Climate, Snow, Water, and Chemistry Observations in Yosemite National Park
A monitoring network for environmental change

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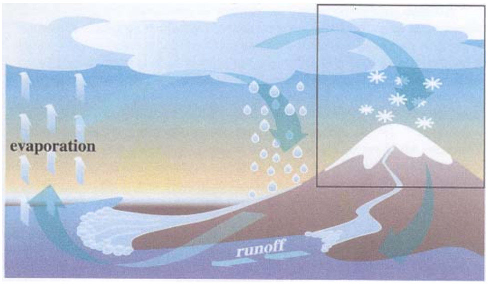
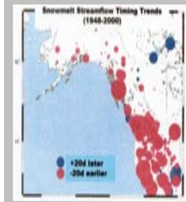


A Natural laboratory for Hydroclimate Studies

Yosemite National Park sits astride the high Sierra Nevada and encompasses the pristine watersheds of two important rivers, the Merced and the Tuolumne. Its pristine conditions, together with the access that park roads and trails provide to the high country, make it a unique setting for scientific studies of the range.

During the 2001 Yosemite Park Research Planning Workshop, and the 2002 Vital Signs Workshop, the Park was identified as having a special role in the earth sciences as a locus for trans-Sierran studies and for studies of the responses of natural systems to global and regional climate change. The Park environs have the potential to be a barometer for hydrologic variations at spatial scales spanning individual basins to the whole of western North America, and time scales ranging from hours to decades.

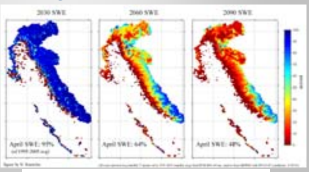
Changes in Spring



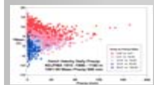
Mid-elevation Sierra Nevada watersheds have shifted 10% of their runoff from April-July runoff to to other periods of the year, and spring and summer snowmelt has declined markedly (Dettinger and Cayan 1995). Over the last 50 years, the start of spring snowmelt runoff has shifted earlier by one to four weeks at several snowmelt-dominated streams over western Canada and over the western United States, including several in the Sierra Nevada of California. Changes in streamflow timing are correlated with spring and winter temperatures, with warmer temperatures leading to earlier runoff. Winter and springs in the western part of North America have warmed by one to two degrees Celsius during the period since 1950.

And Possible Global Climate Change

Although possible future precipitation and temperature changes over western North America are subject to debate, they are generally projected to cause widespread reductions in snowpack accumulation and changes in the timing and intensity of snowmelt-derived streamflow.



Projected changes in snow accumulation under "business as usual"greenhouse gas emissions (Knowles and Cayan, 2002).

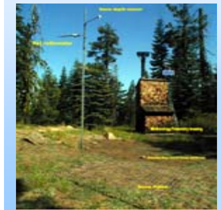


Heaviest precipitation observed in the Sierra Nevada occurs during warm storms. Climate warming could make these events more frequent.

In the long run, it is estimated that in response to projected global warming of 3 °C, the spring-summer snowmelt would be diminished by about one-third (Roos 1987; Knowles and Cayan, 2002), and winter floods would likely increase.

The Importance of Mountain Snowpack

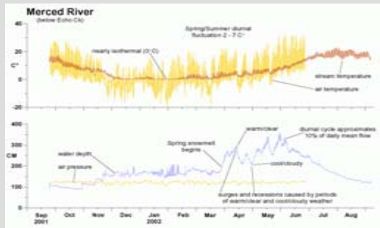
These changes would have important consequences for water resources management, especially for the western United States where largest contributions to annual streamflow in mid- and high-altitude basins is from spring snowmelt runoff. Combined with the annual cycle of temperature, the peak precipitation during winter in the Sierra produces a spring maximum in snow accumulation, so that most snow courses attain peak snow water equivalent by about the beginning of April. Snow course observations are generally collected on or about the first of the month during the winter and spring months. A survey of historical snow course records over the western states indicates that the coefficient of variation (CV) of April 1 snow water accumulation ranges from 20% to well over 100%. Although mountain snow accumulations have been routinely monitored for several years to gage water supplies, these measurements have not been fully exploited as a climate data set.



