HYDROCLIMATIC ASPECTS OF THE UPPER KLAMATH RIVER BASIN

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Abstract

In this study the hydroclimate of the Upper Klamath River Basin (UKB) is examined to identify climate factors that control the temporal variability of runoff in the basin. Runoff for the Sprague River is used for the analysis because runoff in this basin is highly correlated with runoff in other segments of the UKB, and the record of runoff measurements for this basin is the longest in the UKB (1922-present). Because much of the runoff in the UKB is generated from snowmelt runoff, runoff during March through May represents a large fraction (45 percent (%) on average) of water-year runoff in the UKB, and is used as the primary index of runoff for this study. Atmospheric pressures over the northwestern United States during the months of November through February are related to the precipitation that results in the largest proportion of the snowmelt runoff, and time series of these atmospheric pressures are highly correlated with runoff from the UKB. The lag relation between mean seasonal atmospheric pressure and snowmelt runoff in the basin suggests some predictive ability of UKB runoff using atmospheric pressure from the fall and winter seasons.

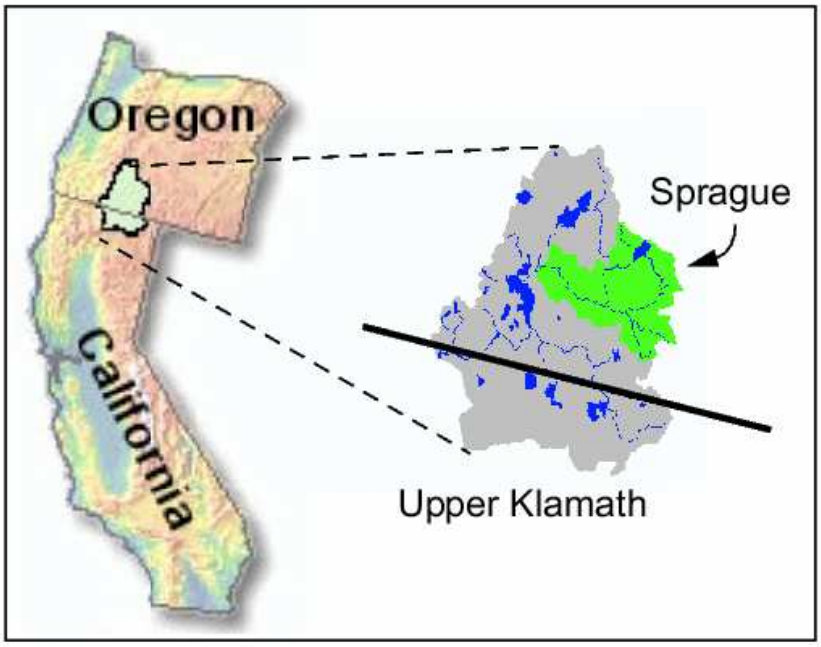

Figure 1. Map of the Upper Klamath River Basin

INTRODUCTION

The Upper Klamath River Basin (UKB) in southeastern Oregon and northeastern California (Figure 1) is an important water resource for both human use and the maintenance of natural habitat for a range of wildlife (Risley and Laenen, 1999). Competing needs for water in the UKB (e.g. water for agriculture and endangered-species) have increased and the increased competition for water has made water-resource management in the UKB complex. One of the first steps in improving water-resource management is an increased understanding of the natural hydrologic processes (i.e. the hydroclimate) of the basin. The principal objective of this study is to identify some of the primary climate factors that control runoff variability in the UKB. Climate factors analyzed include precipitation, temperature (as it relates to potential evapotranspiration), runoff, and 700 hecto-Pascal (700hPa) height atmospheric pressures.

DATA AND METHODS

Runoff for the UKB can be represented by runoff measured in the Sprague drainage basin (Figure 1). Continuous observations of streamflow have been made in this basin for over 80 years. A time series of mean monthly runoff for the Sprague basin (Figure 2a) indicates that runoff in the UKB is largely snowmelt driven, as a large proportion of the water-year runoff occurs during the spring months. For example, on average approximately 45% of the water-year runoff occurs during the 3-month period of March through May (MAM, Figure 2a).

