Spring 2023

BREAKTHROUGHS

Berkeley Rausser
College of Natural Resources

THE FUTURE *of* WATER

Berkeley Rausser
College of Natural Resources

DEAN
David D. Ackerly

EDITOR
Julie Gipple

ASSOCIATE EDITOR
Mathew Burciaga

CREATIVE DIRECTOR
Arnaud Ghelfi

COPY EDITOR
Laura Deck

CONTRIBUTING WRITERS
Ann Brody Guy
Mathew Burciaga
Julie Gipple
Kara Manke
Kristin Baird Rattini
Zac Unger

CONTRIBUTING PHOTOGRAPHERS
Alienor Baskevitch
Mathew Burciaga

CONTRIBUTING ARTIST
Maripaz Franco

DESIGN & PRODUCTION
l'atelier starno, www.starno.com

ONLINE DIRECTOR
Joseph Bunik

ONLINE PRODUCTION
Magaly Santos
Nina Tiêu

PLEASE DIRECT CORRESPONDENCE TO:
Breakthroughs
Rausser College
of Natural Resources
University of California, Berkeley
101 Giannini Hall, #3100
Berkeley, CA 94720-3100

(510) 643-1041
breakthroughs@berkeley.edu
nature.berkeley.edu/breakthroughs

CONNECT WITH US
facebook.com/raussercollege
@NatureAtCal
nature.berkeley.edu/linkedin
@NatureAtCal

MIX
Paper from responsible sources
FSC® C001643

LETTER FROM THE DEAN

When we started planning this water-themed issue of *Breakthroughs* last fall, we were focused primarily on the lack of this precious resource. California's 2022 water year had been the fourth dry year in a row, after all. But then the early months of the year brought a series of atmospheric rivers that filled reservoirs, flooded roads, and piled up snow in the Sierra Nevada. It's been a record-setting wet winter, offering at least temporary relief from the drought. It's called weather whiplash, and we know it is likely to become our new normal.

The stories in these pages delve into this "drought and deluge," as well as many of the myriad other topics relating to water and its issues, importance, and power. We learn from Rausser College experts researching the ways that climate change is affecting the water cycle, and what consequences may result for humans and ecosystems. We explore California policies that aim to create equitable, sustainable, groundwater resources for all. In discussion with two faculty experts, we learn how global inequities around water persist and how they could be dismantled. And we follow the already esteemed career of an alum influencing international water policy.

This is the final issue of *Breakthroughs* during my first term as Dean of Rausser College of Natural Resources. I am excited to share my priorities in our newly released strategic plan and to continue serving the College for a second term. See page 7 for details on our process and vision for the coming years.

I welcome your feedback at dackerly@berkeley.edu.

David Ackerly

David D. Ackerly

Adobe Stock / Marek (cover)

On the cover: An aerial image of a braided river flowing off of a glacier in Iceland.

BREAKTHROUGHS

SPRING 2023 / **CONTENT**

Ground Rules

Working toward sufficient, safe, and equitable groundwater.

Page 10

The Future of Water

A changing water cycle affects humans and ecosystems.

Page 14

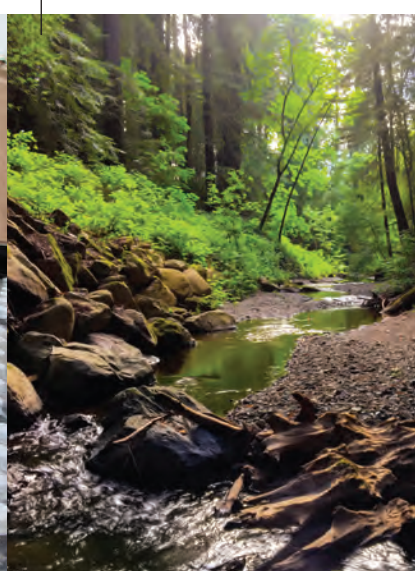
Following the Flow

Assessing California's sensitive freshwater ecosystems.

Page 20

ONLINE

Find more to enhance your *Breakthroughs* magazine experience by following QR codes throughout the issue.



Balancing river health and renewable energy

While the United Nations Sustainable Development Goals promote the use of renewable energy projects, research shows that the expansion of hydropower—specifically through large dams—could negatively impact the people and freshwater species that rely on the world's remaining free-flowing rivers.

Dams across the globe have affected ecosystems by blocking fish migration, altering river structure, and even displacing communities. UC Berkeley's Renewable and Appropriate Energy Laboratory (RAEL), led by James and Katherine Lau Distinguished Professor of Sustainability **Dan Kammen**, is part of an international team focused on efforts to expand clean energy use while reinvesting in the human and ecological health of river systems.

In January, RAEL researchers co-authored a study that describes how low-cost, low-carbon, and low-conflict power systems could serve as viable alternatives to large hydroelectric dams. Published in *Frontiers in Environmental Science*, the paper shows that falling prices and technological improvements—coupled with advances in river knowledge and modeling—have now made it possible for small- to medium-scale solar, wind, microhydro, and energy-storage projects to replace the generating capacity of certain large dams when connected to a larger power system.

Srinagarind Dam in Kanchanaburi, Thailand.

"In partnership with the World Wildlife Fund and academics from several universities, we show that it is possible to utilize rivers in decarbonized energy systems while protecting the critical ecosystems of the world's rivers," said Kammen. "Our research offers developers and policymakers more sustainable models for decarbonizing the energy sector as part of a socially and ecologically Just Transition." — *Mathew Burciaga*

An image generated by DALL·E with the prompt "a robot scientist in nature with clean energy."

Can AI save the planet?

From self-driving cars and medical breakthroughs to surprisingly talented image and text generators like DALL·E and ChatGPT, artificial intelligence is advancing at breakneck speed—and causing lots of speculation, excitement, and concern. In a recent post on the *Energy Institute at Haas* blog, Agricultural and Resource Economics associate professor **James Sallee** pondered whether AI tools will help humanity cut emissions and adapt to climate change, or make matters worse. While AI will boost innovation and economic growth and enable new possibilities for research, posited Sallee, it may also increase disinformation and income inequality as workers are displaced—inducing social division that hinders progress for the climate. "The critical question is whether we've reached the point where as a society we are willing to prioritize addressing climate change, so that innovation on balance will be climate positive," he writes. — *Julie Gipple*

Read more online.

iStock (dam)

The Central Sierra Snow Laboratory

At the top of Donner Pass in the Sierra Nevada Mountains, at an elevation of nearly 7,000 feet, sits an old cabin. It's one of the snowiest places on Earth—a fitting home for the Central Sierra Snow Laboratory (CSSL). When snowfall is at its highest, the front door of the cabin is buried, and resident researchers can only enter through a window on the third floor.

A UC Berkeley field station run by lead scientist **Andrew Schwartz**, the CSSL houses one of the longest ongoing sets of data on snowfall in the world, dating back to 1878. Providing daily, hand-collected measurements of precipitation and regular data on snow water content, the lab offers critical insight into the Sierra Nevada, California's most important water storage system.

