# Measurement strategies for advancing understanding and forecasting of Sierra Nevada water balance

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## Science background

Despite the hydrologic importance of mountainous regions, the processes controlling their energy and water fluxes are not well understood. Multiple community planning documents point to the Sierra Nevada and other mountains of the semi-arid Western U.S. as the highest priority for new hydrologic understanding. This understanding is needed because the expected hydrologic response to the combined stresses of climate warming, changing land use, and population growth falls well outside the range of past experience and prediction, driving the move toward hydrologic models and predictions based on a physical description of the system rather than calibrated black-box models. In addition, neither existing operational measurement systems nor climate reference stations are designed to provide the spatial measurements required to quantitatively establish within-basin fluxes, and thus fail to provide adequate observational data for physically based hydrologic models. A new base of hydrologic knowledge is needed to support decisions that mitigate the effects of climate change on water resources

## Science need

Hydrologic understanding. We lack an adequate description of factors controlling the partitioning of snowmelt into runoff versus infiltration and evapotranspiration, and lack strategies to accurately measure the variability of precipitation, snow cover and soil moisture. This feeds directly into the need to estimate both the amount and timing of runoff given expected changes in seasonal patterns of precipitation, snowmelt and evaotranspiration. Thus, although a new generation of physically based hydrologic models exists, their performance in any given basin is severely limited by hydrologic understanding.

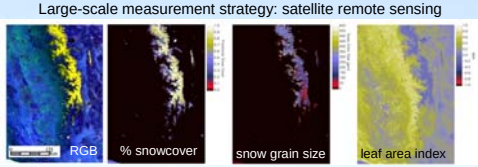
Hydrologic modeling. While the hydrologic community promotes material balance models over statistical models, development of measurement strategies has not kept pace with development of models. Integrated measurement strategies that blend ground and remotely sensed data, particularly satellite data, into the information needed to estimate the spatial patterns of hydrologic fluxes are sorely needed. This includes representative precipitation measurements, snowpack properties, soil moisture, evapotranspiration, runoff and groundwater recharge/discharge. These measurements are essential if the new generation of hydrologic and climate models being applied to mountain systems are to move from being indicators of possible scenarios to actual tools that are used in decision-making.

## Multi-scale hydrologic observatory: nested basins along transects

### Community response

In response to the critical needs for new hydrologic understanding and measurement systems, a planning group has formed for the purpose of building new research and infrastructure for hydrologic science in the basins draining from the Sierra Nevada. This Sierra Nevada Hydrologic Observatory (SNHO) will provide a platform for studying hydrologic processes and building new predictive capability., spanning a range of landscapes, latitudes, elevations and thus climate, soils, geology and vegetation zones. It will address issues of common interest to water managers responsible for hydropower, agricultural water supplies, urban water demands and in-stream water uses.

### Large-scale measurement strategy: satellite remote sensing

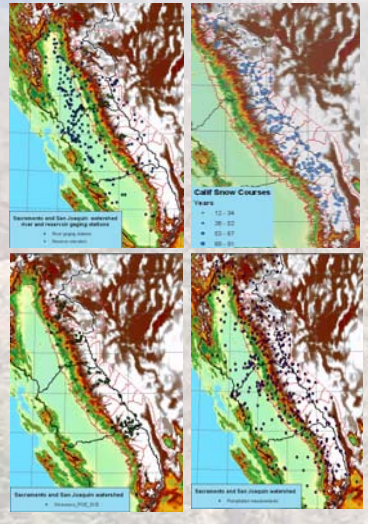



At the largest scales, remote sensing is the only practical way to measure water balance components, link point measurements & provide distributed data for modeling. Recent advances offer more-accurate snowcover maps than routinely available.

### Measurement approach

- Make maximum use of remote sensing data
- Design ground-based networks to make compliment remote sensing
- Deploy ground measurements at a combination of scales: sub-basin to hillslope
- Make heavy use of automated, in-situ measurements
- Integrate date from existing networks
- Address both latitudinal & elevation gradients
- Assure adequate investment in information systems

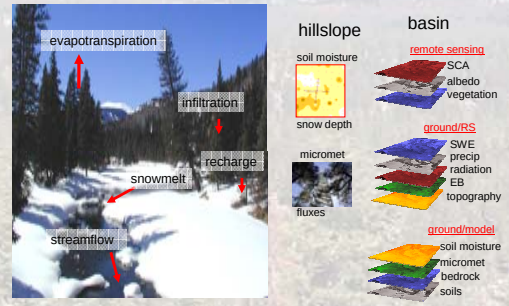
### Existing infrastructure




Rivers in basins draining from the Sierra Nevada have at least one stream gauge above a foothills reservoir, one or more meteorological stations and 5-6 snow sites. Some of basins proposed for more intensive study as part of SNHO have multiple nested stream gauges, decades-long histories of research measurements, good characterization data sets & field facilities that are available to the research community.

