

A WALK THROUGH THE HYDROCLIMATE NETWORK IN YOSEMITE
NATIONAL PARK: RIVER CHEMISTRY



Photo 1. Vernal Fall in spring, 2001

Dave Peterson, Rich Smith, and Steve Hager

Visitors to Yosemite National Park (YNP) are fully aware of the weather, snowmelt, waterfalls (Photo 1), and river discharge and river and lake water temperature. They are not, however, thinking about river chemistry because you can't see, hear, or feel it. So a river chemistry article in Nature Notes needs a familiar background before we break out the instruments.

BACKGROUND

This is the chemistry component of the hydroclimate network described in Jessica Lundquist's Nature Notes article "Monitoring snow from the beach in San Diego: Automatic snow sensors in the Sierra". Our efforts to link large-scale atmospheric circulation to snowpack and snowmelt-driven river discharge and riverine chemistry will ultimately contribute to the accuracy of climate change models and their ability to predict downstream effects on human use (Fig. 1).

Occasionally, examples will be given to indicate why we are working in YNP, and here is the first one.

Yosemite National Park provides a relatively pristine hydroclimate setting that serves as a background for measuring/studying largely human-caused down stream changes. For example, the downstream loss of spring snowmelt discharge (SMD) stands out when plotted against the background of essentially no change in the Merced River discharge at Happy Isles, YNP (Fig. 2). If the YNP data did not exist, sorting out causes of the loss would be more difficult. Further, use of the Merced River in YNP as a measure of downstream change could be applied to river chemistry. In other words, understanding chemical processes in a relatively pristine system will help in defining a largely human-altered system.

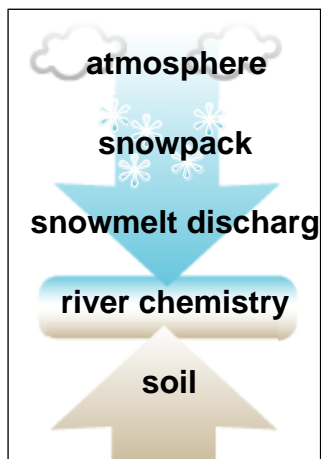


Figure 1 The flow of interconnections in the Yosemite National Park Hydroclimate Network.