More snow means more water trickling down to reservoirs and streams for the benefit of ecosystems, fish, agriculture, homes, and industry. With recent patterns of more rain and less snow, water reaches those streams and reservoirs quicker and may end up evaporating or flowing out into the ocean. Understanding how much snow is being stored in the mountains is crucial for water management.

First a facility of the (then) U.S. Weather Bureau and the U.S. Army Corps of Engineers, then run by the U.S. Forest Service for four decades, the CSSL has been managed by UC Berkeley since 1995. When longtime researcher **Randall Osterhuber** retired in 2019, the lab was almost shuttered as the pandemic forced university budget cuts and a hiring freeze. But professor **Robert Rhew**—then faculty director of the facility—worked to ensure the lab could continue its essential work. A local ski patroller named Justin Lichter volunteered to take measurements for a season so that records would not be interrupted, and Schwartz arrived in April 2021.

Over the past two years, he has revitalized the CSSL, acquiring new equipment, expanding staff, raising awareness about the lab and making sure its data is accessible, and increasing collaborations with researchers from Berkeley and other universities.

"In addition to extending important historical records, we're helping California's Department of Water Resources plan for the future of the state's changing water resources," Schwartz said. The lab is also testing and developing new instrumentation to ensure accurate measurements, he said, as well as investigating how rain on snow and forest fires—both more frequent occurrences due to climate change—affect water and water processes.

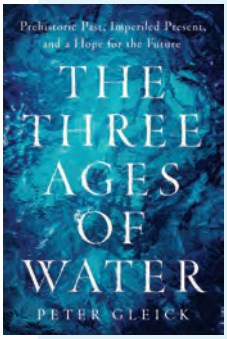
During the major, multiweek storms that hit California in the early months of the year, many meteorologists and news outlets turned to the CSSL for information about the record snowfall. By mid-March it was clear that this season has been the second snowiest in the snow lab's history. "It's been a tough year at the snow lab—we've had issues with flooding and have needed to clear substantial amounts of snow after every storm to make sure that the infrastructure isn't being damaged," said Schwartz. "Despite these challenges, the benefits for the drought are immense."

— Julie Gipple

CSSL lead scientist Andrew Schwartz demonstrates use of a federal sampler for snowpack water measurement (top). University of Nevada, Reno students take snow temperature measurements inside a nearly 18-foot deep pit at the lab in March (middle).

CA Department of Water Resources (Schwartz); Andrew Schwartz (snowbank); Central Sierra Snow Lab (cabin)

Charting a "new age" of water



From the creation of the planet to the present day, water has always been crucial to the existence of life. It is the foundation for scientific and technological advancements spanning from agriculture to space exploration, and it is deeply intertwined with our histories and cultures.

But now, according to alum **Peter Gleick**, PhD '86 Energy and Resources, the very achievements that propelled humanity forward threaten to send us into a new "dark age" marred by "unsustainable water use, ecological destruction, and global climate change." This trajectory is detailed in Gleick's forthcoming book, *Three Ages of Water: Prehistoric Past, Imperiled Present, and a Hope for the Future* (PublicAffairs, June 2023), along with his vision of a sustainable future and a call to instead work toward a "new age of water for the benefit of everyone."

The book chronicles the long and complex history of humanity's relationship with water, showing how rising human populations and growing pressure on natural resources have increased the risk of environmental collapse, driven massive economic inequality, and sown political conflict. But if we learn from the past, Gleick writes, we can create a positive future "with a balance between humans and nature, growing equality and social cohesion, and healthy, stable societies."

— Mathew Burciaga

New AAAS Fellows

In January, three Rausser College professors were named fellows of the American Association for the Advancement of Science (AAAS), an honor considered one of the most distinctive within the scientific community. The new fellows will be formally celebrated in Washington, D.C., later this summer.

David Moore, professor and chair of the Department of Nutritional Sciences and Toxicology, was recognized for advancing knowledge of nuclear hormone receptors. His seminal research has uncovered the role these receptors play in key biological processes like metabolism and diseases like cancer.

Whendee Silver—professor and Rudy Grah Chair in the Department of Environmental Science, Policy, and Management (ESPM)—was honored for her contributions to the fields of biogeochemistry and ecosystem ecology. Her pioneering work has helped illuminate the causes and consequences of climate change, examined the impacts of drought and hurricanes on tropical forests, and revealed possible solutions to climate change through carbon sequestration.

Neil Tsutsui, professor and Michelbacher Chair in ESPM, was recognized for his foundational research on the characteristics of ants. An evolutionary biologist who focuses on communication, behavior, and genetics within insects, Tsutsui has advanced scientific understanding of kin recognition and social behavior in ants.

PublicAffairs (book); Agapito Sanchez (Moore); Mathew Burciaga (Silver); Elizabeth Cash (Tsutsui)

Jill Banfield is a pioneer in the fields of metagenomics and microbiology.

A first in microbiology

In February, **Jill Banfield** was awarded the 2023 van Leeuwenhoek Medal for her contributions to the understanding of microbial communities and interactions between microbes and the environment. The medal is awarded every ten to twelve years by the Royal Netherlands Society for Microbiology in recognition of remarkable advances in the field of microbiology and their impact on science and society.

A professor in the Departments of Environmental Science, Policy, and Management and Earth and Planetary Sciences, Banfield's pioneering work includes the development of genome-resolved metagenomics and the advancement of community proteomics to study diverse bacteria, archaea, and phages, adding new branches to the tree of life. Potential applications for her research include bioremediation, biological carbon capture, and medicine.

Banfield is the scientific director of microbiology research at UC Berkeley's Innovative Genomics Institute, and she is the first woman to be awarded the van Leeuwenhoek Medal in its 125-year history.

Why I Do Science

BY PATINA K. MENDEZ

I'm an aquatic ecologist, entomologist, and educator. Looking back, I suppose I was always interested in insects, but I didn't always know my interest could become a career.

Growing up in San Antonio, I'd spend hot summer days swimming and then playing outside in the cooler evenings. There were many amazing insects to encounter—all the kids would capture fireflies (lightning bugs to us) and put them in jars to light our bedrooms. When I was about 10, there was a large emergence of cicadas, which are known as *chicharras* in Texas. The trees were covered in what looked like tiny, alien robots, and the earth and sky pulsed with sound.

In college, I took an entomology class because I heard the professor was fun. He was! He had us jumping into the bushes after insects, carrying nets around campus, and digging in the dirt. I loved capturing insects, identifying them under the microscope, and drawing them. I found it fascinating to observe these tiny organisms and their complex behaviors. Now, my scientific research focuses on aquatic insects, specifically caddisflies.

"Doing science" requires creativity and problem solving. You get to do all kinds of fun things, such as using art, design, drafting, construction, and electronics to make equipment to gather data. My students and I figure things out together and celebrate when we succeed—it's *electric* when things work! Learning and doing isn't always perfect, and it's important for students to see that persistence and collaboration are critical.

I've been fortunate to develop programs to foster freshwater ecologists from historically underrepresented backgrounds. As a Latina in STEM from a family of two different cultural backgrounds, they're the programs I wish had existed when I was young. I also lead a program that mentors college faculty in bringing the science of human learning into their curriculum design. In both programs, we're learning how to support people as they develop identities as scientists and educators.

