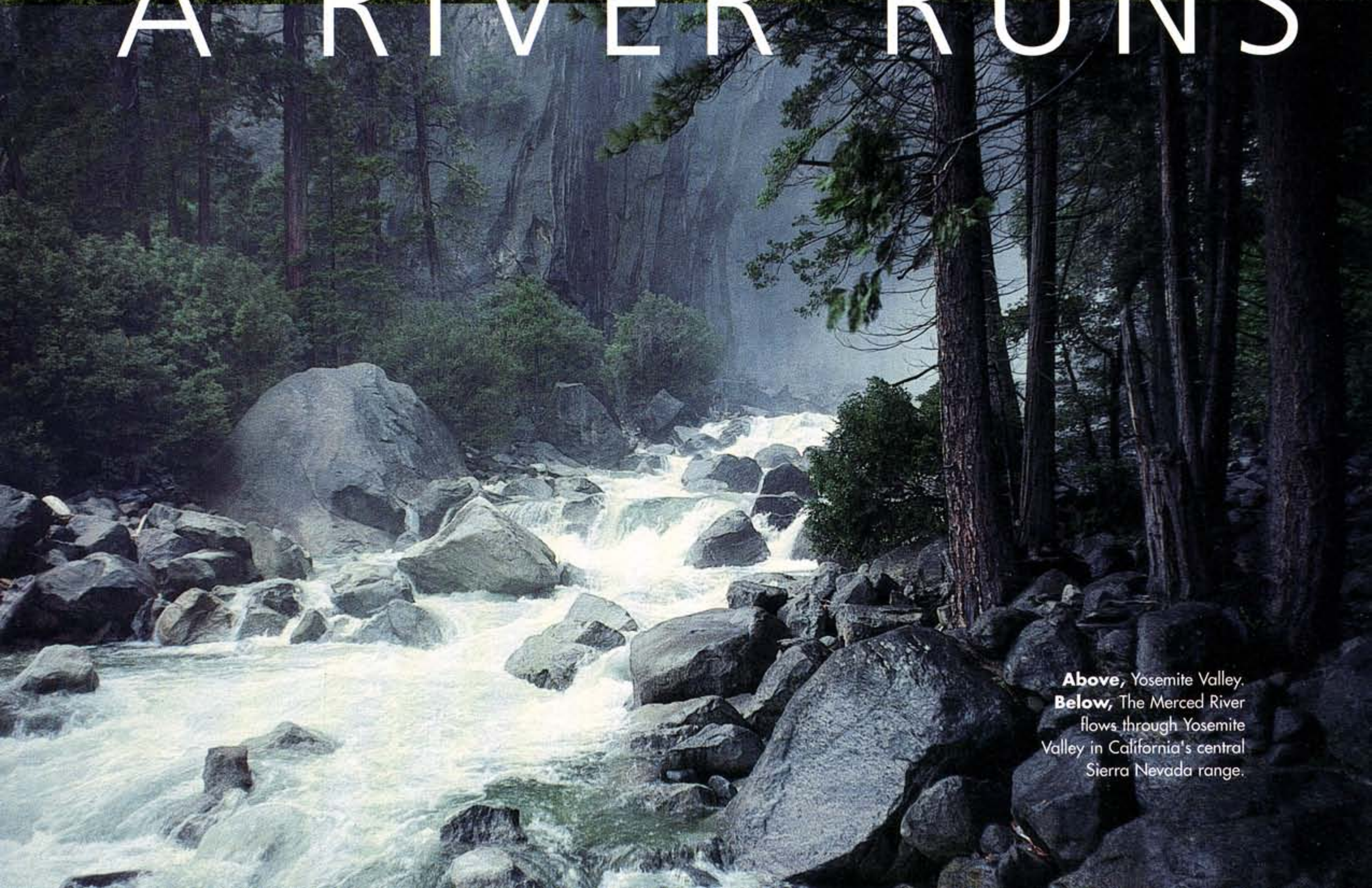
A RIVER RUNS



Above, Yosemite Valley. **Below,** The Merced River flows through Yosemite Valley in California's central Sierra Nevada range.