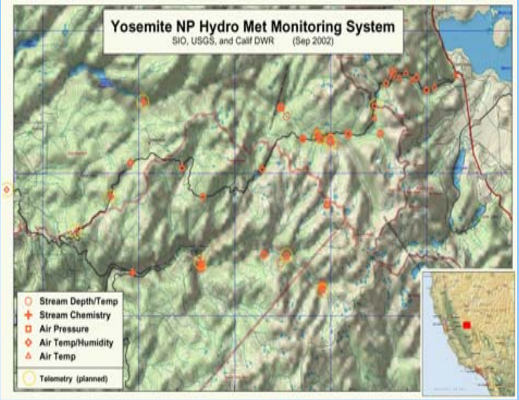
Snow and meteorological instruments at the Gin Flat station operated by the California Cooperative Snow Survey.

Why We Need a Yosemite Monitoring Array

- Quantifying temporal variability
  - understanding natural variability
  - detecting climate change
- Mapping spatial variability
- Understanding processes (physical, chemical, biological)
- Collecting information necessary for numerical models
- Monitoring and predicting extreme events
- Management of resources, ecosystems, infrastructure, public safety.



A Developing Network in Yosemite National Park



The presence of the almost century-long meteorological stations and streamflow gauging stations in the Merced River basin have provided much of the incentive for studies that--to date--have demonstrated the remarkable potential of the Park for earth science investigations. However, these relatively few observation sites need now to be augmented with more monitoring sites, and sites monitoring additional parameters, in both the Merced and Tuolumne River basins. In order to fulfill its promise, meteorological, snowpack, and hydrologic conditions within the Park are now being monitored in more detail and greater consistency than in the past, or elsewhere (at this scale) in the range.

In Yosemite National Park, we are working on our second field season of installing small portable sensors along three transects: the Highway 120 (Tioga Road) trans-Sierra road corridor and the Tuolumne River and Merced River watersheds (see map). Collaborators include the California Department of Water Resources, the U.S. Geological Survey, and the National Park Service. In addition to funding from NOAA and NSF, a new source of funding for our wilderness monitoring efforts has tentatively been identified from the California Energy Commission (awaiting final agency approval).

Highway 120

Along Highway 120, during Summer 2002, we began to instrument a set of meteorological stations that augment the snow/meteorological stations that are operated by the California Cooperative Snow Surveys. Presently, our stations consist of approximately 25 internally-recording temperature/relative humidity sensors, from just above the San Joaquin Valley floor, along the west slope of the Sierra to the crest at Tioga Pass, and down to the Mono Lake Basin at Lee Vining. This array will monitor weather systems and air masses as they sweep across the Sierra from the Pacific, or occasionally, from the interior via the White Mountains and Owens Valley. We have plans to expand the sensor suite at several of these stations to include other elements such as wind and solar radiation.

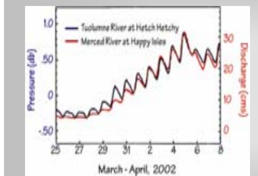
Tuolumne and Merced Rivers

Installation of stream pressure/temperature sensors (housed in concrete anchor) in Dana Fork of the Tuolumne River, carried out by Jessica Lundquist and Julia Dettinger.

Along the Tuolumne and Merced Rivers, we began in summer 2001 to install an array of stream pressure and temperature and atmospheric temperature and humidity sensors. This set of gages is providing much finer detail than has been previously available on hydrologic variability, including snowmelt, summer desiccation, stream temperatures, and in some cases stream chemistry. For example the last year of samples from the Merced River near Echo Creek illustrates the features of the last water year. This 2001-2002 water year (see graph above) shows how river becomes quiescent during winter (water temperatures settle down to near freezing), spring snowmelt pulse, and then several day alternations of higher and lower flow surges. 2001-2002 was an exceptionally early snowmelt year. The first snowmelt pulse occurred in mid-March ,which is among the earliest melt commencement dates since the flow record at the Merced River Happy Isles gage began in water year 1916. The data provided from the array of new gages that we have installed will elucidate where/when and maybe how the snowmelt occurs in the important upper reaches of these Sierra Watersheds.