### Scaling mountain water balance – linking point & spatial data

based on: physical factors, vegetation, land-use history




### SNHO research partners – a growing list

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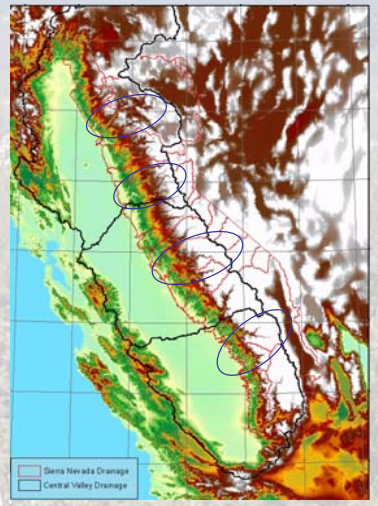
|---|---|---|
| UC Berkeley | Oregon State | Yosemite NP |
| UC Davis | San Diego State | Sequoia-Kings Canyon NP |
| UC Irvine | Chico State | NOAA – CDC |
| UCLA | Cal State LA | USGS – San Diego |
| UC Merced | Northern Ariz Univ | USGS – SEKI |
| UC Riverside | New Mexico Tech | USGS – Menlo Park |
| UC Santa Barbara | Michigan State | USGS – Denver |
| UC San Diego | Ohio State | USGS – Sacramento |
| UC Santa Cruz | Univ Florida | USFS – SW Research Sta. |
| Stanford | Univ Wisconsin | Sierra NF |
| Caltech | Berkeley National Lab | Sequoia NF |
| Univ Nevada, Reno | Livermore National Lab | USDA-ARS Idaho |
| Desert Research Inst. | Jet Propulsion Lab | USACE – CRREL |
| Univ Arizona | Calif DWR | NCAR |
| Univ Colorado | Calif Bay-Delta Authority | USBR |

Individuals from these organizations have contributed ideas and effort to the planning thus far.

### Transect plan




The focus of SNHO's investment in ground measurements & facilities will be meeting critical needs above the mountain front. There are already extensive measurements & complimentary efforts to build research infrastructure in the lower elevations of the Sacramento-San Joaquin drainage.

### Stream stage & discharge measurements on tributary forks ~$10^2$ km$^2$ needed

Some tributary forks have abandoned stream gauges that can be re-activated. Our approach combines high-quality gauges at some sites & simpler stream stage measurements at others

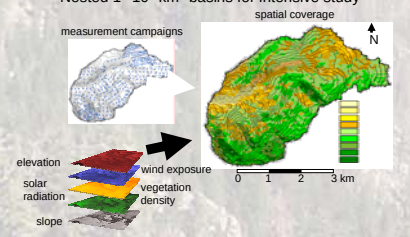
### Point measurement strategy: instrument clusters within headwater catchments


Instrument clusters for intensive, continuous water balance & biogeochemical measurements distributed across vegetation types, latitudinal climate zones & E-W elevational transects will form the backbone of the SNHO ground-based measurement strategy.

### Immediate needs & plans

The critical need is for prototype ground measurement systems, instrument clusters at key locations, to enable Hydrologic modelers and those measuring important hydrologic variables from remote sensing and distributed *in situ* sites have failed to comprehensively bridge rifts between modeling needs and available measurements. Research and operational communities will benefit from data fusion/integration, improved measurement arrays, and rapid data access. In addition, opportunities exist for the deployment of new technologies, taking advantage of research in spatially distributed sensor network and providing the capability for enhanced data recovery and analysis.

### Nested $10^0$-$10^1$ km$^2$ basins for intensive study




Representative headwater catchments with long-term measurements & research facilities are important sites for hydrologic & biogeochemical campaigns, process studies & model development