The lead story in this issue describes the science and the scientists involved in laying the foundations for the multidisciplinary Keck HydroWatch Center's comprehensive exploration of the water cycle at the Angelo Coast Range Reserve and Sagehen Creek Field Station. The aim is “to create a model of the entire hydrologic system that integrates the atmosphere, surface, and belowground variations of water.” California, a state that confronts chronic water shortages, needs the new insights and tools for water management that this ambitious project may bring.

The flows from the Colorado River Basin and from the Sacramento-San Joaquin Basin provide indispensable contributions to California’s water resources. These large snowmelt-driven

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We can predict how our weather will behave — but can we ever learn to forecast our water? Keck HydroWatch says, Why not?

California society was built on the assumption that we would always have access to an abundant supply of clean, inexpensive water. Today the state faces a water-supply crisis. Each year, the public agencies that control our water juggle the competing needs of thirsty residents, agriculture, and industry, as well as electrical-power generation, flood control, and environmental requirements. With each passing year, their complex balancing act becomes more precarious as our population increases, our environmental problems intensify, and climate change alters the long-standing climate patterns that we had come to expect.

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The state’s high mountain ranges are the heart of our water system, wringing precipitation out of the clouds that blow in off the Pacific, storing that moisture as either snowpack or groundwater, and slowly releasing it during the long, dry summer months that characterize our Mediterranean climate. The snowpack in the Sierra Nevada mountains is especially critical, providing roughly 40 percent of the runoff that sustains the state through the dry period of the year.

Historically, Californians have never been content to watch this runoff flow “wastefully” to the ocean. We’ve spent much of the last two centuries diverting water for our own purposes, constructing a vast network of dams and aqueducts that has transformed arid desert regions into rich farmlands and sprawling cities. Increasingly, however, it’s becoming apparent that this approach is no longer sustainable. We have already used most of the state’s obvious dam sites, and we hope to avoid the environmental consequences of continued construction and diversion.

Global climate change is also altering California’s weather patterns and hydrological regime in ways that are having repercussions up and down the state. The best available models predict that moisture that once fell in the Sierra as snow will increasingly fall as rain. And the smaller snowpack will melt more quickly or be absorbed by soils parched by more frequent drought years. Changing weather patterns are already having a dramatic impact on plant communities throughout the state. tinder-dry forests are more and more prone to insect infestations and catastrophic wildfires.

The Keck HydroWatch Center at UC Berkeley was established to answer these basic questions, while also developing technology and processes for monitoring watersheds across the country and around the globe. Now completing its second year, the four-year project funded by the W. M. Keck Foundation is focusing its efforts on two NRS reserves: the Angelo Coast Range Reserve in Mendocino County and the Sagehen Creek Field Station in Nevada County north of Lake Tahoe. These two reserves present dramatically different water cycles, one dominated by heavy rains and the other by heavy snowfall.

Inez Fung, a professor of Atmospheric Science with a dual appointment in Earth and Planetary Science and in Environmental Science Policy and Management, leads an interdisciplinary team of researchers from the Keck HydroWatch Center. She recalls that the genesis for the project was a simple question that no one could answer: “I asked what I thought was a fundamental question: how old is the water in the stream? Is it from yesterday’s rain? Or last year’s rain? Is it last year’s snowfall? How long do watersheds store water in the subsurface? What combination of flowpaths does water follow to reach a stream? What factors determine how much water returns to the atmosphere via plant transpiration? How is freshwater resupplied and recycled?”

How long do watersheds store water in the subsurface? What combination of flowpaths does water follow to reach a stream? What factors determine how much water returns to the atmosphere via plant transpiration? How is freshwater resupplied and recycled?

Many feel it’s time to reassess how our state deals with water. Despite the critical role it plays in our lives, we know very little about how water moves through a watershed once it has fallen from the sky. Though we have good historical records on how much rain has fallen and how much water flows down the major streams, we can’t fill in the details between input and output.

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Looking for an answer, Fung sought out colleagues who were working on different aspects of the water cycle. Together they came up with the proposal for the HydroWatch Center, which Fung believes will revolutionize our understanding of the water cycle. “What was weather prediction like before we had satellites?” she asks. “A local forecaster would look up at the sky and say, This is what will happen with the weather tomorrow. Today satellites have given us the ability to see storm systems develop and move. So we’ve developed not only a better understanding of the weather, but also the ability to predict the weather. What we hope to do with the Keck HydroWatch Center is to develop a similar capability for water. We want to be able to follow the movement of water from the ocean to the land, to see it evaporate and transpire, and move across continents, into streams, and back to the ocean.”

A Scientific Dream Team

Fung’s associates in the Keck HydroWatch Center are all UC Berkeley faculty as well as national leaders in their respective fields. With tongue firmly in cheek, she refers to each one by his stage of the hydrologic cycle. The “air guy,” for example, is Ron Cohen, a chemistry professor, director of the Berkeley Atmospheric Science Center, and a leading authority on the changing chemical composition of the Earth’s atmosphere. Cohen monitors water in the air, water that cannot yet be characterized as precipitation, whether rain, snow, hail, sleet, or fog.

Once precipitation falls from the sky and hits the soil, it becomes the focus of the “mud guy,” geomorphologist Bill Dietrich. Elected to the National Academy of Sciences in 2003, Dietrich is currently a principal investigator in the National Center for Airborne Laser Mapping (NCALM) and in the Science and Technology Center (STC), National Center for Earth-surface Dynamics (NCED).

As soil moisture is taken up by vegetation, it moves into the domain of the “tree guy,” plant physiologist Todd Dawson. Dawson’s specialty is the interaction between plants and their environment. His research has taken him from the California redwoods to the Amazon rain forest. Dawson, a professor in the Department of Integrative Biology, serves as faculty manager for the NRS’s new Blue Oak Ranch Reserve; he is also the director of UC Berkeley’s Stable Isotope Laboratory (see sidebar, page 5), a facility that is pioneering new techniques for determining the source of water and the paths it travels across a landscape.

Once the water reaches a creek or river, it flows to the “stream guy,” hydrologist Jim Kirchner. Kirchner is an expert in watershed hydrology and geochemistry. He also serves as the faculty director of the Sagehen Creek Field Station. Throughout his career, Kirchner has shown an uncanny ability to analyze large datasets and make breakthrough discoveries in fields as wide-ranging as paleontology and environmental science.