Patina K. Mendez is a continuing lecturer in the Department of Environmental Science, Policy, and Management and a specialist at the Essig Museum of Entomology. In 2022, she received the Leadership Career Award from the Society for Freshwater Science and the Rausser College Distinguished Teaching Award.

Elena Zhukova (Banfield); Mathew Burciaga (Mendez)

Double Whammy

EFFECTS OF CLIMATE CHANGE AND URBANIZATION ON CALIFORNIA'S BIRDS

It's well known that climate change is affecting California's birds, but that's not the only threat: urban sprawl and agricultural development have dramatically changed the landscape of the state, forcing many species to adapt to new and unfamiliar habitats.

In a study published in *Science Advances* in February, Rausser College biologists reveal how land-use change has amplified—and in some cases mitigated—the impacts of climate change on bird populations in Los Angeles and the Central Valley.

They found that urbanization and much hotter and drier conditions in LA have driven declines in more than one-third of the region's bird species over the past century. Meanwhile, agricultural development and a warmer and slightly wetter climate in the Central Valley have had more mixed impacts on biodiversity.

Led by professor **Steven Beissinger**, the study presents the latest results from UC Berkeley's Grinnell Resurvey Project, an effort to revisit and document birds and small mammals at sites first surveyed a century ago by UC Berkeley professor Joseph Grinnell.

A lark sparrow, one of the species that has experienced declines.

The researchers resurveyed birds at 71 sites and consulted current and historical data on land use, average temperature, and rainfall. In LA, they found that 40 percent of bird species were present at fewer sites today than they were 100 years ago, while only 10 percent were present at more sites. In the Central Valley, the proportion of species that experienced a decline (23 percent) only slightly outnumbered the proportion that increased (16 percent). In many cases, opposing responses to climate and land-use change by bird species—where one factor caused a species to increase while another caused the same species to decline—moderated the impacts of each threat alone.

— Kara Manke

An appeal for freshwater conservation

The 30x30 initiative—a global effort to set aside 30 percent of land and sea area for conservation by 2030 in hopes of reversing biodiversity loss and mitigating the effects of climate change—has been adopted by state and national governments around the world.

When it comes to the water side of 30x30, most programs focus solely on conservation of oceans, but a recent study by Rausser College researchers argues that freshwater ecosystems must not be neglected. Published in March in the journal *Frontiers in Ecology and the Environment*, the paper urges policymakers to explicitly include freshwater ecosystems in 30x30 plans, and outlines how their conservation will be critical to achieving the initiative's broader goals of addressing climate change and fostering economic sustainability, food security, and equitable outdoor access.

"Freshwater ecosystems are especially fragile and often overlooked in global conservation initiatives," said **Jessie Moravek**, the study's lead author and a doctoral student in the Department of Environmental Science, Policy, and Management. "Many times, conservation practitioners assume that water is protected just because the land around it is protected, but that's not always the case. Rivers, lakes, and wetlands usually need special attention."

Channel City Camera Club via Wikimedia (Lark sparrow); istock (stream)

Rausser College's Strategic Plan

After a year-long, College-wide effort led by Dean David Ackerly, the Rausser College of Natural Resources strategic plan was released in March. The objective of the planning process was to assess the College's shared intellectual and educational mission and identify priorities for improvement and growth in order to ensure the continued success of the College.

The process engaged with both internal and external audiences and stakeholders in Rausser College, including a strategic planning committee, campus leadership, department and dean's office leadership, the College advisory board, and topical working groups including faculty, staff, and students.

Read the full plan online.

The strategic plan includes a refreshed mission statement that reflects the College's academic mission and core values and presents a set of five strategic priorities and initiatives.

Mission

Rausser College of Natural Resources embraces the University of California's public mission, serving the people of California, our nation, and the world.

We conduct fundamental and applied research in the biological, physical, and social sciences. We train and educate future leaders and scholars, and engage with public and private partners to meet the pressing social and environmental challenges of our time. Through our research, teaching, and outreach, we seek equitable, scalable, and innovative solutions that address the climate crisis, promote ecological and economic sustainability, and improve human health and well-being.

Values

- **Excellence:** We value excellence in all we do: research, teaching, and service to society.
- **Access:** We value diversity in our College community and strive to apply the values of equity, inclusion, and antiracism in our research, teaching, and service.
- **Engagement:** We value meaningful and inclusive engagement with our community partners and the public and private sectors.

Our Priorites

Science and Solutions

- Strategic research initiatives
- Educating graduate and professional students
- Investments in research facilities
- Extension and engagement
- Innovation and entrepreneurship

Undergraduate Experience: Excellence, Inclusion, and Discovery

- First-year experience
- Undergrad discovery and research
- Inclusive education initiative

Community and Belonging

- Diversity, Equity, Inclusion, and Belonging initiatives
- Community building and professional development

Financial Strength

- Campus financing
- Revenue diversification
- Philanthropic support

Telling Our Story

- 50th anniversary celebration
- Enhanced media visibility

Navigating Water Issues Worldwide

Rebecca Peters in China's Tiger Leaping Gorge on the Jinsha River in Yunnan Province.

Photography courtesy of Rebecca Peters

REBECCA PETERS, BS '14 SOCIETY AND ENVIRONMENT

BY KRISTIN BAIRD RATTINI

When Rebecca Peters applied to Berkeley as a transfer student in 2011, she grappled with what she considered her "family curse." The three prior generations of women in her family had all attended Berkeley, but none had graduated. "I thought, 'If I get in, I'm going to give this everything I've got,'" she says. "Because Berkeley is the kind of place where you can really make things happen."

As demonstrated by her becoming a Truman Scholar, a Marshall Scholar, and UC Berkeley's University Medalist by the time she graduated in 2014, Peters succeeded in her quest. And she has continued to give her all in her career as an international water policy advisor, which has taken her to more than five dozen countries (and counting) and, most recently, led to a position at the U.S. Department of State.

READING THE WATER LANDSCAPE

Peters had already become involved in environmental activism before she arrived at Berkeley from her hometown of Calabasas, California. In high school, she volunteered with the Mountains Restoration Trust and served on the Calabasas City Council Environmental Commission, which helped transform a section of the Las Virgenes Creek from a concrete storm drain back into a natural landscape.

She got her first glimpse of the immense global landscape of water issues during her undergraduate environmental science studies at Cal Poly San Luis Obispo. A class project took her to the remote town of San Pablo Tacaná in Guatemala to co-develop a water treatment project. "When I returned, I was grappling with everything I had learned and looking for ways I could continue to work on issues of water and community development," she says. "At the same time, I learned about the global poverty minor at Berkeley, which is a really different approach to engaging with issues of power, poverty, and inequality. It was a compelling reason to transfer."

At Berkeley, she pursued not only the global poverty minor but also dual majors: a BS in society and environ-

Peters visiting a textile production facility's wastewater processing plant in Dhaka, Bangladesh.