Stream pressure/temperature gage used in Tuolumne and Merced River installations.

Diurnal Cycles : A New Source of Mountain Climate Information

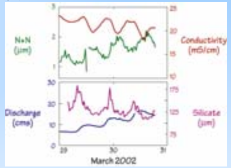


Snowmelt processes are spatially complex and thus difficult to forecast and incorporate in large-scale hydrologic and atmospheric models. Much of the difficulty arises because snow occurs in patches of nonuniform depth and density, particularly in mountainous regions. Fortunately, hourly measurements of river discharge provide another widely available, but as yet utilized, source of information, providing direct information on basin output at a fine temporal scale. Many mountainous streams, including the Merced River at Happy Isles, exhibit a diurnal cycle comprising over 10% of the daily flow each spring (Lundquist and Cayan, 2002). The shape and timing of the diurnal cycle relate directly to the rate and location of snowmelt and to the pathways traveled by meltwater. Thus, changes in the diurnal cycle reflect changes in a given basin's response to snowmelt each year.

Stream pressure (stage) observations need to be calibrated with discharge observations. Brian Huggett is shown taking current meter measurements to determine discharge of the Merced River near Merced Lake.

Stream Chemistry, An Important Measure of Water and Air Quality

Water chemistry is complex and is probably the least understood part of the cycle (which is not to say the other elements are simple). The least difficult chemical parameter to monitor is the conservative or near-conservative specific conductivity (a measure of the dissolved solids concentration). Exceedingly more difficult to monitor, in an on-site automated mode are non-conservative parameters such as nitrate plus nitrite and dissolved silica. Nitrogen is largely derived from atmospheric inputs and dissolved silica is from mineral/soil dissolution or weathering. For purposes here, consider snowmelt discharge as mostly a top-down phenomena driven by atmospheric factors. Water chemistry is complex partly because it is top-down with atmospheric inputs such as nitrogen as well as bottom-up with mineral.soil inputs such as dissolved silica, which are transformed by abiotic and biotic processes.



Aside from this complexity, it is fundamentally important that most of the variations in water chemistry are linked to variations in river discharge (and, therefore, back to variations in atmospheric variables). Thus stream chemistry variations offer a whole new, largely independent set of insights to the workings and changes within the high-mountain basins of Yosemite and the Sierra as a whole.

Where We Are Headed:

Science issues
- Snowmelt: where/when/how?
- Linkages: climate, hydrology ecosystem
- How will climate change operate?
- With what spatial gradients?

Stream chemistry is an important variable to determine source of runoff as well as chemical composition. Dave Clow is shown here taking water samples from the Merced River below Echo Creek.

Technological Goals
- Additional instrumentation
  - solar radiation
  - wind
  - humidity
  - precipitation
  - stream chemistry
  - soil moisture
- Economical, non-intrusive instruments
  - low cost
  - low power
  - miniature, small foot print
- Real-time Data
  - digital cellular
  - phone line
  - satellite
- Climate index stations
  - long term, climate quality observations

Real-time Communications: Opportunities and Challenges

Communications in the Park are difficult because of the high and steep relief. Conditions are especially challenging in river channel bottoms, which are crucial in providing stream gage data but are often isolated by surrounding topography. We are exploring wireless communications options that include digital cellular, satellite, as well as the occasional land line (phone line). At several sites (yellow circled sites on map), we have obtained or have requested Park approval to install communications infrastructure. These efforts must accommodate an intrinsic tension between Park resource management interests, that seek more environmental information, and Park wilderness preservation interests, who are concerned that instrumentation will degrade the wilderness values that they are tasked with preserving.

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