Innovative new sensors — “motes” — will be required to track the water through each stage of the cycle. The development of these motes falls to “sensor guy” David Culler, a professor of electrical engineering and computer science who has been at the forefront in the development of wireless networks for environmental science over the last 20 years. He works with CITRIS, the Center for Information Technology Research in the Interest of Society, a research partnership between industry, the state, and the University (Berkeley, Davis, Merced, and Santa Cruz), created to apply information technology solutions to California’s biggest challenges in energy conservation, transportation, seismic safety, education, health care, and environmental monitoring (<http://www.citris-uc.org>).

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Fung herself might be called the “planet guy.” She is the co-director of UC Berkeley’s Institute of the Environment and has been a leader in global climate change research for 25 years. Her focus is on developing increasingly accurate models for tracking global climate change; lack of accurate information on the water cycle has presented her with a major barrier. Fung is also a member of the National Academy of Sciences and a contributor to the United Nations-created Intergovernmental Panel on Climate Change (IPCC), which shared the 2007 Nobel Peace Prize with Al Gore.

Supporting these principal investigators, of course, is a large group of talented faculty collaborators, research scientists, technical staff, graduate students, and postdoctoral researchers. For example, Mary Power, faculty manager of the Angelo Reserve, has hosted the Keck team at that site and contributed valuable insights on how river food webs are affected by changes in the hydrologic cycle. NRS reserve managers also play key roles. Peter Steel, manager at the Angelo Reserve, and Jeff Brown and Faerthen Felix, manager and assistant manager at the Sagehen Creek Field Station, have contributed to the installation and maintenance of the equipment and networks at their respective reserves. Steel, for example, has worked with Collin Bode, from UC Berkeley’s California Biodiversity Center, to install solar panels high up in a number of 60-meter-tall Douglas-firs to power the sensor network. The two have also installed radios on each tree, creating a self-monitoring, wireless network that will carry data from the forest back to campus.

With this wide range of expertise and cutting-edge technical wizardry, the biweekly meetings of the “Keckians,” held on Berkeley campus at McConic Hall, take on the flavor of a scientific United Nations, as each participant tries to interpret the languages of the others’ specialized knowledge areas. Where geomorphologists speak of “soil composition” and “rock porosities,” the plant physiologists are more interested in “microclimates” and “transpiration rates.” Hydrologists and atmospheric scientists speak in terms of “parts per million of contaminants” or “maximum streamflow rates,” while for engineers it’s all about “sensors,” “motes,” and “network protocols.” Aided by large doses of high-quality chocolate (courtesy of Fung), the scientists struggle to understand and integrate their colleagues’ perspectives as they troubleshoot balky sensors, interpret preliminary datasets, generate new field questions, and brainstorm potential ways to achieve answers.

Their discussions make it clear that tracking water as it moves through the watershed is technically extremely challenging. A large portion of one meeting, for example, focused on surprising first readings from boreholes drilled into the Angelo watershed. Why did the moisture content in the bedrock go off the chart with the first light rains of the season? Was this a normal response? Was something concentrating the moisture, or did something go wrong with the sensors? Did the material used to fill in the boreholes create a “wet-diaper effect” that produced errant readings? How could they find out? How could they fix it?

Welcome to Rivendell

These theoretical discussions become real at the Angelo Reserve, where the Keck team is installing its first sensor network. The team has focused its attention on a small watershed on Elder Creek and dubbed it “Rivendell,” after the Middle-earth Elven outpost in J. R. R. Tolkien’s Lord of the Rings. They’ve also named the individual trees that support the wireless network and solar-power panels. One particularly old and difficult-to-climb Douglas-fir is known as Treebeard, named after the oldest Ent, one of Tolkien’s race of humanoid treelike creatures.

And, indeed, Rivendell bears some resemblance to a scene from a scientifically focused Middle-earth. To protect the fragile soils of the steep hillside, Reserve Manager Steel has installed a network of aluminum ladders that connect with fallen tree trunks to climb from the creekbed to the top of the ridge. Researchers move over this maze as they string wire and install sensors. Other scientists hoist themselves 50 meters
up into the forest canopy to install rain gauges, sap sensors, and solar panels. Wire-filled PVC pipes jut up from the ground, indicating the locations of sensor-filled boreholes that reach down to the bedrock.

Rohit Salve, a research scientist at Lawrence Berkeley National Laboratory, is leading the team that is installing the underground sensors. He pauses from his work connecting a data-logging panel in order to explain the Keck team’s strategy: “To get a handle on what’s going on belowground, we put in a series of soil-moisture sensors. Some are traditional sensors, and some are experimental time-domain reflectometers (TDRs), designed to give us really high spatial/temporal resolution. For example, over here we have a resistance probe that goes down 2 meters with sensors at 10-centimeter intervals. This will give us a detailed pattern of how water is wetting or drying up in the rock below. And since we’re very close to trees and roots, we’re also trying to work out how the roots that are sucking up the water are actually influencing what’s happening to the water around it.”

With a wave of his hand, Salve indicates another pipe protruding from the ground. “We also have seven wells that go down about 30 meters to track the response of the deep water table when the rain comes. Our preliminary findings from last winter were quite interesting. It turns out that fractured rock is a good medium for transporting

**Follow Those Neutrons**

Much of the Keck HydroWatch Project’s breakthrough science will originate in two small rooms on the first floor of the Valley Life Sciences building on UC’s Berkeley campus. This is the Center for Stable Isotope Biogeochemistry, where spectroscopist Paul Brooks maintains and operates two highly automated Isotope Ratio Mass Spectrometers (IRMSs) for the measurement of stable isotope ratios of carbon, hydrogen, oxygen, and nitrogen in organic and inorganic samples.

Water molecules (H$_2$O) are each made up of hydrogen and oxygen isotopes in the ratio of 2:1. As indicated by their superscript (H$^1$, H$^2$, O$^{16}$, O$^{17}$, O$^{18}$), these isotopes differ in the number of neutrons in their nucleus and hence in their mass. This difference changes the rate at which each molecule moves through the hydrologic cycle, allowing scientists to use the relative proportion of molecules with different isotopic compositions as a “fingerprint” for determining the water’s source and history.

Not only can isotope analysis determine the source of the water, but when combined with chemical tracers, it can also show where the water has been underground. Flow through shallow soils, for example, will typically produce water that is relatively high in organic carbon, while water that slowly seeps deeper into the rock is typically low in organic carbon, but high in selenium and sodium produced by rock weathering. By looking at how these chemical signatures become associated with streamflow, scientists can even construct a picture of how the source of water changes as streamflow goes up or down.

