, (2001). An exceedance probability is defined as the probability that the specified value (i.e., streamflow) will be equal to or exceeded during a time period. For example, a water agency may choose to take a 30% risk, which would correspond to a streamflow value that has a 70% probability of exceedance or, only a 30% probability of the streamflow value not occurring. The level of risk selected by the water agency is a function of several factors including water demand, water availability and reliability of the forecast. The "risk" for the water agency is the probability that the forecast will be exceeded. If an agency is only willing to assume a low level of risk, then they will have to operate very conservatively and a low streamflow value will be given as the forecast. A detailed description of the methodology and model can be found in Piechota et al., (2001) and Piechota et al., (1998). The model is statistically based and applies a kernel density estimator (Silverman, 1986 and Piechota et al., 1998) to develop a probability density function for each climate predictor.

The skill of the forecast was measured using the Linear Error in Probability Space (LEPS) score. The LEPS score is a measure of skill that was developed originally to assess the position of the forecast and the position of the observed values in the cumulative probability distribution (non-exceedance probability); the LEPS score can be used for continuous and categorical variables (Ward and Folland, 1991; Potts et al., 1996). The skill associated with each individual forecast is calculated for calibration and cross-validation analyses. Cross-validation provides a more independent assessment of the forecast skill and of the weights applied to each model (Elsner and Schmertmann, 1994; Michaelsen, 1987). Cross-validation allows the model to remove a year, calibrate the model, and then test the model on the year that was removed. The use of cross-validation eliminates spurious predictors and artificial skill. A 10% or greater value is generally considered a LEPS score with good skill.

RESULTS

All Years

As a predictor, persistence exceeds the 95% confidence level for only the 3-month [OND(-1)] lead-time. The climate indices (SOI, PDO and PNA) do not exceed the 95% confidence level for any predictor season. However, several Pacific Ocean SST regions are identified that exceed the 95% confidence level for all seasons. Although the calibrated LEPS score exceeded 10% for all predictor periods (Table 4), the cross-validated LEPS scores were significantly lower for all three predictor periods. Unfortunately, the low cross-validated LEPS scores results in the inability to provide an acceptable forecast for all years.

Table 4. Seasonal [AMJ(-1), JAS(-1) and OND(-1)] predictor selected, calibrated LEPS score and cross-validated LEPS score.

	AMJ(-1)	**JAS(-1)**	**OND(-1)**
Predictor Selected	SST "+" Region	SST "+" Region	Persistence
Calibrated LEPS Score	+13.7%	+10.1%	+10.5%
Cross-Validated LEPS Score	+0.1%	-0.3%	+1.5%

Drought Years

Focusing on drought and the ability to provide a forecast prior to the beginning of the water year (October 1st), the cross-validated LEPS scores for all years for AMJ(-1) and JAS(-1) were re-ranked based on increasing streamflow. The lower quartile of the 50 years of streamflow (i.e. the 12 years with the lowest streamflow) were selected and identified as drought years. The cross-validated LEPS scores for just the drought years improved to 3.4% for AMJ(-1) and 3.9% for JAS(-1). Although still below the goal of 10%, this shows that the model displays moderate predictability for drought years. The challenge for water planners is when to use this drought forecast.

Linear correlations were then performed with SSTs for AMJ(-1) and JAS(-1) seasons for the years preceeding the 12 drought years (lowest quartile of spring-summer streamflow for the period of record). SST regions, as identified in Figures 6 and 7, showed higher correlations values. The figures display correlation values greater than +0.70 or less than -0.70. As previously stated, blue regions represent regions that are positively correlated while red regions represent regions that are negatively correlated. The correlation values far exceed the 95% confidence level of +/- 0.23 used in the "all years" figures. Based on these high correlations, one would expect a strong forecast when the drought SST regions identified are used as predictors in a forecast model. Again, the issue is "when can we use these regions to make a drought forecast?" Future research may focus on identifying trends in these SST ranges and attempting to utilize this data as a forecast model predictor. It is noteworthy that the drought SST regions identified are almost entirely positively correlated, meaning lower sea surface temperatures results in lower streamflow (drought).

