Hydrological and Ecological Sensitivities to Climate Variability for Four Western U.S. Mountain Ecosystems.

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ABSTRACT
National Parks in Western U.S. mountain ecosystems are rapidly changing as a result of the direct and indirect effects of climate change. With warming temperatures, these systems are experiencing earlier reductions in snow accumulation. The impact of these changes on other hydrologic patterns, such as summer streamflow, and ecosystem structure and function may be significant, but is likely to vary across the Western U.S. We used RHESSys, a spatially distributed, dynamic process model of water, carbon, and nitrogen fluxes, to examine the interplay between ecological and hydrological sensitivities to climate in four National Parks across the Western U.S., including watersheds in the North Cascades, WA (Stehekin watershed), Glacier, MT (McDonald watershed), Rocky Mountain, CO (Snake watershed), and Yosemite, CA (Upper Merced watershed). We explored climate-driven patterns in net primary production, evapotranspiration, and streamflow. Analyses show how some systems are more hydrologically sensitive to climate variations, others are more ecologically sensitive. The greatest reduction of summer streamflow in response to warming currently occurs in the Upper Merced watershed whereas the greatest sensitivities of vegetation responses in evapotranspiration and net primary productivity occur in the North Cascades National Park. The Snake and McDonald rivers were not as sensitive to climate changes compared to the other sites.

QUESTIONS ADDRESSED
Assumption: Model-based analysis of ecosystem responses to climate variability can offer insights into the sensitivity and vulnerability of snow dominated mountain systems to future climate change.
1) How do four snow dominated western mountain watersheds, the McDonald, Stehekin, Snake, and Upper Merced differ in terms of historic climate (minimum and maximum temperature and precipitation), ecological (net primary production), and hydrological (evapotranspiration and streamflow) fluxes?
2) How do the sensitivities of hydrological and ecological fluxes to inter-annual climate variation differ across these four watersheds?

RESULTS
Evapotranspiration – Average by Day of Year
Streamflow – Average by Day of Year

VALIDATION
Figure 1: Upper Merced simulated snow versus observed

Table 1: Comparison of observed and simulated mean annual snowfall measurements for four sites, and how climate variables (Tmax, Tmin, Prcp) influence annual snowfall for 40 year calibration runs, conducted for each site.

Table 2: Four site comparison of climate indices with 4 hydro-ecological variables. Upward arrow represents positive relationship, downward arrow represents negative. Width of arrow represents relationship with the steepest slope on the regression line.

Sensitivities to Climate

Evapotranspiration Sensitivity to Temperature
Streamflow Sensitivity to Temperature

NPP Sensitivity to Temperature
NPP Sensitivity to Precipitation

Evapotranspiration and Transpiration Sensitivity to Temperature

Evapotranspiration and Transpiration Sensitivity to Precipitation

CONCLUSIONS
Many western US mountains share common eco-hydrological characteristics, yet their responses to climate vary widely. Key characteristics include:
- Many precipitation patterns are seasonal in nature.
- Snow hydrographs are characterized by, and
- Vegetation productivity is highly responsive to climatic controls.

Major findings:
- Snowfall in the western U.S. has decreased over time, which may be due to warming and changes in temperature and precipitation.
- Inter-annual variability in snowfall across the western US is significant.
- Evapotranspiration was most sensitive to changes in the Upper Merced, leading hydrological sensitivities.
- Streamflow has been impacted by an ecologically sensitive watershed, and NPP and ET, and flow were more sensitive to changes in inter-annual snowfall and climate variability.

Exploring these differences will help in our understanding of various climate change effects in mountain ecosystems, and also for ecosystem management purposes.

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Figure 13: Annual ET versus annual precipitation for four sites, 1956-2003. While Stehekin, Upper Merced and Stehekin all significantly increase with increased precipitation, Snake shows the highest sensitivities.

Figure 14: Evapotranspiration and transpiration sensitivity to precipitation for the four sites, 1956-2003. Stehekin shows the highest sensitivities to precipitation, possibly due to sufficient water availability.

Biedenharn D. M. 2006. Mountain weather and climate: a general overview and a focus on climate change in the Alps. Hydrobiologia 56: 3-16.

RHESSys is a GIS-based, hydro-ecological modeling framework designed to simulate carbon, water, and energy fluxes. By assigning specific climate and topographic variables and nutrients to a methodology for partitioning and parameterizing the landscape, RHESSys is capable of modeling the distribution and spatio-temporal variation between different processes at the watershed scale.

RHESSys represents the temporal and spatial variability of ecosystem processes at a daily time step over multiple years by applying a set of physically based process models over spatially variable terrain.

NPP = Net Primary Production = (GPP - R) (E.)

Watching for climate change impacts on mountain ecosystems, and also for ecosystem management purposes.

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Figure 8: Fraction of summer runoff versus annual mean temperature (ºC) from water years 1956 to 2003. Although runoff increases significantly in response to temperature at all sites, the Upper Merced had the largest decrease.

Figure 9: Annual NPP versus growing season mean temperature (ºC) from water years 1956 to 2003. Snake is a high cold environment, thus NPP increased with temperature. The significant decline of NPP with increase in temperature in Stehekin resulted from decreases in water availability, higher temperatures, possibly due to earlier snowmelt and increased evapotranspiration. NPP in the Stehekin are more sensitive to climate changes compared to the other sites.

Figure 10: Annual NPP versus annual precipitation for four sites. 1956-2003. Stehekin PM showed the strongest response to changes in precipitation. Snake was sensitive to precipitation at the watershed scale.

Figure 11: Annual ET versus growing season mean temperature (ºC) from water years 1956-2003. Transpiration increases with increasing growing season temperature at all sites. Stehekin’s short growing season is lengthened by warmer temperatures. Transpiration was not responsive to temperature at McDonald, possibly due to sufficient water availability.