Simulating and understanding variability in runoff from the Sierra Nevada

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Executive Summary

The Sierra Nevada range captures the lion's share of California's precipitation, making it the state's single most important water resource. This precipitation almost all falls during winter months, and man-made reservoirs line the western base of the Sierras to capture this water as it flows toward the Pacific in streams and rivers. Roughly 2/3 of this precipitation falls as snow, creating a substantial natural freshwater reservoir in the form of the Sierra snowpack. The effect of this natural reservoir is to provide a more consistent supply of water throughout the year. While runoff from rainfall replenishes the man-made reservoirs in early winter, the Sierra snowpack stores water throughout the winter, to be released during the melt season. This meltwater can then be captured in the man-made reservoirs. The steadier supply of water is especially critical for the warm summer months, when agricultural needs in the San Joaquin Valley are greatest.

In deciding how much water to release from the man-made reservoirs, water resource managers must balance the need for a consistent supply of water against the need to control flooding. They must leave enough room in the man-made reservoirs to prevent flooding in case of a large precipitation event, yet they must also keep the reservoirs filled enough to ensure a steady water supply. Thus the timing, magnitude, and spatial distribution of the water accumulation and release from the Sierra snowpack on seasonal to interannual time scales are critical pieces of information for water resource managers. These types of predictions will only be possible with a detailed and quantitative understanding of the physical processes controlling the variability of the Sierra runoff in time and space. On longer time scales, climate change scenarios indicate the delicate balance between the natural and man-made water reservoirs of the Sierras may be threatened by the loss of much of the snowpack. Evaluating the credibility of such predictions and truly understanding the vulnerability of California's water resources to global climate change also requires a detailed and quantitative understanding of the physical processes governing runoff variability in time and space.

This understanding is thwarted by the inadequacies of climate models making hydrologic predictions. The resolution of the current generation of models is roughly 100-200 km, about the width of the Sierra range itself. This is clearly not high enough to capture the landscape-scale processes underlying precipitation accumulation and snowmelt. To address this gap, we propose to apply a 4-km resolution regional climate model covering most of the Sierra range. When forced with known past variations in large-scale weather patterns, regional climate models can be used to reconstruct the local landscape-scale expressions of these patterns with a high degree of accuracy. The model resolution we propose is high enough to capture the characteristic length scales of the region's mountains, and thus to capture the details of the Sierra's rain and snow distributions. The climate model will also be enhanced by a technique we developed to take into account effects of mountain slopes and shadows on the distribution of sunshine. These effects are familiar to anyone who has experienced a mountainous landscape. However, they are not included in the current generation of models, including the regional model we propose to work with here, and are clearly critical for reproducing landscape-scale snowmelt processes in a region of intense topography like the Sierras.

We will use this enhanced regional climate model—tailored to the problem of the Sierra snowpack—to simulate two contrasting snow seasons, one dry (1977) and one wet (1983). For both years, there are detailed observations of timing, magnitude, and distribution of snowmelt runoff throughout the watersheds of the Sierras. These observations reveal markedly different behavior in the variability of runoff in time and space. We will use our simulations to analyze these differences, focusing on the ways in which the mountains shape snow distributions. We will also examine the ways in which landscape-scale processes influence the time evolution of the spring runoff and its variation from one watershed to the next. The high-quality observations will also enable us to validate the simulations in detail, a necessary step in establishing the model's credibility.

This work will establish a physical understanding of the Sierra runoff and create a validated simulation of Sierra runoff at the detailed level of individual watersheds. This will lay the foundation for true predictive capabilities of the spatial and temporal variability of the runoff from the Sierras. These capabilities will apply to the seasonal time scale of greatest interest to water resource managers, and on the climate change time scale of greatest interest to future generations of Californians. We outline plans for multiple projects leveraging the work proposed here to gain funding to pursue these objectives.

Finally, the project will directly support student research training because most of the funds will go to support a graduate student beginning his or her research career. The project addresses a sharply focused research question with a clear methodology, exactly the kind of project that is appropriate for a fledgling researcher.