Figure 6. AMJ(-1) SST ranges as predictors of spring-summer [AMJJ(0)] streamflow for the Truckee River at Farad for drought years.

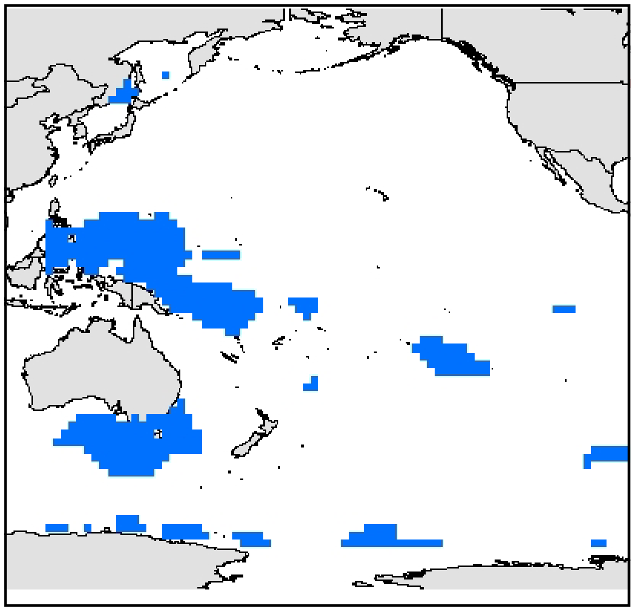
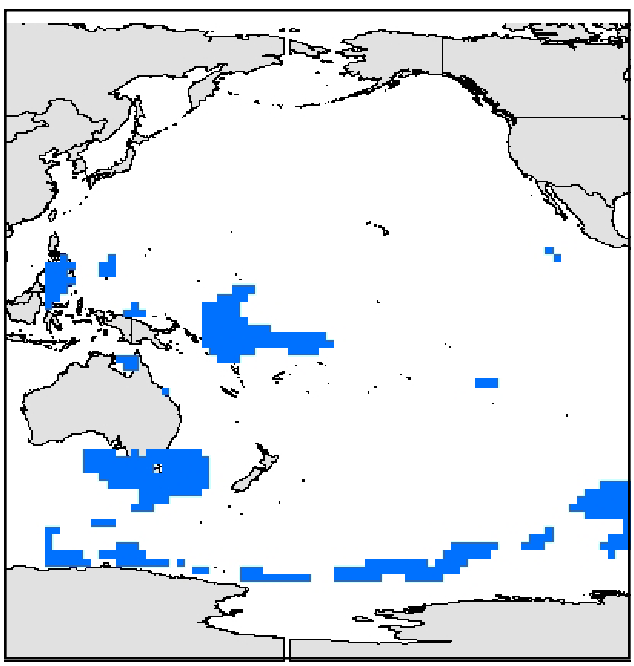


Figure 7. JAS(-1) SST ranges as predictors of spring-summer [AMJJ(0)] streamflow for the Truckee River at Farad for drought years.