Western

Waterways

Echo Hydrologic

Patterns Found

in Yosemite

THROUGH IT

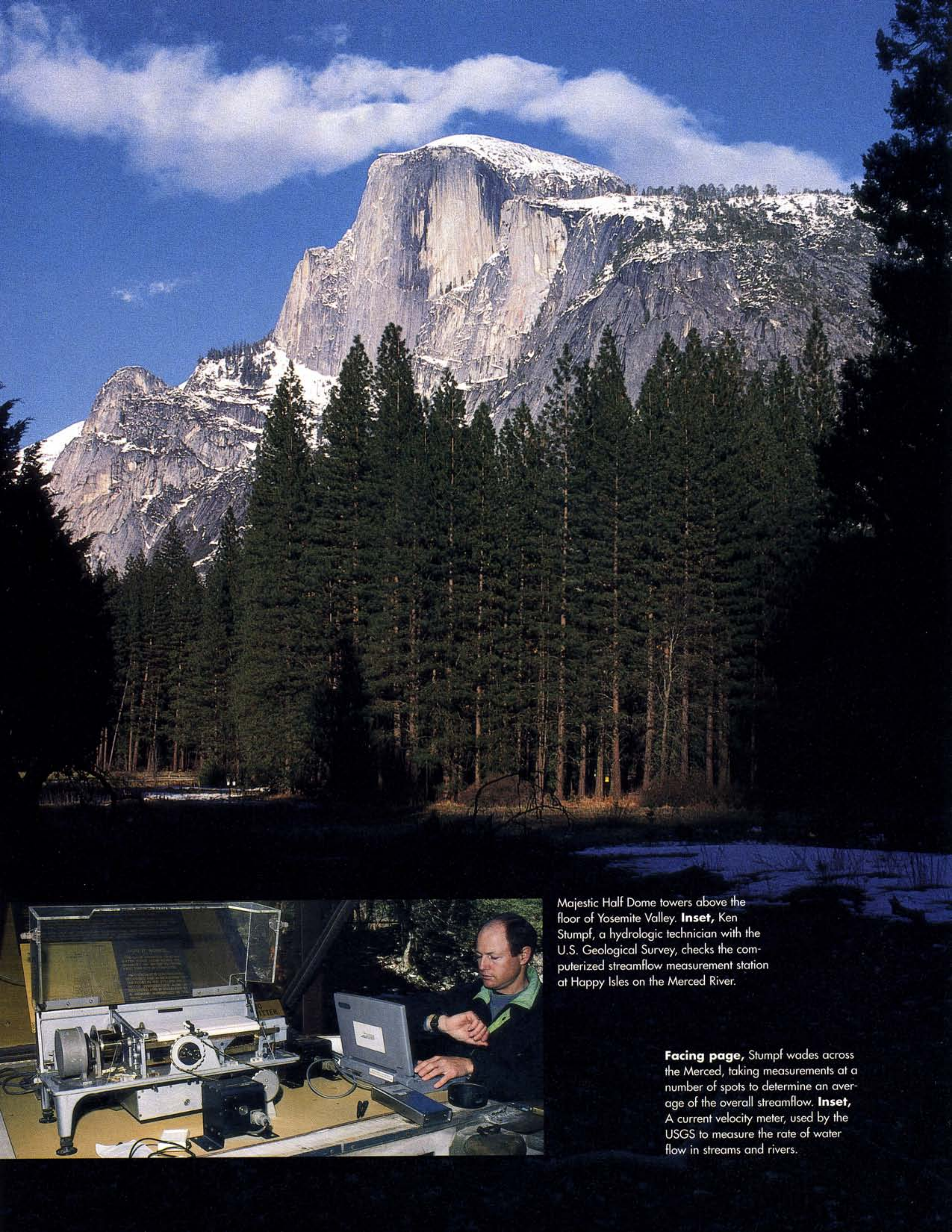
BY JANET HOWARD

TO MOST VISITORS, YOSEMITE NATIONAL PARK in California is a vacation getaway spot; a place to spend time in touch with nature, away from the trials of commuter traffic, deadlines, and endless errands.

To Dan Cayan and Mike Dettinger, however, this beautiful area represents something different: a laboratory in which to better understand how Earth's climate is driving snowpack and water resources for the western United States.

The two Scripps scientists have devised a method for combining climate forecasts with a computer model of a huge Yosemite basin to predict the amount of snowpack that will cover the rugged Sierra Nevada range each winter and, subsequently, the amount of stream runoff that will be available each spring in California.

The ability to accurately predict streamflow based on climate models is critical, as it will allow scientists to forecast months in advance the availability of water for agricultural irrigation, the generation of hydroelectric power, and domestic uses.