With REACH water security programme colleague Aziz Rahman (far right) and community members in Dhaka during household surveys about experiences with river water pollution in 2019.

ment from the College of Natural Resources and a BA in international development and economics. She thrived under the mentorship of three women faculty in the College who "completely changed the course of my life," she says. **Kate O'Neill** "really cared about the practical side of how international environmental policy is made." Political Ecology, taught by her thesis advisor **Nancy Peluso**, "formed my critical thinking skills about how I approach natural resources management," she says. "I apply lessons from that class in my daily life." She was also inspired by the work of her other thesis advisor, **Isha Ray**. "People like Isha have shown so much intellectual leadership in the field—I am standing on the shoulders of giants, and she is one of them."

Peters reconstituted and led the Berkeley Water Group—which to this day serves as a forum in which students discuss their research on water, sanitation, and hygiene—and co-launched a project that augmented access to water and feminine hygiene supplies for girls at 12 rural schools in Bolivia. Those interests dovetailed in the DeCal course she founded and co-taught for six semesters, Water and International Human Rights. "I wanted students to come away with a deeper appreciation for what water means for us individually and in our communities and societies, and to tie that into the broader principles of how we think about human rights and laws," she says.

BREAKING THE CYCLES

As a Marshall Scholar in England, Peters continued her studies of the intersection of water and poverty issues. She earned a master's degree in poverty and international development at the University of Manchester, known for its cutting-edge research cluster on poverty alleviation. The program took her to South Africa to study post-apartheid water governance reforms. She subsequently earned a master's degree in water science and governance at King's College London, studying with esteemed water researchers including Stockholm Water Prize laureate Tony Allan.

After graduation, Peters spent a year researching transboundary river policy and the impacts of hydropower dams at the Asian International Rivers Center in Yunnan, China. She attended the International Hydropower Association conference in Ethiopia and co-authored a report with The Nature Conservancy on how dams and their surrounding river systems can fit together more holistically.

For her PhD at the University of Oxford, she focused on river water pollution in Bangladesh. "Geographic and climatological conditions that affect water vary in different places, but there are shared patterns in water issues anywhere you go," Peters says. "It's never wealthy, powerful people who have a hard time getting access to water. I want to better understand ways to break these cycles of poverty and lack of agency and control over natural resources across the world."

INTEGRATING HER INTERESTS

Peters is now applying her expertise on water and natural resource issues in thought leadership roles on both sides of the Atlantic. Since January 2021, she has been an Academy Fellow, and then Academy Associate at Chatham House, a century-old, independent international affairs think tank in London. And in October 2022, she relocated to Washington, D.C., to join the U.S. Department of State as a contractor serving as international water policy advisor. "I saw the position as a way to integrate my interests in public service, water, and foreign policy," she says.

At the State Department, her team leads the development and implementation of U.S. foreign policy on global water security, transboundary water cooperation, climate adaptation, and natural resources management. "There are high levels of commitment to addressing water and climate," she says. "It's a really exciting time to be working on these topics."

Water is pumped into an irrigation canal at an almond orchard in Firebaugh, California, where drought and groundwater depletion force farmers to consider switching crops or leaving fields fallow.

GROUND RULES

Can the Sustainable Groundwater Management Act ensure sufficient, safe, and equitable water for all Californians?

BY ZAC UNGER

When we talk about California's water supply, most people think of the interconnected network of rivers, reservoirs, and aqueducts that cross the state. But, in reality, according to the California State Water Resources Control Board, forty percent of the state's agricultural and residential water is pumped from underground—a figure that jumps to sixty percent during dry years. Ongoing drought has accelerated groundwater depletion at an alarming rate. In fact, a recent NASA study using remote-sensing technology shows that California's groundwater is being drawn down five times faster than fifty-year historical averages. Experts warn that there is a real possibility of complete exhaustion of the state's groundwater if current conditions persist.

In response to this crisis, California lawmakers passed the Sustainable Groundwater Management Act (SGMA) in 2014, a package of bills that require local and regional authorities to actively regulate groundwater use and create sustainable management of groundwater by 2042. "Prior to that, we had no systematic management of groundwater at all," says **Kristin Dobbin**, an assistant professor of Cooperative Extension in the Department of Environmental Science, Policy, and Management, noting that "we were the last state in the West to enact a management plan."

Though it's a statewide framework, SGMA is based on the premise that the best solutions will be accomplished locally. Under the plan, groundwater basins designated as medium or high priority were required to form groundwater sustainability agencies (GSAs). These local agencies, in turn, were required to create groundwater sustainability plans. Those "roadmaps to sustainability," as Dobbin calls them, were due between 2020-2022, and most are now under review by the California Department of Water Resources. Even as they wait for acceptance or revision suggestions, GSAs are mandated to begin enacting their plans. The final—and most difficult piece of the puzzle—will be actually achieving sustainability and other environmental goals over the next twenty years.

TRAGEDY OF THE COMMONS

A big part of the reason why groundwater supplies in California are so tenuous comes down to their relationship to property rights. "If you own a parcel of land in California, you have the right to use the groundwater underneath that land," explains **Ellen Bruno**, an assistant professor of Cooperative Extension in the Department of Agricultural and Resource Economics. "You'll pay the cost to drill the well and the energy costs to extract it from below, but that's it."

Unfortunately, underground water networks are an unmetered, unregulated, and unmonitored asset that don't correspond neatly with aboveground property lines or political boundaries. This leads to a classic economic problem—a "tragedy of the commons"—created when the water that one farmer pulls by drilling straight down reduces the supply for everyone. And water pumped today won't replenish fast enough to be available in a warmer, drier future. "It's a free-for-all," Bruno says. "What incentive do you have to constrain your own behavior if your neighbor won't?"

Broadly speaking, there are only two ways for the state to transition toward sustainability and ensure adequate groundwater for future use: reduce demand

California Groundwater basins that are subject to the Sustainable Groundwater Management Act.

Justin Sullivan/Getty Images

"What incentive do you have to constrain your own behavior if your neighbor won't?"

— ELLEN BRUNO

or increase supply. Recharging groundwater is difficult. Techniques to capture, save, and later infiltrate water back into the ground do exist, but these solutions are costly and often logistically difficult given existing land uses. And even in a season of heavy rains like California saw earlier this year, tens of billions of gallons can't be captured fast enough.

Most experts believe the lion's share of the groundwater solution will be on the demand side. SGMA, however, is not a prescriptive management plan filled with detailed rules, so each community is left to determine how to achieve sustainability. According to Bruno, there is a lot of heterogeneity across the state in what approach local agencies are taking, but most are considering reducing demand by either limiting pumping or imposing taxes that will make groundwater more costly.

Both those actions will make farming more expensive, she says. Predicting farmer behavior is as essential as understanding the drought tolerance of one crop versus another. Bruno's cooperative extension research, through conversations with farmers and local agencies, is evaluating the impact of certain policies on agricultural water use. "We're assessing how farmers might react if we increase water prices, or if we cap the amount of groundwater that can be pumped in a region," she says. "And we're researching potential benefits of allowing farmers to trade their rights to pump groundwater."

Donna Johnson, a resident of East Porterville, California, delivers bottled water to neighbors. Many town wells in Tulare county have run dry as the result of severe drought and depleted groundwater basins.