“We’re in the early stages right now,” Dawson explains. “We’ve only processed two sets of samples from the Angelo Coast Range Reserve so far, but in the long run we’ll be able to provide Inez [Fung] and her modeling team with robust, empirically derived data that they can put into their global climate model. We’ll know exactly what these trees are doing and what they are using in terms of water, how much rock moisture there is, what the climate and the origins of the storms look like. For the first time, she’ll be able to put all that data into her model and get scenarios of what will happen as the temperature warms or the source of storms changes. We’ll be able to predict much more accurately how the climate will respond and what the watershed is going to look like.” —JB

For more information on the Center for Stable Isotope Biogeochemistry, go to: <http://ib.berkeley.edu/groups/biogeochemistry>.
Keck HydroWatch
"Continued from page 5"

Water quickly, so the rocks deep down in the profile get wet much faster than those near the surface.”

From the day they started working in the watershed, the research team members were puzzled by how its shallow, steep soils could provide enough moisture for the forest throughout the area’s long, hot summers. Rohit Salve, Todd Dawson, Bill Dietrich, and others are now investigating the idea that this deep “rock moisture” might be the key. They propose that, on sunny days, the large trees use both their deep and shallow root systems to extract moisture from the ground. Once the moisture reaches the trees’ leaves, it is transpired into the atmosphere. At night, however, the stomata on the trees close, transpiration stops, and the flow of moisture in the shallow root systems reverses. The trees continue to use their deep roots to take up water, which then flows, via the shallow root systems, into the shallow soils. The next day when transpiration resumes, the trees have two water sources to draw on, one shallow and one deep (see illustration on page 15).

This phenomenon, known as “hydraulic lift,” was discovered by Todd Dawson and his research group and has now been seen in many plants, including sugar maples, African acacias, deep-rooted plants from Australia and California, and even Amazonian trees. “Hydraulic lift provides water not only for the trees, but also for the plants that grow around the trees and have their roots commingling in and around the tree roots,” he explains. “When I published my first paper on this, it created a big ripple effect, because plant ecologists had always supposed that one plant growing up next to another plant was a bad thing. But it turned out that living next to a tree that does hydraulic lift is not bad at all. There’s actually a facilitation going on. This new understanding shocked a lot of ecologists, because they had always thought of plant-to-plant interactions as being competitive. But, in this case, it’s facilitation. And this has become an area where ecological research has really taken off—the competition/facilitation tradeoffs that plants have.”

To determine whether hydraulic lift is happening in Rivendell’s Douglas-firs, the team will need to position sapflow sensors on the trees’ shallow root systems to determine whether the flow of moisture reverses at night. The soils have been too dry and too hard this fall to install the sensors without damaging the delicate roots. Their current plan is to wait for the winter rains to soften the soil.

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**Why Nature at the University of California?**

The most basic rules of the world — the ones we all live by — are ecological rules. You can’t study them or even perceive them very well in a classroom or laboratory. It is imperative to go out on the mountainside, watch the rain fall over a valley, dig into the earth beneath a fallen tree, or wade a creek for cobbles with sources upstream.

The best work in the natural disciplines all starts with observations in nature. We need those wild places where we can study nature firsthand, places where all the intricacy and marvel of the natural world is intact. Everywhere, including California, those places are becoming fewer — and more precious.

These words were written by Kenneth S. Norris, founding father of the UC Natural Reserve System, two generations ago, at a time when the drivers of physical change in the world — such as climate change, energy demand, depleted water resources, relentless urbanization, shifting demographics (population growth, shrinking households, aging workforce), and waste from our consumer society — were not universally recognized, and our impending global environmental crisis was still a nightmare sent to ecologists and back-to-the-land hippies. Now we know better, for the problem has grown so large, we can no longer dismiss it.

In less than half a century, we have made technological advances that enable us to monitor and analyze the world around us with unprecedented precision. But our seeing has become as highly focused as a laser beam, and the same tools that empower us also limit us. Deprived of the broad view of nature through the study and description of the components and processes of the whole natural world (what is typically called “natural history”), we lose sight of our environmental Big Picture and fail to notice critical relationships and evidence that our machines were not designed to study. Deprived of the long view of nature, we forget our natural history and accept sickly, broken habitats and their diminished inhabitants as a normal baseline from which to begin our future investigations.

In the following essay, “Why Nature at the University of California?” UC San Diego Professor Paul K. Dayton calls attention to the sorry state of natural history in today’s academic context and explains why this puts us at a disadvantage in facing the environmental crises that are bearing down upon us. He makes a strong case for reinstating natural history as a foundational academic discipline. Finally, in a separate list of “ideal state” initiatives, he offers action steps to guide us along the pathway back to natural history understanding.

**Introduction**

That the UC Natural Reserve System could have evolved, over a span of two generations, into the largest university-administered system of wildland reserves in the world, yet still retain its informal title as “the University’s best-kept secret,” suggests there is a problem with the respect for the natural sciences in academia. That one of the world’s greatest universities could be almost unaware that it is parent to the world’s largest reserve system would be more sadly ironic than potentially tragic — were it not for the reality that our planet is currently undergoing enormous environmental degradation.

Everywhere we are losing whole populations and even whole ecosystems. Now, as never before, we urgently need to understand the causes of decline, how species interact with other components of the environment, and how ecosystem integrity is determined. But it seems unlikely that such understanding, followed by meaningful conservation and restoration, can ever be achieved unless we recover the tradition of supporting the teaching of and research in natural history. We cannot recover the tradition of teaching and researching natural ecosystems without natural areas such as those in the UC Natural Reserve System.

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In many cases, species become extinct even before they can be described.

Society needs an ecological science that can correct environmental insults and contribute to the management of sustainable ecosystems. But the challenges of ecological management are complex and difficult. For example, all habitats suffer cumulative impacts — how can we evaluate the

### Thirty-two Great Questions that Cannot Be Answered Without Careful Research in Natural History

#### About Community or Ecosystem Stability and Recoverability

1. How do we define and measure stress in multispecies systems?
2. How do we define community or ecosystem stress?
3. How do we define or identify system collapse?
4. Why do systems collapse?
5. What are the thresholds?
6. What processes and relationships maintain stability?
7. What determines recoverability in a system and how is this measured?
8. What processes define strong and weak interactions?
9. When do “normal” or “natural” disturbances ratchet into new “stable states” that resist recovery?

#### About Restoration Ecology

10. How do we define the desired state?
11. What are realistic goals?
12. How are they determined?
13. How should we manipulate successional processes that are little understood?
14. What are the most efficient means of restoration?
15. How do we value species in restoration, and how are the values weighted by consideration of whether they are native or invasive?