Majestic Half Dome towers above the floor of Yosemite Valley. **Inset,** Ken Stumpf, a hydrologic technician with the U.S. Geological Survey, checks the computerized streamflow measurement station at Happy Isles on the Merced River.

Facing page, Stumpf wades across the Merced, taking measurements at a number of spots to determine an average of the overall streamflow. **Inset,** A current velocity meter, used by the USGS to measure the rate of water flow in streams and rivers.

"The combination of reasonably good seasonal climate forecasts and high-elevation snowpack estimates gives us the ability to predict stream runoff such as in Yosemite's Merced River about six months in advance," said Cayan, director of the Scripps Climate Research Division and a researcher with the U.S. Geological Survey (USGS). "Of course, that also provides us with advanced warning of either drought or flood conditions."

As part of their research, the scientists analyzed streamflow measurements taken since 1915 at Happy Isles Bridge, which spans the Merced River at the upper end of Yosemite Valley. By comparing these data to historical records from other streams, the two researchers made a profound discovery: What happens in the Merced River in Yosemite appears to correspond with streamflow levels in other rivers throughout the West.

"What we learned is that just by watching what goes on at the gauge at the upper end of Yosemite Valley, we can say a lot about what goes on in a huge area of the western United States. The Merced River serves as a sort of barometer for rivers throughout the West," said Dettinger, a research associate at Scripps and a hydrologist with the USGS.

While hydrologists traditionally have focused their research on watersheds, individual hydrologic basins that drain into a single river, Cayan and Dettinger have broadened the scope of their work. They include in their studies the large-scale climate patterns that affect streamflow patterns over a much wider network of rivers covering the mountainous western states.

"The weather and climate fluctuations that deposit snow and make it melt are broad," said Cayan. "In other words, the high- and low-pressure systems that orchestrate whether it is warm and sunny or cloudy and rainy are not confined to a single watershed—they cover immense regional scales. So, we can look at this representative watershed as an index of what is going on for a thousand kilometers [more than 600 miles] in all directions."

Cayan and Dettinger became aware of the apparent connection between different watersheds when they and colleague David Peterson of the USGS in Menlo Park, California, started comparing the beginning of snowmelt each spring in the various basins across the West. The scientists noticed striking year-to-year similarities among the rivers the watersheds feed. Analysis of more than 45 years of data from western rivers showed that although the start of snowmelt ranged from March to June in any given year, the rivers tended to stay in lockstep with one another. While the researchers focused their initial efforts on the Gunnison in Colorado, the Yellowstone in Wyoming, the Weber in Utah, and the Merced in California, they later expanded their analysis to include streamflow records collected by the USGS from more than 200 rivers across the western United States.

"What we see is an overarching pattern of high pressure and warm temperatures that instigates the snowmelt runoff in high-elevation streams during most years," Cayan said. "We have found that an interesting characteristic of the fluctuations in runoff timing is that they are controlled mostly by temperature and not precipitation, which is good news because temperature is much more predictable."

To date, officials from various state and federal agencies have predicted the seasonal runoff in California by using the time-honored method of measuring the snowpack of the Sierra Nevada. Each month in the winter and spring they venture to 300 remote sites, sometimes on horseback or skis, to retrieve cores of snow. These are weighed to estimate the amount of water in the snowpack.

Rather than relying on this labor-intensive approach, Dettinger and Cayan are forecasting streamflow in the Merced River by feeding climate forecasts into a model, developed by Dettinger, of a 500-square-kilometer (approximately 193 mi^2) basin in Yosemite called Little Yosemite Valley. Runoff from snowmelt in this