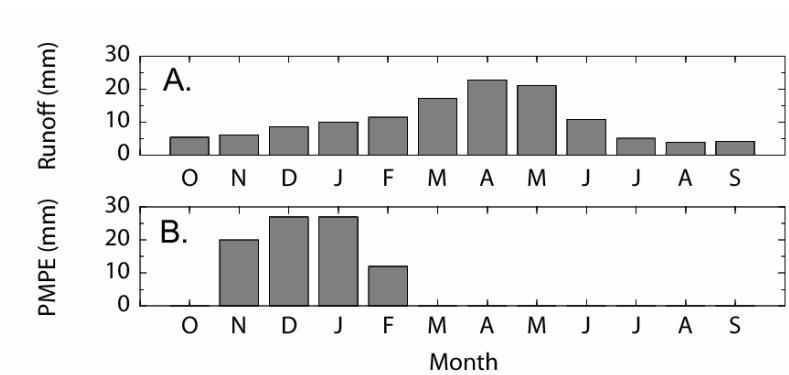

Figure 2. Mean monthly (A) runoff (in mm) for the Sprague Basin, and (B) precipitation minus potential evapotranspiration (PMPE in mm, potential evapotranspiration was computed using the Hamon equation (Hamon, 1961; 1963).

Mean monthly precipitation (water supply) minus potential evapotranspiration (PMPE, climatic demand for water) was computed for the UKB using monthly temperature and precipitation data (1895-2004) for climate division 7 in Oregon (this is the climate division in which most of the UKB is located). PMPE is a simple index of the water that is available to recharge soil-moisture storage and to potentially become runoff (Wolock and McCabe, 1999; McCabe and Wolock, 2002). Potential evapotranspiration was computed using the Hamon equation (Hamon 1961; 1963). An analysis of mean monthly

PMPE indicates that the most water that potentially becomes runoff occurs during the months of November through February (NDJF) (Figure 2b). Much of the precipitation during this period falls as snow and eventually becomes runoff during the spring months. The correlation between NDJF precipitation and MAM runoff is 0.77 ($p < 0.05$).

Because precipitation during the months of November through February has the greatest potential to contribute to UKB runoff, and because a large proportion of UKB runoff occurs during the months of MAM, these periods of time are the focus of the analyses in this study.

RESULTS AND DISCUSSION

Relations with Atmospheric Circulation

A significant factor that controls hydroclimatic variability is atmosphere circulation (McCabe and Dettinger, 2002). Atmospheric pressures for the 700hPa level were chosen for analysis because this atmospheric level provides a good representation of mid-tropospheric atmospheric circulation above many of the complex/local influences at the earth's surface and is strongly related to temporal and spatial variability of surface temperature and precipitation (McCabe and Dettinger, 2002). Figures 3a and 3b illustrate mean NDJF 700hPa height anomalies for the upper (lower) terciles of Sprague MAM runoff during water-years 1949-2003 (700hPa data were not available for previous years).

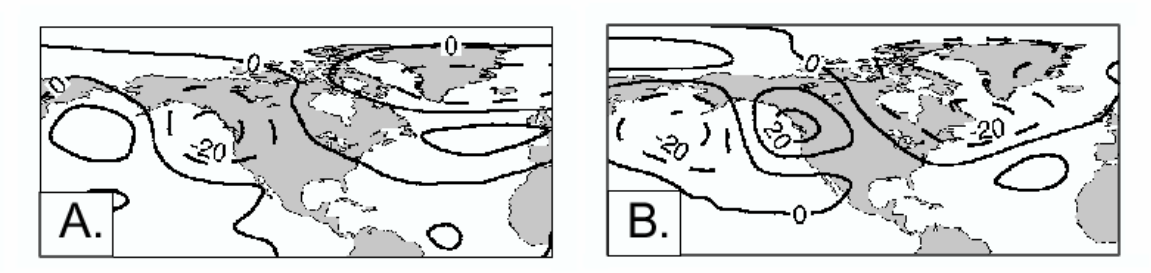

Figure 3. Mean November through February 700-hectoPascal (700hPa) height anomalies in meters for the (A) upper and (B) lower terciles of March through May runoff at Sprague, 1949-2003. Solid (dashed) isolines indicate positive (negative) 700hPa height anomalies. The first solid isoline is the zero isoline and the contour interval is 10 meters.