#### About Sustainable Ecosystem-based Management

16. What are the stresses?
17. How can we measure cumulative effects?
18. How much is too much?
19. What defines limits and thresholds?
20. What defines the relative vulnerability of particular species?
21. Are some species redundant and expendable?
22. How do we define interaction strengths so that we can prioritize the relationships that most need our attention?
23. All ecological relationships have thresholds and almost all thresholds are defined in the context of ongoing natural relationships, but which thresholds are most critical and how are we to measure this?
24. Can cumulative impacts of human perturbations be predicted?
25. How does “sustainable” single-species management morph into ecosystem-based management?
26. How are strong interactions manifested?

These and many similar issues and questions must be understood, if we hope to recover our natural heritage. No monitoring or restoration ecology programs can succeed if they are not based on appropriate questions. Such questions must be defined and prioritized, and this process absolutely depends on excellent natural history, systematics with voucher collections, and careful field research.
ecological damage of particular small impacts in the absence of a baseline of what is natural? That is, since the system is already perturbed, how do we define limits to additional perturbations, even very small ones that could lead to “death by a thousand cuts”? We need to understand stabilizing or successional processes that can simplify communities or make them more complex. These and many other questions (see page 8 sidebar) rely on natural history, but for a variety of reasons, natural history is in short supply.

The past few decades have seen growing concern over environmental degradation, yet this same time period has witnessed the concurrent development of specializations in theory, molecular biology, and genetics. Unfortunately, these specialized paradigms have done little to actually solve the problems by reversing the declines and restoring ecosystem function. Meanwhile, essential natural history courses of all types have been de-emphasized and eliminated in academe. Academic scientists have colonized and studied the serious environmental problems faced by society, but we have failed to take advantage of the public’s concern for the environment and go on to establish high-profile, well-funded research programs in the natural sciences.

The Importance of Natural History in Understanding and Restoring Ecological Systems

Ecological systems are extraordinarily complex and confusing. Yet they must be studied with the classical scientific techniques of simplification, analysis, and synthesis: testing theory remains the cornerstone of science. The process of simplifying the complex natural world is difficult and invariably relies on a keen sense of natural history. A commonly seen trap is that hypotheses are based on inappropriate simplifications and assumptions that contradict natural history. Bad assumptions can be measured and precise, be aesthetically pleasing, and appear to be useful aids to problem-solving, but the tests may be irrelevant or lead to the right predictions for the wrong reasons (Dayton, 1973; Dayton and Sala, 2001).

Clearly, our goal in ecological science is to make interesting, accurate generalizations about nature on the basis of relevant and frugal parameters. A central challenge in ecology is to weed out the marginally relevant parameters, because all of nature is trivially related. But our generalizations should be based on those few parameters that account for most of the uncertainty or the ecological structure under study. Creative ecology is based on a deep sensitivity to natural patterns and processes. Naturalists have the ability to synthesize perceptions of nature into hypotheses about the processes that cause the patterns and then use the powerful scientific procedures for testing hypotheses.

In the same sense, the environment must be managed in ways that are responsive to the population thresholds and vulnerable aspects of the natural systems so poorly understood. Perhaps the only way this type of management can be accomplished is with acute sensitivity to the natural history of the particular system. Because the life-history patterns operating within natural systems are so different from system to system, ecological management may be founded on fundamentally different ground rules, and these rules are not easily extrapolated between systems. Management should be derived from the important, but often idiosyncratic, natural history. Understanding complex ecosystems must be based on how populations behave under different environmental situations, on how their life histories both restrict and provide different demographic options that can respond to diverse environmental stresses. This type of natural history can help us predict population and system responses to environmental variation in complex systems. Excellent natural history is necessary to help us focus and prioritize questions for study and identify areas to monitor. In summary, science and management demand that complex systems be simplified, but the art of appropriate simplification depends on a basic understanding of the important natural history. There are no shortcuts.

Insight into the Devolution of Natural History

Almost a decade and a half ago, Graeme Caughley (1994) observed that conservation biology had split into two lines of research. He identified the first line as a paradigm focusing on the generic effects of small populations declining or becoming isolated. Caughley observed that powerful molecular and theoretical tools with easily defined questions and objectives had recently dominated the field, received almost all the financial support, and resulted in many publications and careers vested in this line of research. Groups working on molecular biology and theoretical ecology have been highly successful within their own circles and have branched into many specialties. These specialists have produced

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Why nature at UC?

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many breakthroughs important to those respective fields. However, Caughley observed, this reductionist approach has contributed rather little toward actual solutions for the increasingly severe global realities of declining populations, extinctions, and habitat loss.

The second line of research discussed by Caughley addressed the difficult problem of why populations are in decline in the first place. It is here where the real solutions must be found, and this progress must rely on a profound understanding of natural history, ranging from taxonomy to complex ecosystem dynamics. Consider Wallace, who probably deduced natural selection before Darwin and observed patterns in nature wherever he went. Consider Bates and Muller, with their appreciation of mimicry, a subject now thought to be of fundamental evolutionary importance. Natural history is the foundation of ecology and evolution science. There is no ecology, no understanding of the functioning of ecosystems and communities, no restoration, or in fact, little useful environmental science without an understanding of the basic relationships between species and their environment, which is to be discovered in natural history.

What a surprise and disappointment it is, then, to observe that, despite the critical, fundamental contributions that natural history has to make toward actual solutions of our global environmental crises, this area of inquiry is being largely ignored and dismissed. Natural history has been displaced, expelled from academe, and is presently viewed as less prestigious than other disciplines. The question is even asked: is natural history a science?

Why Natural History Is Dismissed

But why is natural history so dismissed? Natural history and systematics often are disparaged as stamp collecting, the implication being that the practitioners mindlessly collect facts. This elitist attitude is based on ignorance of the value of the old naturalists and systematists who were deeply observant and who synthesized their observations into patterns and general rules or hypotheses about the natural world. They saw and understood much in nature and carefully wrote it down, sometimes in beautiful poetic prose that rings through the ages. They struggled under the enormity of the truth they were communicating, and one can sense their commitment to understanding nature. It is a terrible disservice to imply that they were collectors of trivial facts. This was never true; nobody collects facts or describes species in a vacuum. Furthermore, no generalizations can be made without repeated observation. Good natural history is timeless.