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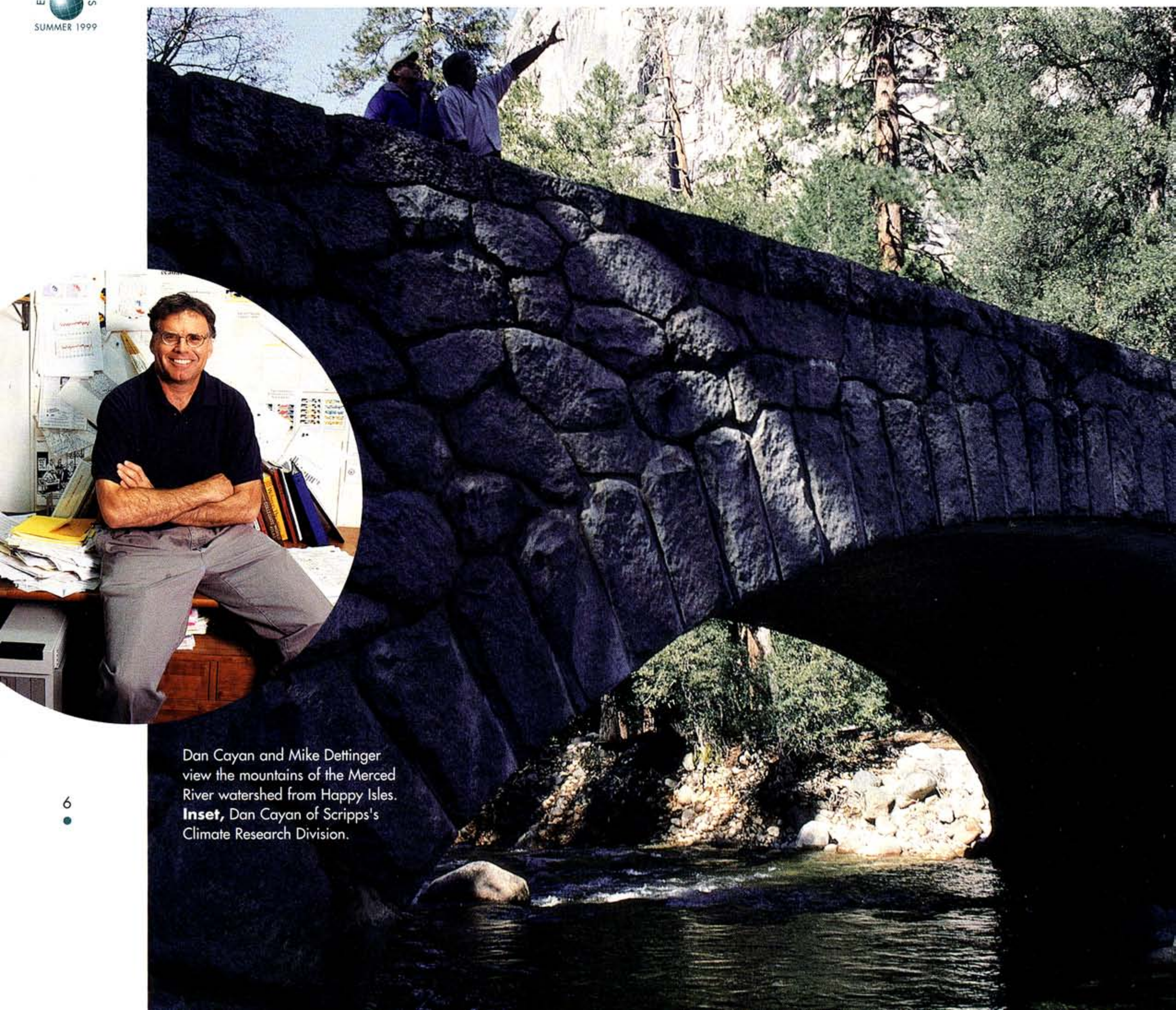
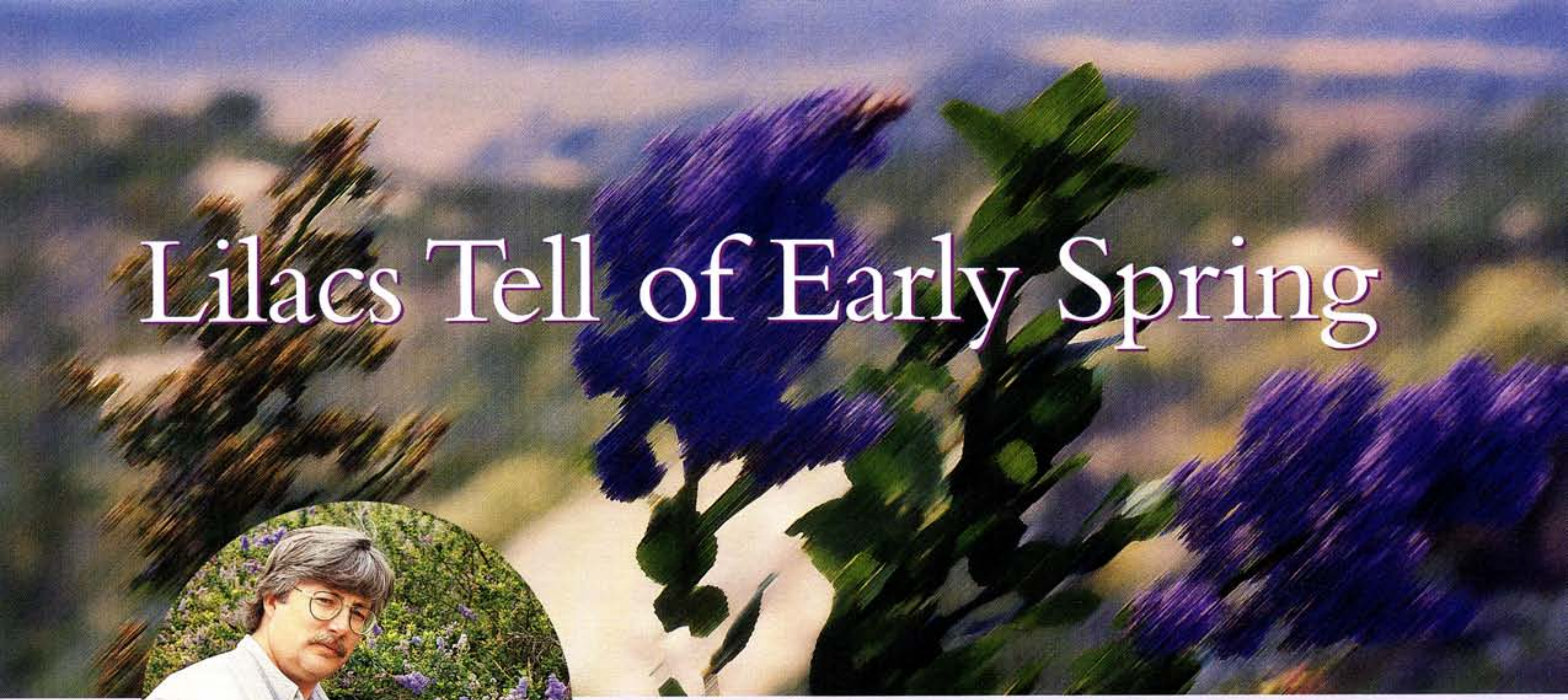