The NDJF 700hPa height anomalies suggest that when Sprague MAM runoff is high (Figure 3a), negative atmospheric pressure anomalies exist over northwestern North America (N.A.) and atmospheric pressures over the Aleutian Low region are slightly elevated. The negative anomalies over northwestern N.A. indicate a breakdown in the ridge of high atmospheric pressure that generally exists over this region during the winter months and the positive anomalies over the Aleutian Low region indicate a slightly weakened Aleutian Low. This pattern of negative and positive 700hPa height anomalies suggests increased zonal atmospheric flow across the northwestern United States (U.S.) which results in enhanced transport of atmospheric moisture (and storm systems) into the

northwestern U.S. The increased transport of moisture results in increased precipitation and subsequently increased runoff.

When Sprague MAM runoff is low (Figure 3b), the pattern of mean NDJF 700hPa height anomalies is almost the inverse of the pattern for high Sprague MAM flows (Figure 3a). For low runoff conditions, positive 700hPa height anomalies dominate northwestern N.A. and negative anomalies dominate the Aleutian Low region. This pattern of atmospheric pressure anomalies indicates a strengthening of the Aleutian Low and of the ridge of high pressure that generally exists over western N.A. during winter months. This pattern of anomalies indicates a blocking of the flow of atmospheric moisture (and storm systems) into the northwestern U.S. resulting in decreased winter precipitation and subsequently decreased MAM runoff.

Correlations between MAM Sprague runoff and mean NDJF 700hPa heights for the period 1949-2003 indicate significant correlations over the Aleutian Low region and particularly over northwestern N.A. (Figure 4). The pattern and signs of the correlations support the findings illustrated in the composite maps of mean NDJF 700hPa height anomalies for high and low MAM Sprague runoff, and indicate that the relations discussed are statistically significant at $p < 0.05$.

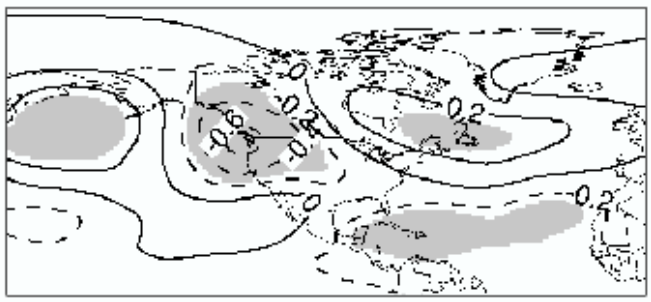

Figure 4. Correlations between March through May total Sprague runoff and mean November through February 700-hectoPascal heights, 1949-2003. The soild (dashed) isolines indicate positive (negative) correlations. The first solid isoline is the zero correlation isoline and the contour interval is 0.2. The gray shaded areas indicate correlations that are significant at a 95-percent confidence level.

The correlation results indicate that mean NDJF 700hPa heights averaged for the area over the northwestern coast of N.A. explain over 42% of the variability in MAM Sprague runoff (Table 2). The amount of explained variance decreases for mean seasonal 700hPa heights averaged for earlier time periods (Table 2). However, although small, the explained variance is statistically significant for mean seasonal h700Pa heights averaged for periods as far ahead of the MAM runoff period as August through November. Seasonal precipitation provides a larger explained variance of MAM runoff than do 700hPa heights for the time periods just before the MAM period (Table 2) because these time periods include the precipitation that ultimately becomes runoff. However, for earlier time periods the 700hPa heights explain a greater amount of MAM runoff

variance than does precipitation (Table 2). These results suggest that there is some predictive capability using fall/early winter 700hPa heights to estimate MAM UKB runoff that is not available using precipitation data.