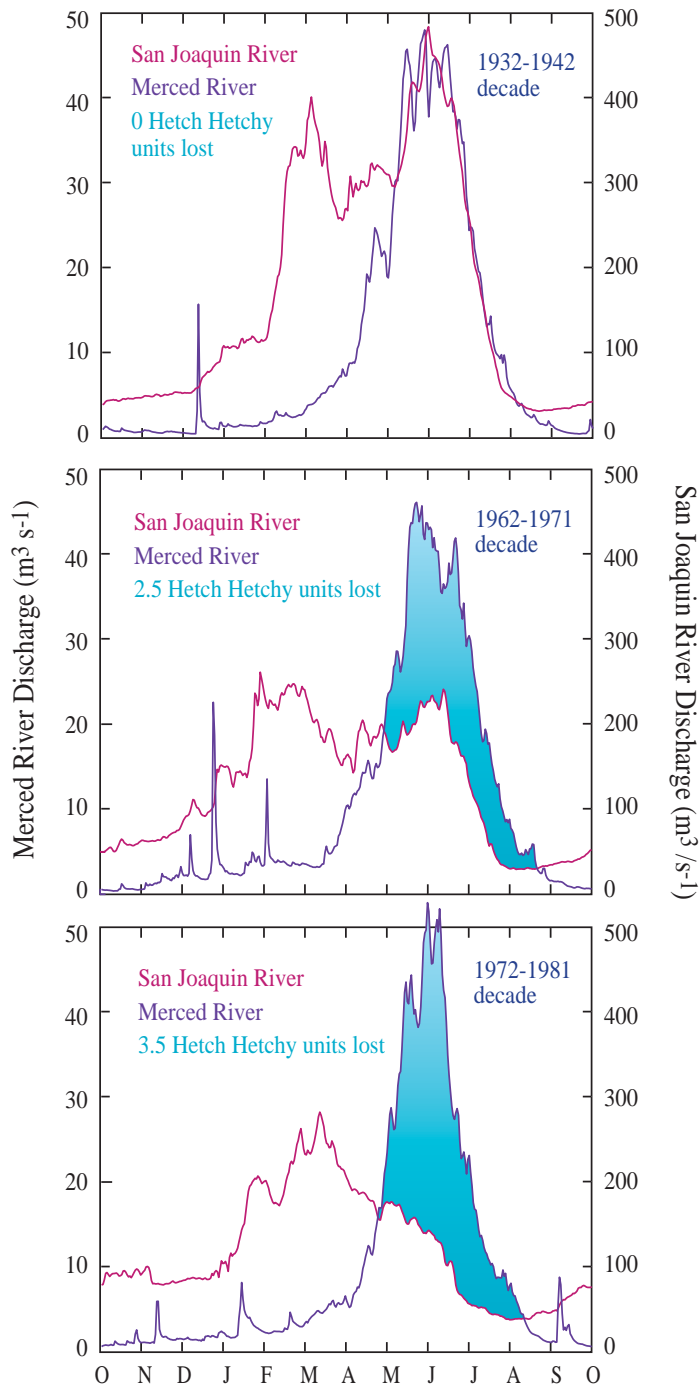


Figure 2 The decadal spring snowmelt discharge near the mouth of the San Joaquin River (Vernalis) and the tributary Merced River (Happy Isles, Yosemite National Park). Decadal averages filter out the large year-to-year fluctuations. Note the differences in scale. Also, the Hetch Hetchy Reservoir on the Merced's twin river, the Tuolumne River, is used to put the discharge decrease into perspective.

The volume of water in the reservoir is one Hetch Hetchy unit.

- = 360,000 acre-feet
- = 120,000 acres of irrigated farm land per year
- = 59,000,000 toilet flushes
- = 190,000,000 glasses of water

The next point for background is probably the most important one. Ever since you were at your mother's knee, you were told how watersheds are exceedingly complex. "Little of what you learn from one could be transferred to another". This was especially true for river chemistry. Therefore, to better define the principles and processes of rivers, a brute force watershed-by-watershed effort lasting many decades was expected. If you look at us (Photo 2), 3 or 4 decades of fieldwork seems a bit unrealistic.

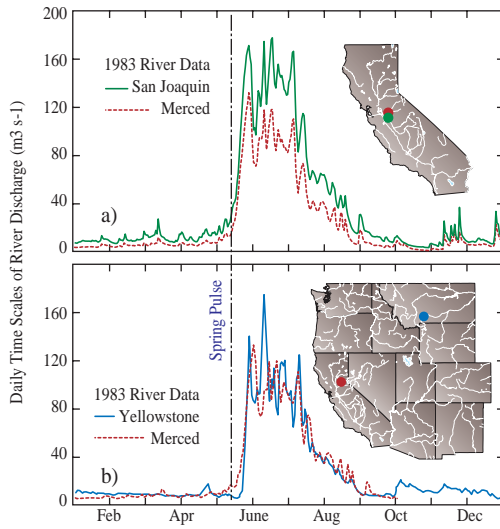


**Photo 2. Steve Hager, Rich Smith and Dave Peterson
The Three Musketeers**

Fortunately, one of our first surprises in research was the discovery of the remarkable synchronicity between snowmelt-driven watersheds. SMD variability correlates strongly with air temperature variability and the air temperature variations are large scale. Therefore, SMD variability is large scale, explaining why the same or similar SMD signatures cut across many watersheds (Fig. 3). Yahoo, this cuts our complexity problem to a much more reasonable size! By the way we consider water quantity (river discharge, the amount of water per unit time) and quality (chemistry) as parts of the same problem.

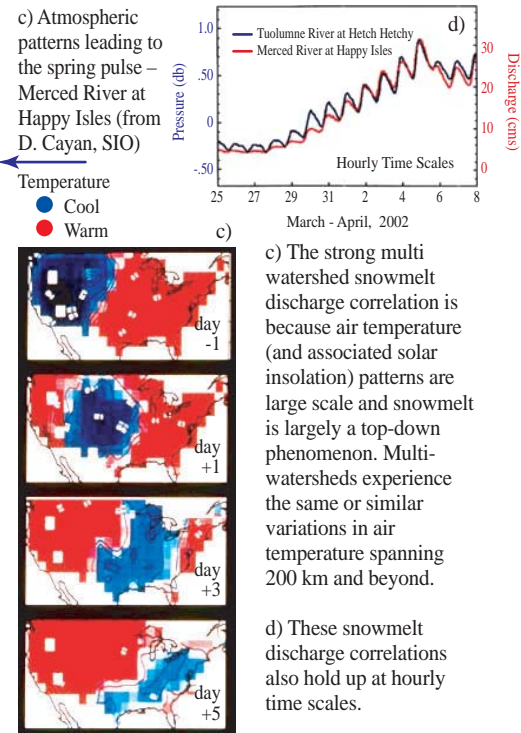
Hydroclimatology is a relatively new discipline that evolved when researchers appreciated how much both hydrology and climatology benefited from the strengths of the other (i.e., the whole is greater than the sum of the parts). We could provide a list detailing why studying alpine hydroclimatology in general and in YNP in particular is important. However, the relatively pristine environment and the large scale coherence gives sufficient background to begin our discussion on the river chemistry component of the Hydroclimate Monitoring Network (HMN).