Unfortunately, many scientists have the opinion that natural history is old-fashioned. Ironically, such opinions are formulated by specialists, masters of techniques, rather than true detectives of the natural world. Real progress in understanding nature tends to be made by the generalist, but the selection for individual recognition lies at the extreme — the specialist. Stephen Fretwell (1972) described this process in terms of divergent fitness of ecologists attempting to integrate general theory and natural history. In this context, ecologists are judged by specialists, and in order to be successful in the eyes of specialists, one must specialize also. The selection to specialize is based not on the real understanding of nature, but on social influences from colleagues usually acting as competitors and judges. The irony is that ecological progress depends upon a synthesis of theory and sophisticated analysis, modern technology, and especially natural history.

More than ever, ecologists study problems caused by human activity, but often they study them in the absence of an understanding of natural patterns. Usually ecologists have not sufficiently considered human culture as an integral part of the equation or how unequal power among cultures leads to destruction. Because of funding realities, many scientists pursue funding opportunities themselves rather than asking what questions are most appropriate and what scale of study is optimal. Rather than seriously attempting to solve problems, they continue the tradition of testing hypotheses, often at inappropriate scales too small to be readily scaled up to regional levels or generalized across ecosystems. Often they ignore other science traditions, long-term common-sense observations, and their own scientific foundation of natural history. Questions not founded in reality are not constructive.

What Instructors Don’t Know They Cannot Teach

It seems that many of today’s ecologists go about their business oblivious to natural history. Consider the environmental curriculum of most universities in the United States. Not only are the students not encouraged to study
A Plan to Revitalize Natural History at UC and Beyond through the UC Reserve System

- At each UC campus, staff positions have been dedicated to bringing in additional field ecology expertise relevant to the NRS sites administered by that campus.

- These positions are being used to create synergy with UC campus venues for multidisciplinary collaboration, such as UC San Diego’s campuswide Environment and Sustainability Initiative (ESI). (Editor’s note: ESI was created to bring together the intellectual resources of the campus around the challenges of sustainability; its goals are “to identify environment and sustainability questions that require collaboration across disciplines within the University, and to build partnerships with entities beyond the University, to provide the knowledge to inform policy as well as contributing to solutions and adaptations to address present and future environmental problems.” [http://esi.ucsd.edu/esiportal/index.php?option=com_content&task=view&id=14&Itemid=27])

- UC staff are building a capacity for K-12 education in natural history through outreach to teachers-in-training and in-service teachers, as well as through mentoring at the secondary public school level.

- UC staff are building a capacity for informal education in natural history through outreach to the public using NRS sites and the added expertise.

- UC staff seek beyond UC to collaborate with active programs at other academic institutions. The NRS is already partnered with many state and federal agencies, such as California State Parks, the National Park Service, the USDA Forest Service, and the National Oceanic and Atmospheric Administration (NOAA) — and these partnerships are being reinforced and expanded.

- Additional field ecology courses based on systemwide use of NRS sites are being created. NRS founder Ken Norris initiated this approach over 30 years ago, and the concept manifests in a limited way at several UC campuses, including Berkeley (IB 157L: Ecosystems of California), Davis (ENT 109: Field Taxonomy and Ecology), Riverside (BIO 163: Evolutionary Ecology of Terrestrial Vertebrates), and Santa Cruz (ENVS 107ABC: Natural History Field Quarter and BIOE 159ABCD: Marine Ecology Field Quarter).

- Resources are made available for the adequate maintenance of NRS sites and for ensuring safe, easy access to all reserves, whether local or remote.

outdoors — there is little opportunity to learn “classic” botany, vertebrate and invertebrate zoology, mammalogy, herpetology, ornithology, ichthyology, and so forth. Many first-year graduate students do not know the major phyla or life histories — sometimes even the anatomy or developmental biology — of their own study organisms. Without grounding in these fundamentals of natural history, students will have little opportunity to understand how nature works. Moreover, some students have been taught ecology using textbooks based almost entirely on molecular biology and theoretical population biology. No wonder that natural reserves, a resource essential to the study of natural history, often go misunderstood, the fact of their existence viewed with puzzlement by university administrators.

Consider how few students are now being trained in taxonomy. Our ability to identify any of the species in extremely important habitats, such as the continental shelf ecosystems, which include perhaps hundreds of thousands of species, will be lost with the retirements of the aging experts. This loss means that we will not perceive any but the most massive changes. Without systematics, we are not likely to identify, Continued on page 12
Why nature at UC?

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much less to study, those species that have weak interactions; thus, we are not able to debate questions of species redundancy or food-web stability. Without collections and voucher specimens, we will not be able to interpret the work of the old literature. Not only do we need better natural history to understand these trends, but also such research depends upon retrospective analyses utterly dependent on well-curated biological collections (Levitan, 1992; Shaffer et al., 1998). Yet institutions everywhere react to declining budgets by eliminating their collections and the necessary curators. How ironic that the same administrators who decry the loss of the Royal Library at Alexandria can move quickly to sacrifice their own collections — the natural equivalent of that famous library of the early third century BC.

How Natural Reserves — Especially When Organized into a System — Stand Ready to Help Alleviate the World’s Current Environmental Crises

The UC Natural Reserve System (NRS) is often described as “a library of ecosystems.” Indeed, in a state where protected, representative natural areas are almost impossible to find and research, the NRS — with its 36 reserves encompassing more than 135,000 acres throughout California (as well as providing research access to several million acres of public lands) — is a different kind of library, but one approaching the Ptolemaic scale in cultural and scientific value. Further, the NRS has this in common with Alexandria: its collection, though large and diverse, is also fragile and vulnerable. If ever the holdings of such a library are lost, they are lost forever.

Obviously, one of the primary goals of the UC Natural Reserve System is to recover the biological natural science courses in all our academic institutions and to ensure that students experience nature firsthand — for example, at an NRS site — and receive instruction in the fundamentals of the natural sciences. Unfortunately, in the general university context, this training has not been available for so long that far too many students have had to go without it and far too few teachers are now available to impart it. A parallel exists with many indigenous cultures that have lost an entire generation of people no longer conversant in their languages or cultures. In some cases, grandparents are now training the young people. In this sense, dedicated professors can still find “academic grandparents” who can help them learn the natural sciences. But like the native languages and cultures, we must move quickly if we are to save this critical component of our scientific culture.