Table 2. Percent (%) of variance in March through May (MAM) Sprague runoff explained by mean seasonal 700-hectoPascal (700hPa) heights over northwestern North America and mean seasonal precipitation (P) averaged for different 4-month periods prior to the MAM runoff period, 1949-2003. Asterisks indicate explained variances that are significant at a 95-percent confidence level.

Four-Month Period Used for Predictor Averages	Explained Variance (%) 700hPa	P
June through September	0.8	0.0
July through October	5.3	0.0
August through November	14.4*	0.0
September through December	28.1*	0.0
October through January	38.4*	50.2*
November through February	42.3*	56.4*

Trends in the Timing of Snowmelt Runoff

In addition to the magnitude of runoff, the timing of snowmelt runoff (SMR) also is important (Stewart et al., 2004; Regonda et al., 2005; McCabe and Clark, in press; Mote et al., 2005). One of the expected hydrologic effects of global warming is a shift in the timing of SMR to earlier in the year (Mote et al., 2005; Regonda et al., 2005). Consistent with this hypothesis, a number of studies have identified declines in spring snowpack (Mote et. al., 2005) and a shift to earlier SMR for many rivers in the western U.S. (Stewart et al., 2004; Regonda et al., 2005; McCabe and Clark, in press). The observed shift to earlier SMR is especially noticeable for basins in the northwestern U.S. (Stewart et al., 2004; Mote et al., 2005; Regonda et al., 2005).

Daily runoff observations for the Sprague gage were used to compute for each water-year the water-year day on which 50% of the mass of the total water-year runoff occurred (hereafter referred to as the center of mass date (CMD)). This methodology has been used in previous studies as an index of the timing of SMR (Stewart et al., 2004; Regonda et al., 2005; McCabe and Clark, in press). The CMD time series was then analyzed to identify any changes in the timing of SMR. Results indicate a large amount of variability in the CMD for the Sprague (Figure 5). Until about 1950 the Sprague CMD seemed to trend to later in the water year, whereas from about 1950 until the late 1990s the Sprague CMD trended to earlier in the water year. The trend to earlier CMD from about 1950 until the late 1990s seems to be consistent with the findings of other research that SMR has

become earlier for many parts of the western U.S. (Stewart et al., 2004; Regonda et al., 2005; Mote et al., 2005). However, since the late 1990s the Sprague CMD seems to have been occurring later in the water year. Whether there is a long-term trend to earlier SMR in the UKB, or whether the trend to earlier SMR during the 1950 to late 1990s period reflects low frequency climate variability in the UKB is uncertain at this point.

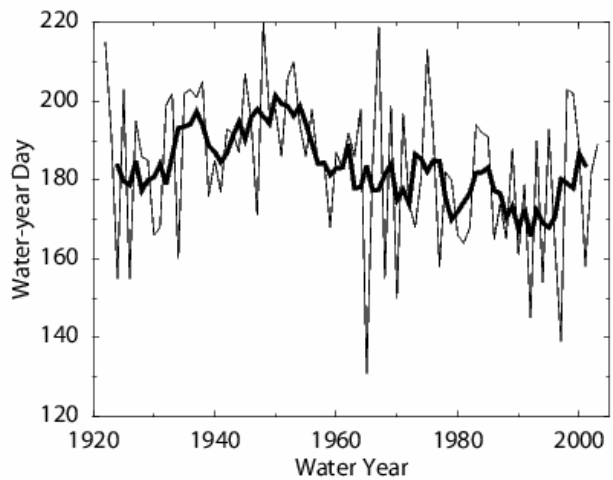

Figure 5. Water-year day (days since October 1) when 50 percent of total water-year runoff occurred, Sprague gage, 1922-2003. The thick line is a 5-year moving average.