Snowmelt Discharge is coherent over large spatial scales.



Snowmelt discharge correlates at fine scales across multi watersheds in the central and southern Sierra, such as the San Joaquin River (a), Kings and Kern to the south and Stanislaus to the north and Walker and Carson on the leeward side of the Sierra (not shown), that sometimes extends from the Sierra Nevada to the Rocky Mountains (b), note the slight delay.

Why is this so? A Partial Explanation of the Spring Pulse Phenomenon.



c) The strong multi watershed snowmelt discharge correlation is because air temperature (and associated solar insolation) patterns are large scale and snowmelt is largely a top-down phenomenon. Multi-watersheds experience the same or similar variations in air temperature spanning 200 km and beyond.

d) These snowmelt discharge correlations also hold up at hourly time scales.

Figure 3.

METHODS

Our hydroclimate study sites and monitoring instrument example are in Fig. 4

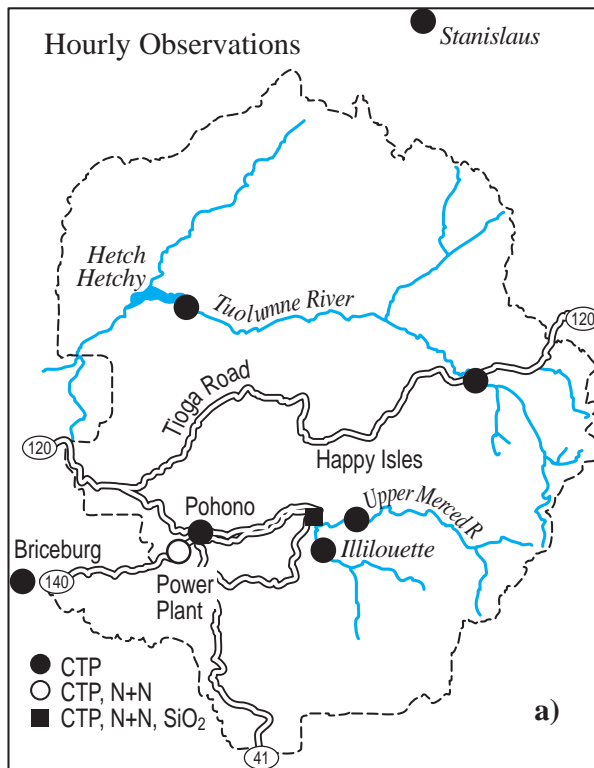
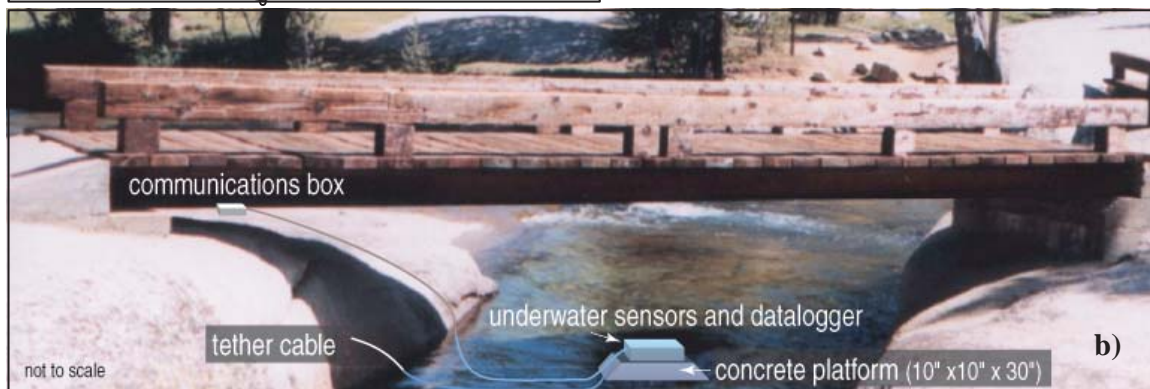


Figure 4 a) A map of the Yosemite National Park showing Water Chemistry Observation sites. CTP is conductivity, temperature and pressure; N+N is nitrate plus nitrite; and SiO₂ is dissolved silica. b) A typical CTP setup hidden under a bridge.