Why Academe Must Seize the Opportunity to Inform Society’s Concern for the Planet

While society is concerned about the declining quality of the biosphere, most anthropogenic stresses are protected through political resistance to conservation in favor of short-term economic gain. Representative natural areas are almost impossible to find, and few endangered species show signs of recovering, even with millions of conservation dollars spent on their behalf. A sad commentary is that our ability to respond to and defend natural systems has been eroded within academe by scientific elitism against natural history and systematics. In almost all cases, we lack appropriate natural history to evaluate relationships and population thresholds, and we have lost virtually all instruction in taxonomy. It is a poignant paradox to lose biodiversity while simultaneously losing the scientific knowledge base of what it is (Zanettell and Rassam, 2003). The academic foundation necessary to solve these problems is often missing. Those attempting to study these problems must start from scratch to describe what they are seeing.

The real solutions to our global environmental crises will be political in nature, because we can only manage people, not ecosystems. But how do we manage people in such a way that political solutions to these serious problems can be found? Modern academic systems tend to focus on the research, often at the expense of our educational responsibilities. If academe is to influence the political process, it will be necessary to educate the students and the public about both the environmental crises and the complicated processes of reversing the declines. The current political sea shift away from environmental concern in favor of economic gain is a trend we must reverse at any cost.

Children grow into tomorrow only as they live and learn today. Political support for conservation and restoration depends on public passion, which must be based on real understanding of what they wish to protect and what will be required in any effort to restore ecological balance. The value system within academe must change so that the

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About Paul K. Dayton

Paul Dayton is a professor of oceanography in the Integrative Oceanography Division at Scripps Institution of Oceanography, University of California, San Diego.

A biological oceanographer, Dayton researches coastal and estuarine habitats, including seafloor (benthic) and kelp communities. He has conducted investigations in several parts of the world, including spending 50 months in McMurdo Sound, Antarctica, performing research during almost 1,000 dives under the ice. The scientific papers resulting from these research projects are largely believed to have set the standard for Antarctic undersea ecology.

He has studied many near-shore benthic communities around the globe and is presently working on California kelp communities. Dayton’s studies also include the impacts of overfishing on marine ecosystems.

Dayton coauthored a study released by the Pew Oceans Commission on the ecological effects of fishing in marine ecosystems of the United States. The report, which has been called “a watershed study,” presents overwhelming evidence that the unintended consequences of fishing on marine ecosystems are “severe, dramatic, and, in some cases, irreversible.”

He has served as a director of the Ocean Conservancy and has served on many National Research Council Panels and committees regarding environmental issues. In 1990, he was appointed a member of the U.S. Marine Mammal Commission by President George H. W. Bush.

Dayton is the only person ever to be awarded both the George Mercer (1974) and William Cooper (2000) awards from the Ecological Society of America (ESA). He also received the 2004 E. O. Wilson Naturalist Award from the American Society of Naturalists and the 2004 Faculty Research Lecture Award from the UCSD Division of the Academic Senate. He was awarded a Scientific Diving Lifetime Achievement Award from the American Academy of Underwater Sciences in 2002. That same year, he received an Award for Merit from the Aquarium of the Pacific in Long Beach, CA, for his outstanding scientific research and his work in management and policy.

Dayton’s affiliation with the UC Natural Reserve System dates to 1974. He is currently the San Diego campus representative to NRS Universitywide Advisory Committee. His son, Gage Dayton, has followed in his father’s footsteps and was recently selected to be campus NRS director at UC Santa Cruz.

Dayton and his family reside in Solana Beach, CA.
**Why nature at UC?**

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academics and the public understand natural history. This understanding can only come via our academic system. We cannot protect or restore what we do not know. And we cannot know it without having it available.

— Paul K. Dayton  
Professor, UC San Diego

**References**


**Editor’s Note: Portions of this essay were adapted from two papers by Paul K. Dayton—**

The importance of the natural sciences to conservation  

P. K. Dayton and E. Sala, op. cit.

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**Keck HydroWatch**

*Continued from page 6*

soils before they install their sensors. While their idea remains a hypothesis at this point, confirmation of their theory would have major implications for land managers, emphasizing the important role that large, old trees play in sustaining the other plants in the forest.

For Dawson, this line of research confirms the value of working in interdisciplinary groups. “Bill [Dietrich] is an earth scientist, but he appreciates how biology impacts the earth systems he studies. Inez also. Five years ago, when I started showing her some of the things we were learning about transpiration and trees, she was amazed: ‘Really? Plants are doing this? This is going to have such a huge impact on our global climate models.’ Now, she’s one of the biggest advocates of the roles trees play in hydrology. For a long time, I’d been thinking about rock moisture and how plant roots get into deep rock cracks, but I’d never known how to approach it. It was really Bill who said, ‘We’ve got to measure this,’ and then Rohit got involved. Those guys have the expertise in earth sciences to know how to approach the problem.”

Others on the research team have also been busy this summer, installing a wide array of different sensors. Although the plant physiology team could not install sap-flow sensors in the tree roots, they did climb into the forest canopy at Angelo to install 16 sap sensors to determine where the trees are getting their water and how much they’re drawing in each day. Other scientists set up hyper-accurate rain gauges and weather stations. Jim Bishop of Earth and Planetary Science at UC Berkeley and Todd Wood of Lawrence Berkeley National Laboratory (who together developed robotic sensors in the open ocean) automated water sampling in the creek and in a nearby well so they could analyze the chemistry of the water. Bill Dietrich and his students have installed time-delay cameras for the hydrology team and installed water-chemistry samplers in the creek and in a nearby well, as well as time-delay cameras for monitoring sediment transport in the
seasonal tributaries. Finally, Jay Taneja, a graduate student on David Culler’s sensor team, has designed and produced several dozen custom motes for recording microclimate data throughout the watershed, both on the ground and in the trees. Eventually the system will include more than 200 motes.

Currently, most of these data collection points are linked by wires to a series of central control panels. To access the data, researchers must make the three-and-one-half-hour drive from the San Francisco Bay Area to the Angelo Reserve to download the information stored on data loggers. No wonder the ultimate vision is to create a “wireless watershed” with sensors that transmit data to central data loggers, then up into the wireless network Steel and Bode have installed in the treetops, out to an Internet node on a nearby peak, and into the researchers’ office computers a couple hundred miles away.

There, Fung and her team of statisticians and modelers are gearing up to make sense of the large volume of data the system will produce. “I’m not an outdoors person,” admits Fung, “so it will be incredible to be able to sit at our office computers and view real-time data as rain falls in the Elder Creek Watershed.”