Education Images/Getty Images; Jim Block (Bruno)

Bruno's work is critical for informing managers of irrigation districts and hydrologists and consultants at the Department of Water Resources as they consider how to price groundwater usage. "Providing empirical evidence on the price responsiveness of farmers will help inform their management plans," she says, potentially mitigating the amount of land that needs to be fallowed and the negative effects on farmers and consumers.

WORKING FOR WATER EQUITY

In June 2021, the Tulare County town of Teviston—whose 1,185 residents rely on two wells—ran out of water. Their trouble began in 2017, when one well began delivering water that was brown and sludgy. Then their only remaining pump sputtered to a halt as sand choked the machinery. While there is never a good time for a community to run dry, this was a particularly inopportune moment: temperatures topped 112 degrees and most of the residents relied on swamp coolers—which need a constant supply of water—to escape the heat. But even when both wells were working, the water they pumped was contaminated with 1,2,3-Trichloropropane, a carcinogenic pesticide residue.

Numerous groundwater-reliant communities like Teviston stand to benefit from SGMA's new regulations. "Rural drinking water users can be seen as a type of indicator species for our groundwater ecosystem," Dobbin says. "They have the shallowest wells that are the first to dewater and most prone to contamination." By making sure that GSAs prioritize these communities and their access to clean water, Dobbin says, "we center equity and we can make the most gains in advancing sustainable groundwater management."

Dobbin points out that SGMA necessarily interacts with Assembly Bill 685—The Human Right to Water in California—which was passed in 2012 and made the state the first to legislatively recognize a human right to safe, clean, and affordable drinking water. "The success of these two policies is intricately bound together," she says. "We cannot realize the human right to water without sustainable groundwater management, and we cannot achieve sustainable groundwater management as defined in SGMA without adequately accounting for vulnerable drinking water users of groundwater."

Community members in vulnerable towns can provide insight into the challenges they face, but ensuring that their voices are fully considered can be difficult. Dobbin worked

with one man who was the president of a tiny public agency providing drinking water for an unincorporated community of just a few hundred homes. He knew that being involved with SGMA was critical for ensuring his community's long-term access to safe drinking water, but meetings were held during working hours, several towns over, and meeting announcements and cancellations were regularly sent via email, which he didn't have regular access to. These and other factors can create real barriers for participation in the process.

"People of all backgrounds are driven by the idea of answering questions to help advance solutions to water problems."

— KRISTIN DOBBIN

Both Bruno and Dobbin occupy a critical space between lawmakers and policy professionals and the local residents, farmers, and water managers making day-to-day decisions about how to allocate water. The ability to link these groups will be key as SGMA reaches full implementation. Bruno—who regularly speaks and publishes policy briefs about her research on groundwater pricing and other water issues—was awarded a New Innovator in Food & Agriculture Research Award from the Foundation for Food & Agriculture Research to support her SGMA-related work. In January, Dobbin was appointed to the advisory group for the California Water Board's Safe and Affordable Funding for Equity and Resilience (SAFER) program, which was launched in 2019 in part to realize the mandates of AB 685.

DRIVING SOLUTIONS

Fifty years ago, if you'd asked the average Californian about the role of UC Cooperative Extension, they'd probably tell you it was something like helping farmers grow bigger strawberries with fewer mushy spots. But as the work of extension specialists like Bruno and Dobbin shows, the mandate has broadened and become more nuanced. When it comes to SGMA—a massive bureaucratic attempt to combat a seemingly intractable problem—extension is crucial to guiding the concrete actions needed to achieve California's high-minded goals.

Dobbin, for her part, is excited about the way in which extension benefits a wider swath of stakeholders than have traditionally had a voice in agricultural decision-making. "Sometimes there is this belief that university research is too wonky for many people to understand," she says. "But my experience has been that people of all backgrounds are driven by the idea of answering questions to help advance solutions to water problems. We can deploy information into communities, but with SGMA it's also about closing the loop and bringing knowledge back from the field to the policymakers."

Whether it's the residents of Teviston trucking in drinking water, small-scale farmers deciding whether to fallow their land, or massive pistachio-growing corporations trying to predict the long-term viability of their crop, every Californian has a stake in groundwater management. As the state faces climate change and drought, SGMA can either be a powerful conservation tool or a worthwhile endeavor that never quite finds its footing.

Success over the coming decades will require a delicate balancing act between competing interests and an effort to include the small farmers and drinking water districts impacted by water inequity in California. "I'm excited about the way UC is putting resources behind serving a broad population of Californians and doing everything we can to reach all Californians," says Dobbin. "This is the mission of Extension and a way for the University to provide a truly public service."

GROUNDWATER AND CANNABIS

A water use that has received very little study, says Associate Professor of Cooperative Extension **Ted Grantham**, is cannabis cultivation—both legal and illegal. It had been assumed that most growers relied on surface water diverted from streams or—when prohibited from doing so between April and November by "forbearance agreements"—stored rainwater to cultivate their crops. But Grantham and colleagues at UC Berkeley's Cannabis Research Center have found that in fact, most cannabis farmers actually rely on groundwater to meet their irrigation needs. Grantham says that the bulk of cannabis cultivated in California is in areas not subject to the Sustainable Management Groundwater Act. "It's a large regulatory gap that is not being addressed under the current policy," he adds.

Mathew Burciaga (Dobbin)

THE FUTURE OF WATER

How climate change is altering water as an ecological system—a system that includes us. **BY ANN BRODY GUY**

ILLUSTRATION BY MARIPAZ FRANCO • PHOTOS BY MATHEW BURCIAGA

This winter's explosive rainfall events brought weeks of torrential atmospheric river storms to California, yet many of the state's reservoirs remained below annual averages. "We are in a flood emergency while we still have an active drought emergency," Karla Nemeth, director of California's Department of Water Resources, told the *Washington Post* in January. "That pretty much says it all about the new normal we have with climate change."

That new normal is a more intense water cycle, with wetter wet periods and longer, drier droughts. Rausser College of Natural Resources experts point out that the warming climate does not seem to be changing either the average or total amount of precipitation—those levels are remaining relatively consistent. It's the variability that's changing.

"Climate change is not just simple warming," says **Dennis Baldocchi**, a professor of biometeorology, the study of how climate and weather interact with living organisms—including plants, animals, and people. "It's the timing of the rains. It's the amount of warming when it's warm." Those changes in variation affect how water comes, goes, and moves through entire ecosystems.

Baldocchi and numerous other scientists in the Department of Environmental Science, Policy, and Management work at the complex nexus of climate change and ecosystems—water, the planet, and people. What are the impacts from this new variability, and how do those effects trickle down to the ecosystems that both generate and depend on the water supply? Their findings are a wake-up call that an intensified water cycle has implications far beyond nasty weather.

"We need to design water systems for the driest years and take advantage of surplus in the wetter years."

—Dennis Baldocchi,
professor of biometeorology

CALIFORNIA AS A LABORATORY

Baldocchi says California's baseline—with sustained wet and dry periods—is a good model for understanding these changes. He thinks about the water system like an engineer working the knobs on a sink that can be turned to adjust what comes out of the spigot. "What are the input and output knobs? We have to manage these things very, very well."