Dan Cayan and Mike Dettinger view the mountains of the Merced River watershed from Happy Isles. **Inset,** Dan Cayan of Scripps's Climate Research Division.



Lilacs Tell of Early Spring

Mike Dettinger, a Scripps researcher and hydrologist for the USGS.

It was one of those serendipitous discoveries of which every scientist dreams.

It all started when Scripps researcher Dan Cayan went looking for plant data that would help a student better interpret satellite imagery of vegetation and snowpack cover across the western United States.

In his quest, Cayan stumbled across one of the most extensive and remarkable efforts ever undertaken to track plant life in North America.

The story begins in 1957 when Montana state climatologist Joe Caprio and colleagues took clones of a single lilac plant and shipped them to people across the western United States. Caprio asked them to simply watch the plants and drop him a postcard each year noting when the fragrant plants first sprouted buds, when they grew their first leaves, and when they achieved first bloom.

The people receiving the plants were volunteers—members of garden clubs, amateur weather observers, and the like. Caprio's network soon grew to include more than a thousand observers across the West. For more than 35 years, they faithfully watched their lilac bushes, jotted their notes on postcards, and sent them off to Caprio, who painstakingly charted the plants' progress on hand-drawn maps.

"This was a monumental effort, although it was done on a very simple basis," said Cayan. "He had laid out this very scientific network all over the West and managed to keep it going until 1995."

When Cayan and Scripps colleague Mike Dettinger started sifting through Caprio's records of when the lilacs first bloomed each year, they revealed a stunning fact: Spring has arrived earlier since the mid-1970s.

"It was obvious from the beginning that there was a marked change during the last 20 years toward earlier springs," said Cayan.

Caprio's records, which eventually included honeysuckle bushes in addition to lilacs, reflected the same trend toward earlier springs that Cayan and Dettinger had noted after analyzing decades of records tracking stream runoff into Yosemite's Merced River.