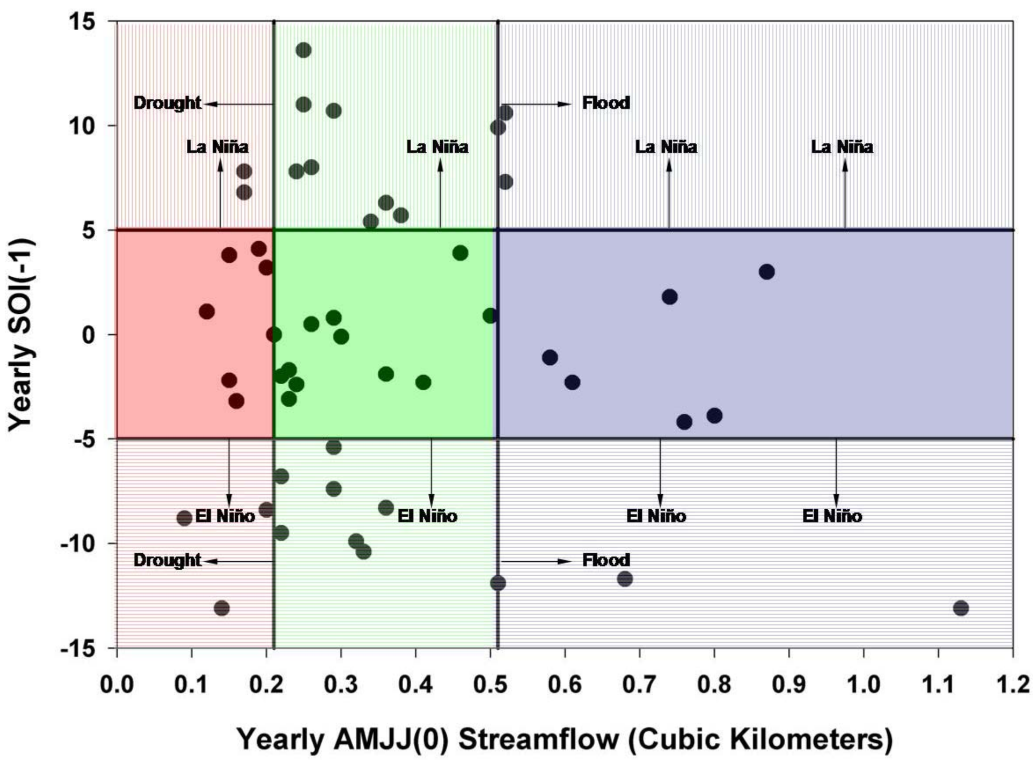


CONCLUSIONS

The study presented here provides several noteworthy results for long lead-time forecasting of the Truckee River. Persistence shows only high (> 95% confidence level) correlations for the 3-month [OND(-1)] lead-time. This result is not too surprising since early snowfall will result in saturated soil conditions and yield higher runoff. Long-term climate indices such as PDO and PNA show little correlation and predictability for spring-summer streamflow. This may be explained by the 20 to 30 year oscillations, and, thus, short lead-times (3 to 9 months) may not be appropriate for forecasting. It may be necessary to "lag" these indices by several or many years to produce desired results.

Although the SOI is a short-term (6 to 18 months) oscillation, the Truckee River is in a region that is not significantly (or consistently) influenced by ENSO (Brandon, 1998), and, thus, this predictor is probably not appropriate. The lack of a significant ENSO signal is again revealed in the SST figures (Figures 4 – 6). Note that none of the SST regions identified lie in the equatorial region of the Pacific Ocean, which is the region most associated with ENSO activity. Additionally, previous year SOI was plotted versus current year streamflow (Figure 8). An SOI(-1) value greater than +5.0 is considered a La Niña year (vertical hatching), while an SOI(-1) value less than -5.0 is considered a El Niño year (horizontal hatching). The highest quartile of streamflow is considered floods (blue) while the lowest quartile is considered droughts (red). The figure displays a "spread" of data in which no observable trend exists. A previous year La Niña produced two droughts and three floods for the following year's spring-summer streamflow. A previous year El Niño produced three droughts and three floods.

Figure 8. SOI(-1) versus spring-summer [AMJJ(0)] streamflow for the Truckee River at Farad.



A long lead-time forecast for all years is unavailable based on the low cross-validated LEPS scores. However, the model displayed moderate predictability for drought years. Linear correlations of drought year AMJJ(0) streamflow to previous year seasonal AMJ(-1) and JAS(-1) SSTs providing encouraging results. Numerous regions of significant correlation were identified in and around Australia and the southern Pacific Ocean. Additionally, these regions are positively correlated which shows that lower sea surface temperatures results in lower streamflow. Future research may be able to utilize this data for forecasting.

ACKNOWLEDGMENTS

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