It is merely a coincidence that the younger scientists, Dan Cayan, Dave Clow, Mike Dettinger and Jessica Lundquist are hiking and climbing to study the chemical variability and processes in the high elevation creeks and streams, whereas the “older” scientists are placing instruments near roads and under bridges.

CONDUCTIVITY

A first goal was to measure river chemistry at the same hourly/daily rates of the more traditional variables such as air temperature, precipitation, snowpack and SMD. However, we did not know if this was possible, especially for some of the most dilute water in the world. As we hoped, water conductivity (a measure of total dissolved salts or salinity) became our workhorse and conductivity is the parameter we will illustrate and discuss first.

Photos 3 to 6 show a variety of field activities/conditions while installing/retrieving the instruments and the concrete base for the CTP. Rich designed and built the base in his garage. He claims it weighs less than 100 pounds (I have not yet had the time to verify that is an underestimate).



Photo 3. Rich downloading CTP data onto his computer. All he would need is a cup of coffee to feel content.



Photo 4. Rich and Steve installing the concrete block for the upper Tuolumne Meadow bridge location.



5 a)



5 b)

Photos 5a and 5b. Richard tethered to a bridge abutment at the Happy Isles location, wearing a 50-pound divers belt so he will not be swept away by the strong current. Park visitors give encouragement. Richard used a high technology plastic turkey baster to make sure the CTP was free of sand. 5b. Richard risks all for Science yet again.



Photo 6. Dave and Rich exchange an instrument.

Conductivity is probably the most difficult part of riverine chemistry to understand. What we are measuring directly or indirectly is the concentration of substances dissolved in the river. The concentration depends on three factors: the rates of supply, dilution (negative dilution is evaporation) and removal. Don't be concerned if you do not fully understand what this means, we don't either. Perhaps the least difficult to understand is dilution.

Dilution

River conductivity (salinity) increases naturally downstream from YNP due to evapotranspiration (water evaporates and plants transpire water vapor) and decreasing precipitation. Along the San Joaquin Valley floor conductivity increases due to inputs of high conductivity agricultural and urban drain (waste) water. Sometimes agricultural drain water is diluted (blended) with higher quality (low conductivity) water so it can be recycled. In dry years the San Joaquin River salinity can rise over 600 parts per million. High salinity may be controlled by dilution with water from the New Melones reservoir. You may have read, "The solution to pollution is dilution".

When you are mixing two water sources that have extremely different salinities the amount of each source can be estimated based on the salinity of the mixture. One of the best examples of this is San Francisco Bay Estuary. The coastal ocean salinity is approximately 30 parts per thousand whereas the delta river water is only 150 parts per million (the ocean is 200 times saltier). So, when coastal ocean water mixes with river water in the estuary, a salinity of 15 parts per thousand is about half of each. As a result, when delta flow increases (more low salinity water), the Bay salinity decreases. One is the mirror image of the other (Fig. 5).

A similar discharge/salinity relation is observed at Happy Isles but with very dilute solutions (i.e., snowmelt salinity is approximately three parts per million or one millionth as salty as the coastal ocean). Note: to convert conductivity to salinity multiply conductivity in micro Siemens per centimeter by 0.6 to approximate salinity in parts per million. If you flip discharge to calculate the inverse, instead of cubic meters per second, you have seconds per cubic meter, and then scale this to fall in the range of conductivity, you get the covariation in Fig. 6. This is more interesting because it shows when the time per unit discharge increases, conductivity increases over a range of discharge rates.