"We went through and picked out the day when snowmelt really took off for each year in the stream record, which serves as an indicator of when spring arrives," Dettinger said. "What we found was that during the last few decades the snowmelt has started earlier and earlier."

This trend had been noted previously by Maury Roos, a California state hydrologist. Intrigued, Dettinger and Cayan began examining stream gauge data taken at other rivers and noticed the same trend in the Yellowstone in Montana, the Gunnison in Colorado, and the Weber in Utah. On average, according to the snowmelt records, spring now arrives about two to three weeks earlier than it did in the early 1950s, Dettinger said.

A continued hastening of when snowmelt begins could spell trouble for western states, as they depend on snowpack to hold large quantities of water in reserve for use throughout the hot summer months.

"Our precipitation is very seasonal—we get this big slug of water between November and March, but most of our water is consumed during the rest of the year," said Cayan. "So a gradual spring and summer snowmelt release helps delay the delivery of water until a period when it is most needed."

The scientists found that the trend toward earlier snowmelts has been driven by changes across the Pacific Ocean basin in which the central north Pacific has become cooler while waters along the Pacific coast have become warmer. (See CalCOFI article p.20.)

But they say it is too early to judge whether the changes are tied to a larger pattern of global warming.

"It could be driven by anthropogenic influences, or it could be natural variation," said Cayan. "Right now, if you twisted our arms, we would say it is probably natural variability, but it merits close watching."

high-altitude basin (bordered at its outlet by the scenic landmarks Glacier Point to the west and Half Dome to the east) forms most of the Merced River.

Because all of the water draining from the basin eventually passes into Yosemite Valley where the Merced River flows under Happy Isles Bridge, the scientists can check the accuracy of the model by seeing how closely it predicts streamflow rates measured at a stream-gauging station there. The Merced River is nearly dormant through winter until the snowpack warms up enough to begin the spring melt and send water rushing to fill its banks. Because Little Yosemite Valley is essentially a massive granite bowl, a minimal amount of water is lost to absorption. The basin's location at altitudes above 5,000 feet (1,524 m) also prevents much water from evaporating.

"What the basin really represents is a 500-square-kilometer (approximately 193 mi^2) rain gauge," said Dettinger, standing on Happy Isles Bridge and gesturing to the swiftly flowing water beneath. "It is a closed system in that all of the water that comes out of the basin, comes out right here."

Gazing up at the sheer walls of Glacier Point beyond which Little Yosemite Valley lies, Dettinger admits he is humbled by the magnitude and raw beauty of the basin he and Cayan are working to understand.

"When you come to a place like this, it grounds you in terms of how infinitely complex the system is that generates the flow in this river," he said. "At the same time, Dan and I have recently started to recognize that all the

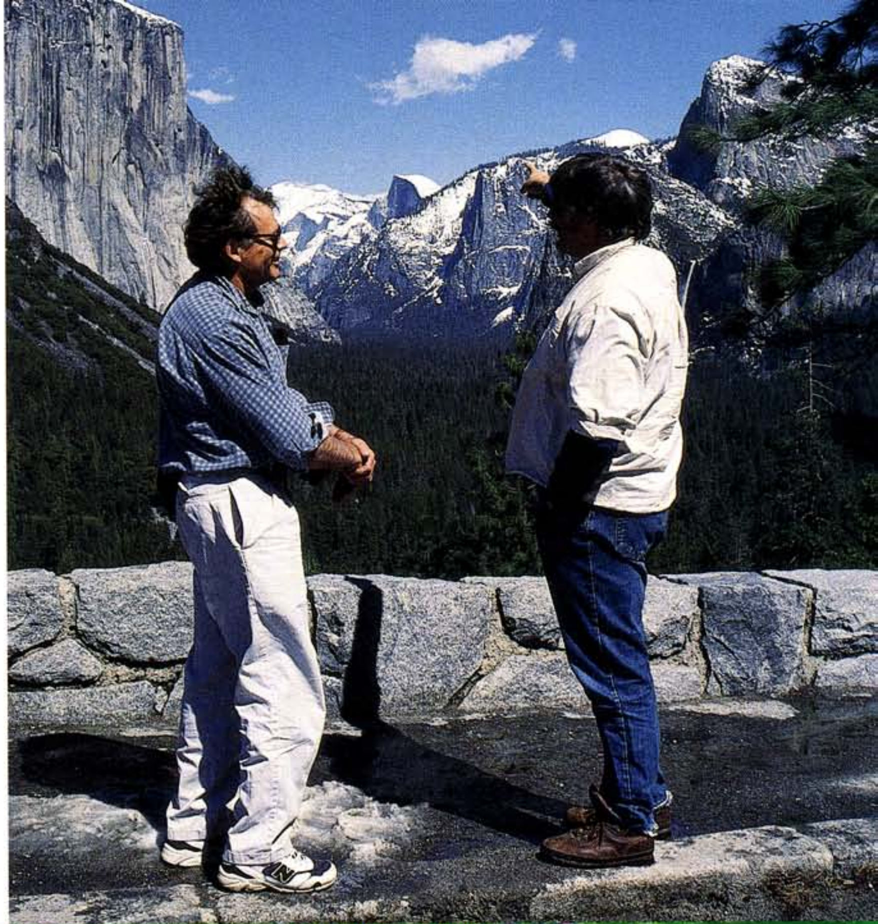
Three views of the hydrologic features studied by Cayan and Dettinger. **(A)** The western United States and locations of four widely separated river basins. **(B)** Central California showing the locations of Yosemite National Park and the Merced River basin above Happy Isles Bridge. **(C)** Yosemite National Park and the Merced River drainage (the Little Yosemite Valley area). Water from this area empties into the Merced River. Scripps scientists study the Merced River drainage at Happy Isles Bridge in the north end of Yosemite Valley.