His research in the Sacramento Delta, for example, is helping California manage the system that sends water south to support San Joaquin Valley agriculture, which, he points out, uses 80 percent of the state's water. It all flows through the Sacramento Delta, which is protected from seawater incursion by what Baldocchi calls "a weak levee system."

California's Department of Water Resources is converting some nearby farmland to wetlands—a project that will help protect the critical Delta system from seawater and also fight climate change by sequestering carbon. But the prolonged drought has threatened the project, which requires infusions of water from the Delta. Without enough water, the fledging wetlands will just evaporate, undoing years of work. "Can we deliver a little less water without reversing the carbon sinks that we formed?" Baldocchi says. He is working with the state to optimize water management for dry years.

Turning the knobs that control water supply and demand has helped Baldocchi measure fluxes in evaporation and understand how different environmental drivers—length of droughts, temperature variations—are causing them to change. "With its wide range of ecosystems and microclimates that experience great seasonal and year-to-year variation in rainfall, California makes a good natural laboratory," he says. "Understanding how our ecosystems respond can inform us how others around the world may react under changing conditions."

A core problem, he adds, is that the state's system was designed based on the wet years. Since droughts are part of our natural climate, he says, "We need to design our water systems for the driest years and then take advantage of the surplus in the wetter years," especially because climate change will amplify these extremes.

OPTIMIZING IRRIGATION

Irrigation is another knob that can be turned to adjust water use. **Paolo D'Odorico**, the Thomas J. Graff Professor of Natural Resources, studies how to optimize irrigation across a large scale, to sustainably manage the changing climate's impacts on agriculture. "By looking at the whole world, we can identify areas where we can expand or reduce irrigation,

"We are more likely good stewards if we see the environmental implications of our consumer decisions."

—Paolo D'Odorico,
professor of ecohydrology

and calculate how many more people we can feed and how much more food we can produce," he says.

Counterbalancing water across the whole world is an audacious notion, but D'Odorico's method is straightforward, modeling global data to measure the key components of water balance—precipitation, runoff in storage, and the amount of water crops or other plants use. He divides the world into tiles or pixels, then calculates how much water the crops use and how much rainwater and irrigation water is available, identifying locations where irrigation could significantly improve yields.

A big caveat, he says, is to integrate an awareness of both social and environmental impacts. Irrigation requires investment, and many parts of the world only have rain-fed agriculture. "We need to make sure that even smallholder and subsistence farmers in developing countries have access to opportunities to adopt sustainable irrigation," he says. "There need to be ways to finance these solutions for everyone so the benefits are not only for large agribusinesses."

NATURAL SYSTEMS, HUMAN VALUES

Agriculture and energy sometimes compete for limited water resources, which complicates the water landscape. In regions where water rights can be traded, farmers can leave their land fallow and sell their water rights to energy companies, which require large amounts to extract fossil fuels. Farmers may also choose to grow biofuel crops like corn and sugarcane. In both cases, the energy sector displaces food production, D'Odorico says.

However, if an energy company doesn't have enough water, it may reduce energy production, which can have pocketbook consequences for consumers. It's a deeply monetized system, at least in the U.S., so policies and pricing mechanisms like subsidies and laws can be valuable tools—knobs to adjust—to control or incentivize different types of water use, D'Odorico says.

Globalization further complicates things, he says, disconnecting people from the impacts their choices have on resources and the environment. For example, the U.S. imports a lot of berries from Mexico, but much of that production is done unsustainably. U.S. commodity subsidies present a whole tangle of disconnection issues, where crops grown with local resources and large government subsidies are then shipped to other markets. "We are more likely good stewards of the land...if we see the environmental implications of our consumer decisions," he says.

It's important to recognize the cultural lens we impose on these issues, D'Odorcio says. "Do we value a pristine system, biodiversity?" He ticks off more human-centered values: carbon sequestration, food security.... "Even keeping nature for the next generation is still very anthropocentric."

GOING UNDERGROUND

These may be complex issues, but they are more transparent because they take place above ground. To really understand the breadth of changes the new climate variability is bringing, scientists say, you have to look beneath the surface.

Laureano Gherardi, assistant professor of plant ecology, researches the impacts of climate variability on plants and landscapes across long time periods.

He's studying the ways plant communities shift how their roots grow as a buffer against climate change. As backyard gardeners know, a light rain will hardly penetrate the soil,

"Large rain events have cascading effects—hydrologic variables intensify after rain intensifies."

—Laureano Gherardi,
professor of plant ecology

often just evaporating, while heavier rains seep deep into a plant's root system. This is true across different ecosystems, Gherardi says. Very wet conditions, with moisture that reaches deep in the soil, may benefit deep-rooted species like shrubs. That causes changes over time, such as grassland changing to shrubland, which is no longer usable for grazing. In agriculture, the same conditions may result in nutrient leaching, as excess water carries soil nutrients far from root systems. Downstream, that can lead to dead zones, low-oxygen conditions that kill fish and other aquatic organisms.

Adapting to new climate conditions generates inefficiencies and changes the way the water cycles through the watershed. "Large rain events cascade down to all the other processes," he says—there's a lot of runoff, and the rivers and streams run higher. "All of these hydrologic variables intensify after rain intensifies." Droughts have comparable cascading effects, he adds, benefiting drought-adapted species that change the ecosystem services being provided.

Most pressing, he says, is to study the interactions of different elements of global change, including land use and ecosystem management, rather than focusing on impacts from just rainfall or temperature spikes.

MEASURING WATER

Gherardi notes that temperature is naturally correlated to seasons within a narrow, predictable range, whereas "rainfall can go from zero today to 30 millimeters tomorrow, so rainfall is inherently much more variable," making it harder to measure and predict.

"Water managers need good data to allocate resources correctly and to understand ecological implications."

—Manuela Girotto, professor of hydrology

That's important because a lot of water management is just knowing how much there is. Mountain snow is a critical water storage mechanism for the state; when it melts in spring and summer it provides runoff that feeds into the streams—surface water—and it also recharges groundwater and soil moisture.

Manuela Girotto, an assistant professor of hydrology, is adding precision to water measurements in California. An engineer by training, Girotto uses satellite and remote sensing observations and modeling to measure how much snow is in the complex mountain environment and how it's changing. "Water managers need good data to allocate resources correctly," she says, "and to understand ecological implications such as how low-soil moisture will affect fires and plant productivity."

She's also working with the Berkeley Artificial Intelligence Research Lab, using AI to aggregate data from multiple sources that provide indirect, narrow observations of snow—for example, thermal observations from space that suggest location, and microwaves that can indicate the depth. Taken together, the data may prove complementary, she says, yielding richer information and new insights.

With warming temperatures, Girotto says, it may not get cold enough at lower elevations to turn rain into snow, and what snowpack there is will melt earlier. She hopes more intense winter storms can cancel out some of the problem, with larger storms accumulating more snow higher up.

Girotto also uses satellite data to measure groundwater, which, she's found, is in decline. In addition to decreasing and less predictable recharge from snow and rainfall, aquifers are also depleted by pumping for farming and industry (see page 10). While new laws may help curb this problem, "We need to be smarter about how we use that groundwater resource," she says.