**Contrasting Watersheds**

The value of the Natural Reserve System’s ecosystem diversity, from reserve to reserve, became evident early this summer when scientists from the Keck HydroWatch team traveled from Angelo, near Northern California’s coast, to visit the Sagehen Creek Field Station, in the Sierra Nevada, and begin planning the layout for their second watershed-monitoring system. Located in a valley high on the eastern side near the Sierra crest, Sagehen receives some of the heaviest snowfall in the state. The watershed is broad and stretches from high-altitude evergreen forests to sagebrush at the reserve’s eastern edge. Broad meadows and fens line the creek.

As was the case at Angelo Reserve, a lot of scientific data has already been collected at Sagehen. Weather and streamflow records stretch back to the 1950s, and 10 weather stations currently collect data at different elevations in the basin. Detailed, laser-based LIDAR maps lay out the topography in great detail (see *Transect 23:2*, page 1), and a 2007 field class from UC Santa Barbara, under the direction of emeritus professor Art Silvester, created a geologic map of the entire watershed (see *Transect 25:2*, page 11). Researchers from the University of Nevada, Reno, the USDA Forest Service’s Pacific Southwest Research Station, the Desert Research Institute, and a number of other institutions have also installed a range of sensors throughout the basin.

“Stream guy” Jim Kirchner knows this area and its hydrological characteristics well. As faculty manager of the Sagehen Creek Field Station, he has hiked all of the nearby watersheds (see sidebar, page 6), taking water samples and recording streamflow data. “Understanding how water cycles through the natural environment,” he explains, “is the key to understanding a host of things we need a better handle on, like the availability of streamflow...”

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and groundwater for ecosystems and people, as well as the availability of soil moisture for the trees on the landscape, keeping the forest moist enough so that it doesn’t burn down. There are many issues in managing this kind of landscape, and how water is processed at the surface of the Earth is pivotal for all of them.”

Kirchner is also very aware of some of the missing links in our understanding of the water cycle. Plant transpiration is one of the factors he has in mind. More than half of the precipitation that lands in the Sierra evaporates back to the atmosphere. If water managers want to know how much rainfall will end up in a stream, they need to understand what controls evaporation across a landscape. Scientists have a general understanding of what affects transpiration rates. Transpiration goes faster when the atmosphere is dry, the weather is warm, and the landscape is wet, but slower when the atmosphere is humid, the sky is cloudy, or the landscape is dry. But they don’t know the details, and so they find it difficult to make accurate future predictions.

Kirchner provides some good examples. “What will happen to evaporation rates if we cut down, or lose, half the trees in a forest?” he asks. “What will happen over the next 50 years if 50 to 80 percent of the snowfall comes as rain instead? How will that change low flows in the summertime?”

These are the kinds of questions Kirchner and his partners in the HydroWatch Project hope to answer. “Right now, our answers would be little better than guesses,” he admits. “And those are things we need to know in order to forecast the impact of climate change. If we’re wrong about water yield from the Sierra Nevada by 20 percent, that’s roughly equal to all that the cities of California use each year. (Agriculture uses most of the other 80 percent.) California’s water managers need to know how the landscape is going to respond to the weather, how much water won’t be available because it’s going to evaporate back into the atmosphere, and how this number will change 20 years down the road.”

One HydroWatch goal is to develop new ways to visualize and measure water flow through the ground with new types of sensors and communications technology. The time-domain reflectometers, or TDR probes, installed at Angelo’s Rivendell study site, for example, provide a new level of detail on the moisture content of soil. But will the new technology reveal new information? Kirchner is confident it will. “This is not just a shot in the dark,” he asserts. “We have good reason to think there are some interesting things out there, based on tantalizing data we’ve collected with existing instruments. The measurements we’re already getting from the meadow here at the Sagehen field station are telling us something about how the system works. We just need to unpack the story in more detail to get a much richer understanding of the basic processes that control hydrologic behavior. More precise probes and sensors might allow us to do that.”

Streams as Landscape Sensors

Beyond the obvious management implications of the Keck Center’s findings for California’s water and land managers, the group is also focusing on questions that are interesting for their own sake. Fung’s original question — “How old is the water in the stream?” — is a perfect example.

Kirchner acknowledges he doesn’t have an answer yet to that one. He does know, however, that a landscape can hold water for weeks or months and then, when a heavy rainstorm hits, release that water into a stream in a matter of hours or even minutes. Many hydrologists have tried to model this behavior, but testing the validity of these models will require new types of technology.

In the meantime, Kirchner is pursuing a separate line of inquiry that might provide a valuable new perspective. Rather than relying on TDR probes or boreholes that record data in a single spot, he’s exploring ways to use streams to get a better sense of what’s happening across a landscape. In a sense, he’s back to looking at input and output signals again, but this time in a more sophisticated form. What is the rainfall rate in and what is the streamflow rate out? What are the chemistry and isotopic composition of the rain, and what are the chemistry and isotopic composition of the streamflow? His concept is to use streams to synthesize a broader spectrum about what’s happening underground.

“I’m fascinated with the idea that what happens in the stream reflects what’s going on across the landscape,” he explains, “so I’ve been developing techniques for watching the fluctuations in the stream on time scales of minutes and hours, and using that to infer what’s happening on the landscape. How hard is it raining? — or, rather, how fast is the forest transpiring water back to the atmosphere? And I’ve found that, under some circumstances, I can figure out what’s going on in the landscape by...
Kirchner’s inspiration for this approach came from his long-term daily monitoring of Sagehen Creek. During the spring, the streamflow depended on snowmelt. Each morning as the sun rose, the stream would begin to rise and would continue to rise through the day, peaking at sunset. Then, in the evening when the snow stopped melting, the streamflow would decline as it drained the landscape of water. The next day, a new pulse of water would surge into the landscape, and the process would start again.

During the summer, Kirchner noted, the pattern was reversed, and that reversed pattern depended on plant transpiration. When the sun rose, plant transpiration pulled water out of the landscape and streamflow declined. This process continued all day until the evening, when the sun went down and the plants stopped transpiring. At that point, the stream would start to rise again. Kirchner is now building on these observations to develop techniques for quantitatively looking at the stream’s behavior: “If it’s raining [this hard], then we expect the stream to rise by [this much], [this many] hours later.” He’s also using his modeling technique to look backwards: “If the stream rose by [this much], then [this amount] of rain must have fallen or [this amount] of snow must have melted.”

“So what we’ve done is develop techniques for quantitatively looking at that relationship both forwards and backwards,” Kirchner explains. “We can know whether a summer day was cloudy, because plant transpiration will be lower, and hence the decrease in streamflow will not be as great. You can absolutely see this. I can download the streamflow record from Sagehen Creek and know what the weather is up here — then I can check the weather station and verify it. That’s big fun to look at!”