Mountains characterize the landscapes and dominate the river drainages. Snowmelt and streamflow fluctuate in response to local factors—such as changes in air temperature and shading by local mountains—that are usually studied at the smallest of these scales **(C)**. Cayan and Dettinger's studies have shown that both snowmelt and streamflow fluctuations at this smaller scale are remarkably synchronous with larger scale occurrences **(A and B)**.

complexity doesn't change the fact that the day-to-day fluctuations of this river are echoed with surprising precision by rivers all over the West."

Because the USGS has been collecting records at Happy Isles since 1915, Dettinger was able to verify the accuracy of his model by feeding it historical climate data and then comparing the stream-flow simulations with measurements actually taken at the time.

"There has been remarkably little work done to take historical forecasts or to make forecasts for the past and see how good the forecasts are and to what



Cayan and Dettinger at the Yosemite Valley overlook.

degree water managers and agricultural interests should trust them," he said.

In addition to checking the reliability of the model using historical data, Dettinger and Cayan also began providing real-time forecasts of runoff in the wake of the devastating flood that hit Yosemite National Park during the New Year's holiday of 1997.

The flood was triggered when a warm, moisture-laden storm system pummeled the region and caused the unusually deep snowpack covering the lower part of the Sierras to begin to melt, sending a torrent of water cascading into the Merced and other Sierra Nevada rivers. During four peak hours of the flood, more than a billion tons of water rushed into Yosemite Valley, destroying campgrounds, roads, and park facilities. All three highways into the park were closed, stranding thousands of people in an area where health officials worried that sewage-contaminated floodwater could cause the spread of disease. By the time it was over, the park had suffered $180 million in damage.