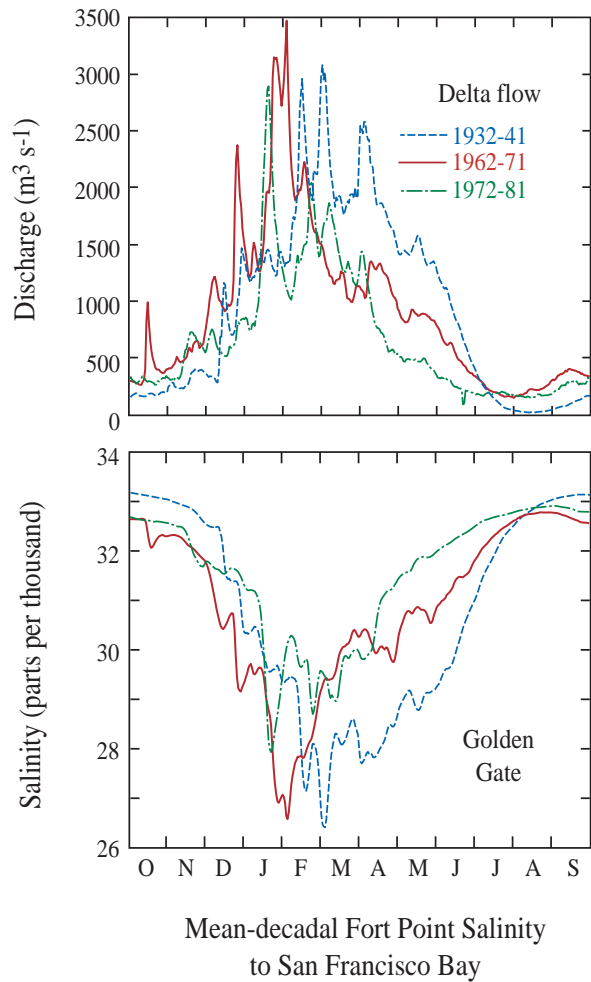


Figure 5 Decadal variations in San Francisco Bay Delta discharge and the salinity response at Fort Point near the Golden Gate Bridge.

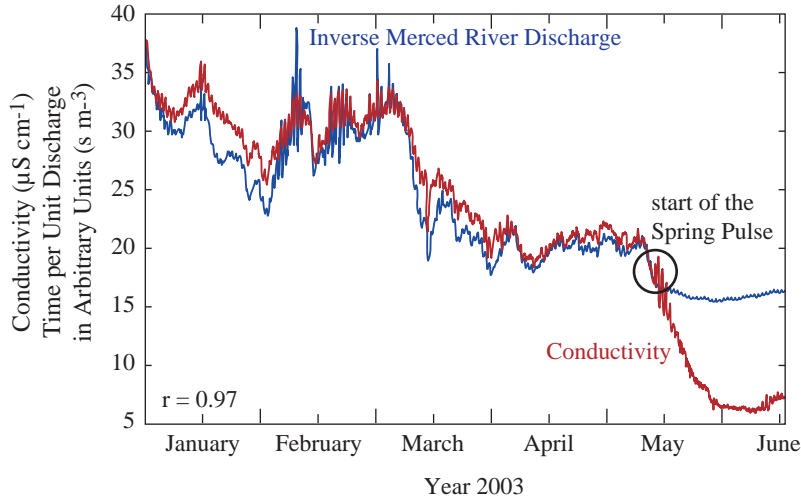


Figure 6 Hourly conductivity and the inverse of Merced River discharge at Happy Isles, YNP, 2003. The small variations are the daily cycle in the melt rate due to fluctuations in temperature and direct solar heating

One of our goals is to better understand the origin of variations in riverine salinity starting with simple field observations. Note the conductivity differences in three nearby watersheds (Fig. 7). In general, the salinity is low above Happy Isles because the soil is sparse relative to bedrock. The salinity is higher above Clark Fork of the Stanislaus River where the run off (river discharge per unit area), is the same as the Merced River but the soil cover is more extensive. Soil increases the surface area of the soil/water interface and, therefore, increases the rate at which soil minerals in the watershed dissolve (causing a higher rate of salt supply). It also increases the volume (between soil particles) in which salty soil water can be stored. The salinity is even higher in the West Walker River above the Bridgeport Bridge (not shown in Fig. 4), where the soil is similar to the Clark Fork, but the runoff (precipitation) causes even higher salinity, because less flow decreases the salt transport (removal) out of the watershed.