Correlations between the Sprague CMD times series and MAM temperature and precipitation (computed using data from climate division 7 in Oregon) are -0.50 ($p < 0.05$) and 0.34 ($p < 0.05$) respectively (the correlation between MAM temperature and precipitation is -0.10 and non-significant). These correlations indicate that SMR is earlier (later) when temperatures are higher (lower) and precipitation is lower (higher). Thus, warm/dry MAM periods are related to earlier SMR. Increased temperatures result in decreased snow/precipitation ratios which lead to increased winter runoff. In addition, increased temperatures result in a more rapid melting of snow which also leads to earlier timing of SMR.

Although MAM temperature and precipitation are significantly correlated with the CMD time series on an inter-annual basis, neither the MAM temperature or precipitation time series indicate statistically significant trends over the 1922-2003 period.

Correlations between the Sprague CMD time series and MAM 700hPa heights support the interpretations above (Figure 6). The correlations are negative between the CMD time series and MAM 700hPa heights over northwestern N.A. This negative relation indicates that when atmospheric pressures are higher-than-average over northwestern N.A., SMR timing is earlier in the UKB. Higher-than-average atmospheric pressures over northwestern N.A. results in increased temperature and decreased precipitation in the northwestern U.S., whereas lower-than-average atmospheric pressures result in cooler/wetter conditions in the northwestern U.S. These relations between the timing of UKB SMR and atmospheric circulation (and resultant temperature and precipitation in

the UKB) are consistent with the correlations between the CMD time series and temperature and precipitation time series.

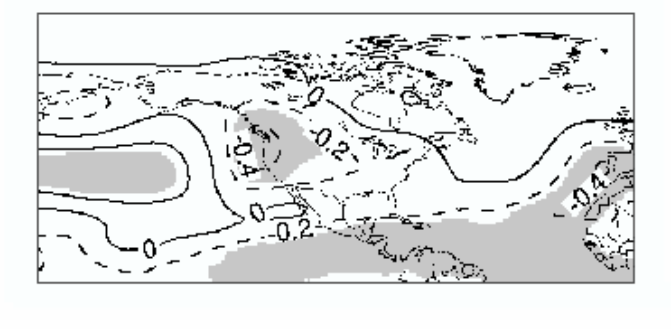

Figure 6. Correlations between the water-year day (days since October 1) when 50 percent of total water-year runoff at Sprague occurs and March through May 700-hectoPascal heights, 1949-2003. The solid (dashed) isolines indicate positive (negative) correlations. The first solid isoline is the zero correlation isoline and the contour interval is 0.2. The gray shaded areas indicate correlations that are significant at a 95-percent confidence level.

CONCLUSIONS

Hydroclimatic variability of the UKB was examined for the period 1922-2003 using runoff data from the Sprague River basin. A large proportion of water-year runoff in the UKB occurs during the months of March through May and is a result of precipitation that primarily falls as snow during the months of November through February. Because NDJF precipitation is highly correlated with MAM runoff in the UKB, there also are significant correlations between NDJF atmospheric pressures over northwestern N.A. and MAM runoff. When NDJF atmospheric pressures are lower- (higher-) than-average over northwestern N.A., the transport of atmospheric moisture (and storm systems) from the North Pacific Ocean into the northwestern U.S. is enhanced (reduced) resulting in increased (decreased) precipitation and subsequently increased (decreased) MAM runoff. Although this relation between seasonal atmospheric pressure and MAM runoff is strongest for the atmospheric pressures averaged for NDJF, the relation remains statistically significant (although smaller) for lagged periods as far back as August through November. The magnitude of the correlation between seasonal atmospheric circulation and MAM runoff suggests some capability to estimate MAM runoff one to two seasons ahead of time.

The timing of SMR in the UKB indicates a large amount of inter-annual variability that is significantly correlated with inter-annual variations of MAM temperature and precipitation. However, for the 1922-2003 period the temperature and precipitation data do not indicate statistically significant trends and whether a long-term trend in SMR exists in the UKB is uncertain.

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