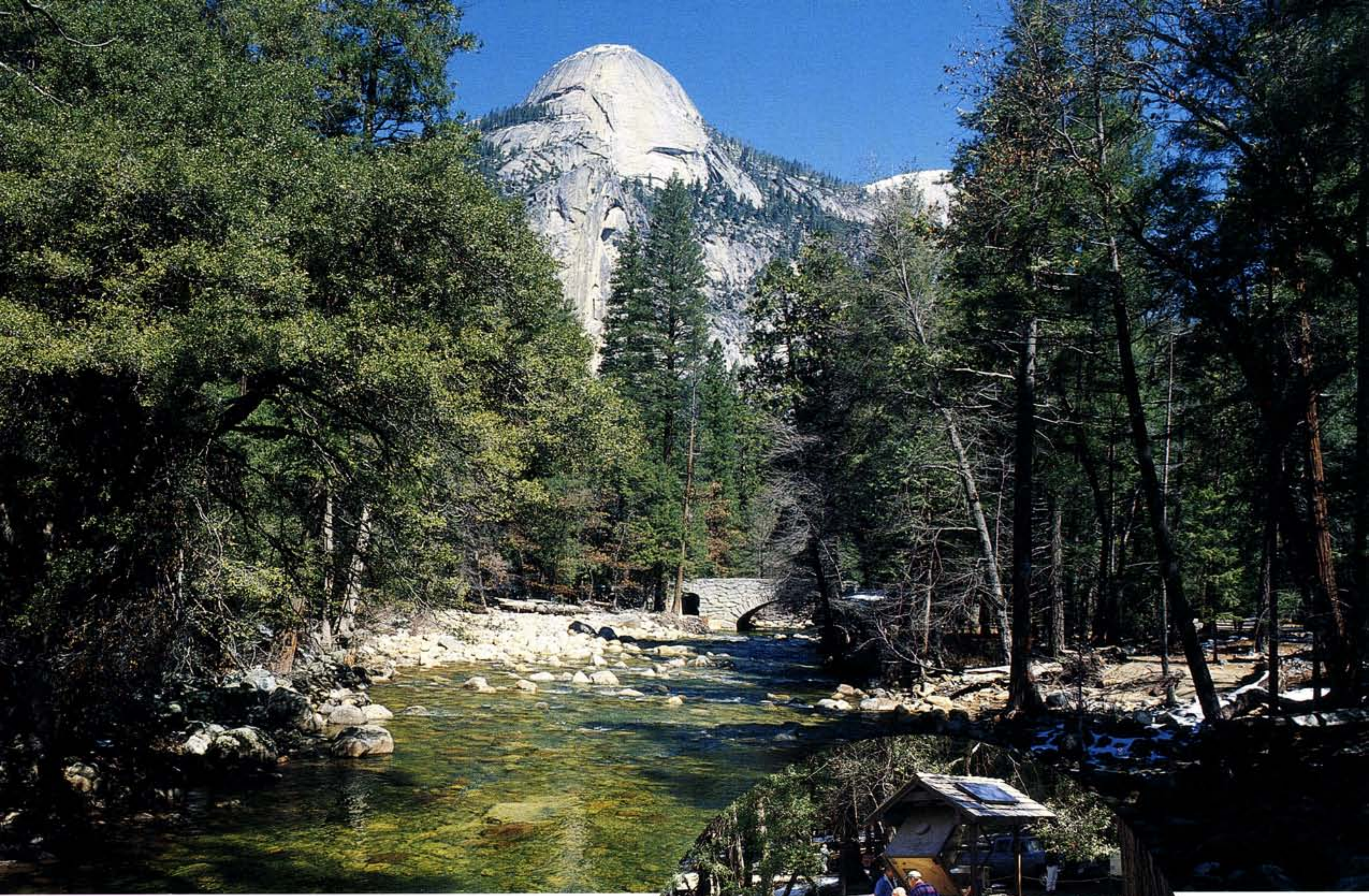
The event left the two researchers wondering if the terrifying episode could have been foreseen.

"The agencies involved were aware that something might be on the horizon. We were hearing rumblings of big storms a week ahead of time, but the agencies involved don't do forecasts beyond 72 hours," Dettinger said. "What we have since shown is that the size of this flood could have been predicted a full eight or nine days ahead of time."

While park officials were still reeling from the impact of the floods, the threat of new storms loomed over the valley.

"I started getting desperate calls from people saying, 'Mike, you've got this model, can you tell us if the next storm is going to be as dangerous as the previous one,' " Dettinger said. "We weren't in the forecasting business

Lower Yosemite Falls is formed by the abrupt entry of Yosemite Creek, a tributary of the Merced watershed, into the Yosemite Valley.



yet, so I scrambled around but really had no way of telling them anything that I could justify."

Luckily, the next storm that moved in was cold enough that it did not trigger more snowmelt, and the crisis ended. The experience, however, motivated Dettinger and Cayan to begin moving into forecasting mode.

"It really shook me up, and I began thinking that as a matter of ethics I should do the right thing and make my model useful for preventing disaster," Dettinger said. "We didn't expect that the payoff would be so great—that we would also figure out that what we understood about the Merced River would be directly applicable to other rivers around the West."

The Merced River at Happy Isles station. **Inset,** Dating from 1915, this is one of more than 7,000 streamflow stations operated by the U.S. Geological Survey. It was selected as a national hydrologic benchmark because of its location in a national park on a stream largely unaffected by human activity.

Data collected at streamflow stations are used in operations and planning for power development and for agricultural, industrial, municipal, and recreational uses of water. Water samples are collected for analysis of dissolved minerals and gases, trace metals, bacteria, and suspended sediment.