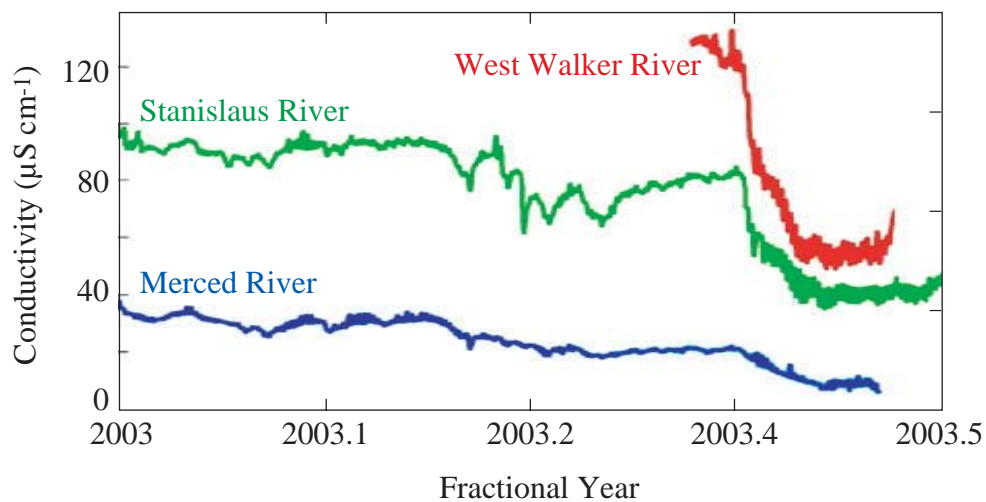


Figure 7. Natural variability in hourly conductivity in the Merced, Stanislaus and West Walker Rivers at Happy Isles, Clark Fork and Bridgeport Bridge respectively, 2003.

Because conductivity measures a relatively unreactive chemical property (salinity), mixing water with different conductivities can account for much of the variability. Reactive chemicals, such as nitrate, a plant nutrient, are more complicated to study than conductivity. The instruments needed to study reactive chemicals are also more complicated.

Developing/maintaining the nitrate and silica analyzers is similar to flying the Starship Enterprise (Photo 7) This is where wireless data transmission to Steve and Rich's office in Menlo Park is especially important (photo 8), because then they will be able to see when things go bad (Fig. 8). The nitrate measured at Happy Isles represents an input of nitrogen to the floor of Yosemite Valley. A similar analyzer is at a downstream location to monitor the nitrate output from the floor of the valley.



Photo 7. Steve Hager checks out his nitrate and silica analyzers.

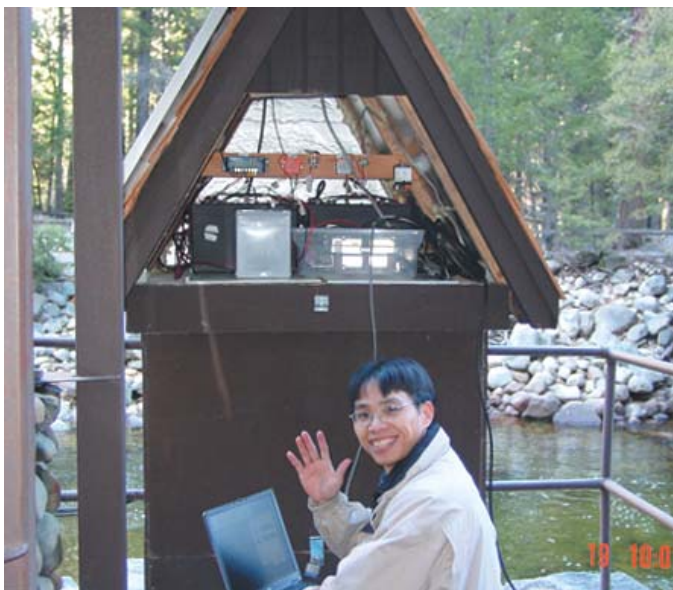


Photo 8. Frank Lin establishing a wireless data transmission system for Steve's analyzers (The dog house was also designed and built by Rich in his garage).



Figure 8 Plot of wireless data transmission for nitrate and silica before and after Steve arrived at the scene of the breakdown.

RECYCLE

A very generalized nitrogen budget (Fig. 9) illustrates a concept that differs from supply, dilution, and removal we just discussed for conductivity. The input of nitrogen from the atmosphere to the watershed is approximately 10% of what is needed to sustain plant growth (satellite derived estimates of plant growth were kindly provided by Jeff Hicke, Colorado State University). Further, the leakage from the watershed down the river is only 1% of that used by the plants. Both the relatively small atmospheric input and the very small leakage indicate nitrogen is recycled from plant litter. This means the system is under saturated with nitrogen (i.e., could make use of more nitrogen if supplied). This is also a good situation typical of alpine watersheds along the west coast. Too much atmospheric nitrogen could result in more “leakage” into the river, which might have a negative influence on the watershed ecosystem.