WATER AND FORESTS

Because forests are a big part of California's water-storage infrastructure, forest management is a critical knob in the state's water management. **Scott Stephens**, an expert in fire science and the Henry Vaux Distinguished Professor in Forest Policy, says there's ample evidence that forests can be managed to maximize the amount of snow they store while making them more resilient to climate change.

"We know that forests can actually help conserve water," Stephens says. "Research has shown that some forest configurations—more open forests with some small patches with no trees—can conserve more snow and allow more water to get into the ground and, subsequently, into streams." Conversely, canopy that is too dense catches the snow, he says, where it just dissipates.

"High-severity fires are damaging the infrastructure of water storage."

—Scott Stephens, professor of wildland fire science

The Illilouette Creek Basin of Yosemite National Park, roughly 70 square miles in the Upper Merced watershed, is part of a living laboratory where, since 1972, lightning fires have been monitored carefully, but not suppressed. "Those fires have really sculpted that landscape," Stephens says. The amount of forest was reduced by 26 percent, he says, killing trees and creating openings where other types of vegetation have come in—meadows, grassland, shrubland. The four- to five-acre gaps in the canopy provide enough open space for snow to reach the ground, but enough surrounding trees to keep the areas cooled and reduce wind, which can blow away surface snow. "It stays there longer, like a mini snowbank that melts into soil, groundwater, and stream water," Stephens observes. "Since you don't have as many trees in the area, the amount of water being used by those organisms is less," he notes.

As a former postdoctoral researcher in the Stephens Lab, **Gabrielle Boisramé**, PhD '16 Civil and Environmental Engineering, compared Illilouette to six similar watersheds just outside the natural burn zone. All of them lost significant stream water in the last 50 years, while Illilouette saw a slight *increase*. "There's just more water in that system," Stephens says.

When Dennis Baldocchi isn't working in wetlands, he studies grasslands and savanna—mixed woodland and grassy areas with open canopies, a lot like the fire-sculpted Illilouette landscape. He's come to see savanna as providing the equilibrium in California's ecosystem that makes forests resilient. "Historically, both natural fires and periodic burning by Indigenous people would have kept the landscape open," Baldocchi says.

When fires are suppressed, the forest just keeps growing, Stephens says, thickening the canopy and creating fuel that, when combined with hotter, more prolonged droughts, sets the stage for megafire events. Megafires create huge, continuous swaths of tree mortality that go on for miles, and also kill off conifer seed banks in their path. "It's really exterminating forests," Stephens says.

For water, that means a lot of volatility. These open wounds on the landscape are exposed to sunlight and wind, so the snow melts more quickly or blows away. Those effects cascade through the ecosystem, reducing soil moisture, which makes it harder for trees and plants to recover and can lead to erosion. Stephens points to the huge 2020 North Complex fire, which burned at about 60 percent high severity in the watershed that feeds the critical Lake Oroville reservoir. With no plants and trees as anchors, rains carried soil off the land, down the streams, and into Lake Oroville. "These high-severity fires are damaging the infrastructure of water storage," Stephens says.

In Illilouette, he says, "None of that is happening. The soil moisture is so much greater, there are openings, and there are areas that have low-density forest and high-density forest. The fire is literally self-regulating."

CULTIVATING CULTURAL CHANGES

Despite the solid science, there's cultural resistance to changing the landscape—idyllic notions of pristine landscapes have a firm grip on the culture, and, conversely, many people want to own and develop land as they please. And, Stephens notes, many people have a problem with the uncertainty of letting fires burn; wildfires can be managed, but not precisely.

But he is adamant that management, including mechanical treatments and unsuppressed burns, makes forests resilient to climate change, and—not coincidentally—also makes them the most efficient water storage systems.

There is progress. Stephens cites huge increases in state funding for forest management work along with the Roadmap to a Million Acres, a strategy to treat a million acres a year to reduce fire danger.

"I think more and more emphasis will be placed on water as a feature of these lands that needs to be thought of actively," he says. "It's got to be about stewardship." Illilouette, he points out, is just being stewarded by lightning. "Actions can be the absence of meddling."

Indigenous speakers from the Amah Mutsun Tribal Band and North Fork Mono Tribe speak about traditional forest management practices each semester in Stephens' classes. "They all talk about active stewardship of land to meet the objectives of the people and the land," Stephens says—as both a strategy and philosophy that was practiced for thousands of years.

"It feels like we're headed right back to that," he says. "I hope we head there quickly, because it's just so necessary."

FOLLOWING

Rausser College researchers advance knowledge of California's sensitive freshwater ecosystems. BY MATHEW BURCIAGA

California landscapes are shaped by our desire to control the absence or abundance of one key natural resource: water. More than a century ago, water from the Owens River was diverted to promote growth in the city of Los Angeles. The Tuolumne River was dammed to create the Hetch Hetchy Reservoir, supplying water to San Francisco. The Central Valley Project and California State Water Project both use water from the Sacramento-San Joaquin Delta to provide municipal water for more than 23 million people and irrigate California's largest agricultural region.

The state's complex, multipurpose network of dams, reservoirs, and other facilities forms one of the most elaborate water management systems in the United States—one that is under stress as climate change results in extreme weather events like extended drought and excessive precipitation.

Stephanie Carlson, a professor of fish ecology and A.S. Leopold Chair in Wildlife Biology, worries that this variability will make it harder for California's water managers to meet urban and agricultural demand while also ensuring the health of the state's freshwater ecosystems.

"We saw extreme competition for California's limited freshwater during the 2012-2016 drought," she says. "This year, in contrast, we are seeing storm after storm and widespread flooding. This extreme variability is a major challenge for managing California's aquatic ecosystems and the wildlife and people they support."

Carlson's research into California's freshwater woes aligns with that of her colleagues **Ted Grantham** and **Albert Ruhi**. Together, these faculty members lead the Freshwater Research Group, a consortium of researchers who regard freshwater as our most important natural resource and work to understand, monitor, and promote its resilience.

iStock

THE FLOW

Flowing from the Klamath Mountains to the Pacific, California's Smith River is a critical habitat for salmon and trout species.

After being assessed by graduate student Brian Kastl, a juvenile coho salmon is returned to Willow Creek, a tributary of the Russian River.

Sean Perez

CONNECTED CYCLES IN CRISIS

"Humans exert tremendous control on California's water cycle," says Ruhi, who studies how freshwater ecosystems respond to drought, dams, and other stressors. "Most of the state's precipitation falls in the Sierra and ends up in the Sacramento-San Joaquin Delta—the hub of California's water supply, supporting two-thirds of the state's population and millions of acres of farmland. It's a very managed system."

Ecosystems that previously existed in an unaltered state are now burdened by the water infrastructure that sustains our urban areas, and environmental factors like drought and climate change further stress these sensitive habitats and the species that depend on them. A 2011 assessment found that only about 20 percent of California's freshwater and estuarine fishes can be considered stable—a finding that Carlson considers to be an indicator of a steady decline in ecosystem health.

Much of Carlson's research focuses on migratory species of wild salmon and steelhead trout, which were historically abundant in many of California's waterways. Every month of the year, salmon migrated up the Sacramento and San Joaquin Rivers and connected tributaries to breed; their offspring used the same waterways, migrating to the ocean to feed and grow before returning to breed several years later, thereby completing the life cycle.