**High-Risk Science**

Inez Fung once referred to the HydroWatch Project as “high-risk science,” because no one could predict the value of the data the team would collect until after they were collected. As the team completes its first full sensor deployment, answers will begin to emerge. Will attempts to pry open the black box of long-standing hydraulic models reveal critical new information — or simply confirm the validity of existing models? Will the new probes and techniques developed by the team improve the accuracy of future streamflow models? Will the Keckians get the data they need to make more accurate predictions on global climate change?

Kirchner is optimistic that the project will pay rich dividends. “Almost by definition,” he explains, “when you’re investigating the unknown, you don’t know what you’re going to find, sometimes even after you’ve found it. And you don’t know necessarily how it’s going to be useful. Yet we have seen, over and over and over again, that if you let smart, curious people follow their instincts and try to figure out how the world works, you discover something that turns out to be useful.”

Fung echoes Kirchner’s confidence: “Once we’re successful with the sensor technology, we’ll be able to develop an understanding of how water goes up and down trees — when it goes up and down into the root system, how roots access the water at various depths in the soil, whether the roots fracture the rocks, and what goes back into the stream. If we’re successful and have the system replicated around the country and around the world, then we’ll have developed an underground system for tracking water under our feet. That will be cool.”

Whatever its outcome, the project illustrates the value of the University’s Natural Reserve System. As Kirchner notes: “Trying to find out how the forest landscape works biologically, and hydraulically, and geochemically, is the best reason I can think of for places like Sagehen and Angelo to exist. Such research stations are rare. California is lucky to have 36 of them.” —JB

**For more information:**
Visit the Keck HydroWatch Center homepage at: [http://hydrowatch.cs.berkeley.edu/Welcome.html](http://hydrowatch.cs.berkeley.edu/Welcome.html).

And see page 13 of the NRS publication, *Special Research Projects: National Centers & Other Landscape-scale Projects that Utilize NRS Reserves*, online at: [http://nrs.ucop.edu/program_reports/Research_Projects.pdf](http://nrs.ucop.edu/program_reports/Research_Projects.pdf) — also available in hard copy, upon request, from the NRS System-wide Office: 510-987-0150.
basins are vulnerable to changes in the timing and magnitude of snowmelt runoff. Winter and spring temperatures increased in North America during the twentieth century. In the Sacramento-San Joaquin Basin, the snow extent and depth decreased, and snowmelt-driven streamflow shifted to earlier in the year. Figure 1 (right) illustrates the various adverse consequences associated with such changes in hydrology. No systematic decline in the snowpack has yet been reported in the Colorado River Upper Basin. However, climate-model projections suggest that temperatures will continue to rise in that region, resulting in a smaller snowpack, increased evaporation losses, and earlier peak spring runoff.

The Colorado River is the major source of water for Southern California. The 1922 Colorado River Compact (ratified by the Boulder Canyon Project Act of 1928) allocated 4.4 million acre-feet (MAF) of Lower Basin water annually to California. One acre-foot (326,000 gallons) is the amount of water required to cover one acre (43,559.5 square feet) to a depth of one foot. The seven primary beneficiaries of this allocation are the Palo Verde Irrigation District, Yuma Project, Imperial Irrigation District (IID), Coachella Valley Irrigation District, Metropolitan Water District (MWD), and the City and County of San Diego. Agricultural use accounts for over two-thirds of the allocation. In 2003, unable to meet its water needs, San Diego bought annual rights for 0.2 MAF from IID under a 75-year agreement. In 2004, MWD, which supplies water to 18 million Southern Californians in 26 cities, purchased annual rights to 0.11 MAF from IID for 35 years. These transfers of water from rural to urban uses were the largest in U.S. history. Such transfers that take substantial agricultural land out of production are occurring on a massive scale globally.

We now examine the dependence of Southern California on the long-term reliability of Colorado River flows. Lee’s Ferry is the accounting point between the river’s Upper and Lower Basins. Streamflow data for 1906-2007 are available from the U.S. Bureau of Reclamation. They represent the best available estimate of what the flow at Lee’s Ferry would have been in the absence of reservoir regulation and other anthropogenic interventions. When combined with tree-ring chronologies, these data allow reconstruction of annual Colorado River flows for hundreds of years (see Figure 2, facing page). These long-term records show vividly the very large amplitude of the year-to-year variations in streamflow. An extensive dendrochronology study in 2007 extended the record back to AD 762. The 1999-2004 period was notable for the lowest total five-year flow observed in the twentieth century. However, an even drier five-year period occurred in the mid-nineteenth century. The longest drought in the 762-2005 record lasted over 60 years, from 1118 to 1179. In one interval of this devastating drought, the Colorado River flow remained below normal for 13 consecutive years.

The highest sustained flows in the record for the twentieth century occurred in the early part of that century, a period that coincided with the negotiation
of the 1922 Colorado River Compact and the resulting allocation of Colorado River flow (see Figure 3, below). Consequently, water that was not likely to be in the river on a consistent basis in the future was divided among the Lower Basin states (California, Nevada, and Arizona).

The above “case history” shows yet again that many questions about the Earth’s functioning can be examined only in the context of reliable, very long-term datasets where twenty years may be a very short time.

— Alexander N. Glazer
Director, Natural Reserve System

References


Water Work Takes to the Air

The Keck HydroWatch Project received media attention this summer when it was featured on KQED, San Francisco’s public television station. “Tracking Raindrops,” an 11-minute piece on the project, was aired on Quest, a multimedia program that explores Northern California science, environment, and nature stories. The program was a collaboration between the KQED Quest staff and NRS science writer Jerry Booth, who provided most of the program’s field footage. “Tracking Raindrops” can be seen on KQED’s Quest website: <http://www.kqed.org/quest/television/tracking-raindrops>.

Booth’s camera crew shot the footage as part of a National Science Foundation (NSF)-supported documentary he is producing on the Angelo Coast Range Reserve. “Mapping the Future” will document a year in the life of that Mendocino County reserve and will feature the work of the HydroWatch Project, the National Center for Earth-surface Dynamics, the National Center for Airborne Laser Mapping, and other research projects ongoing at the reserve. It will be completed in the spring of 2009 and will be shown on UCTV (<http://www.uctv.tv/>) and other outlets. In addition to Booth, the production crew included Director of Photography Dave Drum, Engineer Rob Weiner, and Production Assistant Lobsang Wangdu. Those who are interested can follow the production of the documentary at: <http://nrs.ucop.edu/Reserves/Angelo/mapping_future.htm>. —JB

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