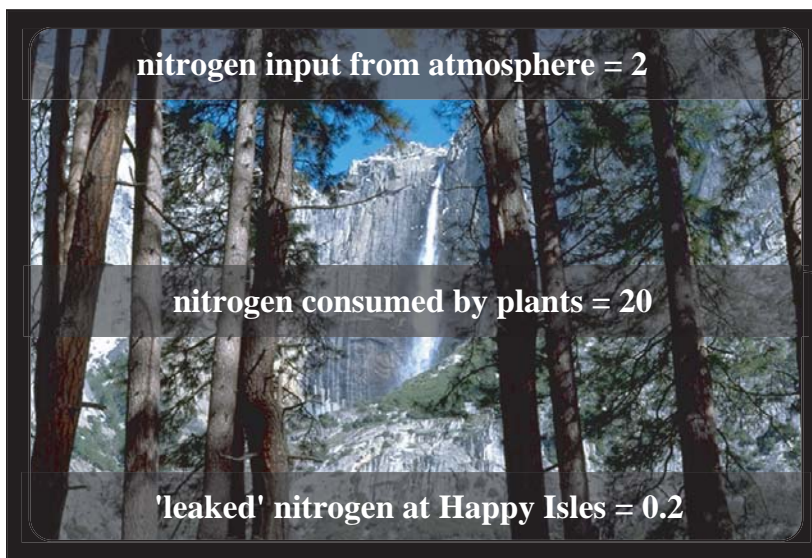


Figure 9. General nitrogen budget for the Merced River water shed above Happy Isles. Nitrogen is in kg per hectare per year.

The recycling concept in reference to plants is probably somewhat fuzzy and needs an analogy. However, in what follows, do not think of recycling in the context of being a good citizen. Think of it as a way to minimize the effects of a shortage in supply.

If California consumed 100 beverages in aluminum cans every year and only 10 cans were made from raw materials (bauxite), the 90 additional cans would be made from recycled aluminum. If aluminum recycling was very efficient, only a few cans would disappear each year (and would need to be replaced). If 100 cans were made from raw materials, the incentive to recycle would be weak and more cans might end up in rivers, lakes and the ocean. However, the incentive to recycle is probably higher if recycled aluminum were needed to meet the demand. The plants in YNP have a very high incentive to recycle nitrogen as indicated by the only 1% leakage.

It is too soon to develop a story about dissolved silica. Silica is the most important component in the granite rock of the Sierra Nevada. As such, dissolved silica is famous as a measure of dissolution (weathering) of the Sierra Nevada rocks and minerals.

Finally, from a Parks management perspective, think of this study as one measure of the Sierra Nevada ecosystem's health. Related to this effort, and more directly applied to managers needs, is our monitoring effort near the head of the Hetch Hetchy reservoir in collaboration with the San Francisco Water and Power Administration and YNP. Work is under way to establish wireless data transmission at that location with near real-time data for scientists and managers. Richard Smith is seen walking from this site looking for a place to get the boat and with an eye out for rattle snakes that love to mingle with the driftwood stranded on the shore of the Hetch Hetchy reservoir (photo 9). We see the most bears at this location and during fall snowmelt, get soaked from the tributary waterfalls. Is there anyone who has a better job than we do? No.



Photo 9. Richard Smith packing out the tools needed for installing/maintaining a monitoring site above Hetch Hetchy Reservoir.



Photo 10. Holding a couple of sample bottles, Dave says, “cheers.”

Addition information:

Web site for a broad spectrum of hydroclimate research (the SIO CAPS site)
Hydroclimate Monitoring Network <http://meteora.ucsd.edu/cap/>

Web Site for notebook on who is doing what and where.
<http://sfbay.wr.usgs.gov/access/HydroClim/SiteBook.pdf>

Web site for a more detailed example of a river chemistry analysis.
<http://sfbay.wr.usgs.gov/access/HydroClim/Hydroclim Tutorial.pdf>

Examples of other related Nature Notes:

E.F. Van Mantgem, Understanding Surge in the Sierra

David Carle, Tapping the Sierra Nevada Reservoir

N. King Huber, Yosemite Falls – A New Perspective