The National Oceanic and Atmospheric Administration (NOAA), the federal agency responsible for stewarding the nation's fisheries and marine ecosystems, reports that dams block steelhead from reaching more than 80 percent of their historical spawning and rearing habitat in California's Central Valley. Carlson says lost access to historic habitat is a major obstacle to salmon recovery. Fish that relied on these cooler, higher-elevation waters had distinct patterns of growth and

Left to right: Stephanie Carlson, Albert Ruhi, and Ted Grantham lead the Freshwater Research Group.

migration age compared to lower-elevation fish. According to Carlson, those life histories—or paths through the life cycle—are rare in the context of today's highly modified rivers. "Long before we lose species, we lose the many forms of a species," she says. "Those many forms—such as salmon populations that spend different amounts of time in freshwater before migrating, or others that return to breed at different ages—provide options in an increasingly variable world."

"California's freshwater ecosystems are in a state of crisis," says Grantham. "We've documented steady and consistent declines in ecosystem health since the 1970s, and those trends are expected to continue." In the state's North Coast region, where rivers have fewer dams than those in the Central Valley, Grantham has still observed human impact on freshwater ecosystems, as people divert water from streams to their lands for agricultural and domestic use.

While an individual diversion might not dry out a stream, cumulative impacts are worrisome, he says, especially during dry years when water supplies are naturally limited. During these periods, even small reductions in streamflow can negatively affect ecosystems in a multitude of ways. Low flows directly limit the availability and quality of habitat for wildlife and can act as a barrier to migratory fish at various points during their life cycle. Depleted streamflow can also increase water temperatures, which Grantham says may push species over their range of tolerance and lead to toxic algae blooms.

MONITORING CHANGE

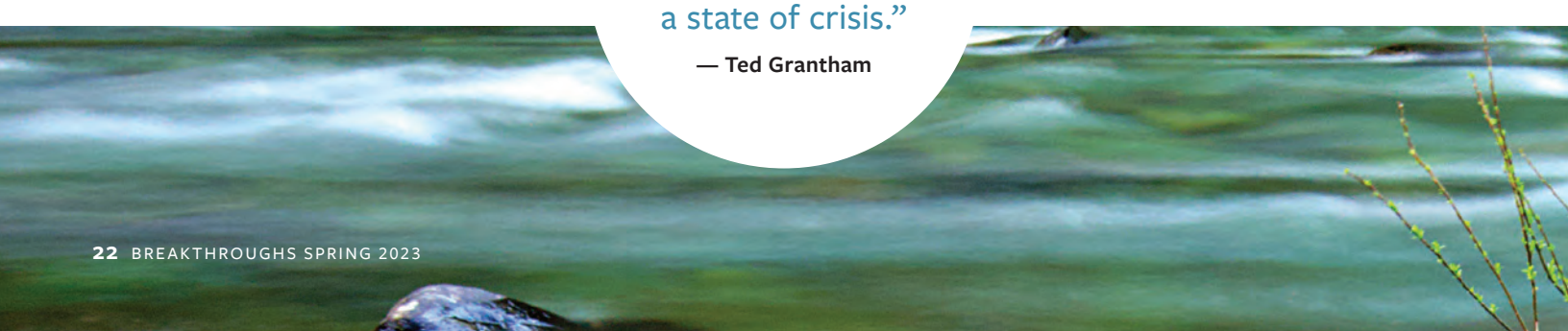
The Freshwater Research Group is working to understand historical conditions and monitor changes to predict what the future may hold for California's fragile freshwater ecosystems. Some of the research also involves mimicking projected conditions in a controlled environment to assess outcomes.

In a recent experiment conducted at the Sierra Nevada Aquatic Research Laboratory—a station managed by the UC Natural Reserve System—Ruhi manipulated water levels in artificial streams to simulate the long-term effects of predicted climate trajectories. The results were unexpected: rather than causing an across-the-board decline in ecosystem biodiversity, low water levels in the artificial stream increased the development rate and shifted the timing of the metamorphosis and emergence of aquatic insects, which could have cascading effects on predators like lizards, birds, and bats. "You can find climate impacts on one species, but when you look at the ecosystem as a whole, new responses emerge," Ruhi says. "We must consider not just how individual species respond, but also whether the interactions among them change—including in adjacent ecosystems."

While a low flow can permanently alter a stream, Grantham says it's important to remember that most of California's rivers and streams are naturally intermittent, and they are capable of supporting a rich diversity of plants and animals and providing water for people. However, Grantham says, very few long-term flow records from intermittent streams exist. "Knowing the natural hydrology of intermittent streams can help researchers understand their sensitivity to human stressors, their role in supporting terrestrial and aquatic biodiversity, and how these ecosystems may change in the future."

> "California's freshwater ecosystems are in a state of crisis."
>
> **— Ted Grantham**

Jim Block



Graduate student Kyle Leathers conducting water flow experiments in artificial channels at the Sierra Nevada Aquatic Research Laboratory.

Since 2019, Ruhi has documented instances of intermittent streamflow throughout Pinnacles National Park, where rivers and streams provide water and refuge to an array of fish, birds, mammals, amphibians, and invertebrate species. "We know that the watershed is intermittent, but thought that some sites would hold water year-round," he says. "Last year, to our surprise, most of the sites dried up." The research shows that drought might degrade the few perennial freshwater habitats of an otherwise hot and dry region.

Carlson and members of the Freshwater Research Group have found that salmon breeding in intermittent streams encounter different conditions than those in year-round streams, which likely has consequences for size and migration timing. "Life-history diversity is now recognized as a key ingredient for a resilient salmon complex," she says. "Maintaining a diversity of river habitats—including some that flow year-round and others that are seasonal—contributes to resilience because some populations perform best during wet years and others do better during dry years."

WATERSHED-LEVEL PLANNING

Last November, federal regulators approved the removal of four hydroelectric dams on the lower Klamath River in California and Oregon after finding that the environmental benefits far outweigh the impact. Billed as the largest dam removal in the world, NOAA officials estimate that several threatened species of native fish—including coho salmon, Chinook salmon, and steelhead trout—will regain access to 400 miles of habitat.

But projects of that scale aren't always feasible. "Some dams won't go away anytime soon because they provide critical flood control or hydropower," says Ruhi. "However, even then there are opportunities to manage them better."

In recent years, the National Park Service and the U.S. Bureau of Reclamation have examined the effects of water releases from Arizona's Glen Canyon Dam. The timing and volume of water needed for hydropower generation leads to fluctuations in river water level, a change that can be deadly for aquatic insects, says Ruhi. When river flows drop after a hydropower release, insect eggs laid along the high-water mark typically dry out and die within hours.

On weekends, when electric demand is low, water managers have tested releasing a steady flow of water from the dam to minimize disruption. Ruhi and others evaluated the results of this test and found that the alternative release schedule improved egg-laying conditions for aquatic insects, which benefited the food web by providing an abundance of prey for fish. "They tweaked their operation effectively," he says, "showing that even when rivers are significantly altered—in this case by one of the nation's largest dams—we can still increase ecological integrity."

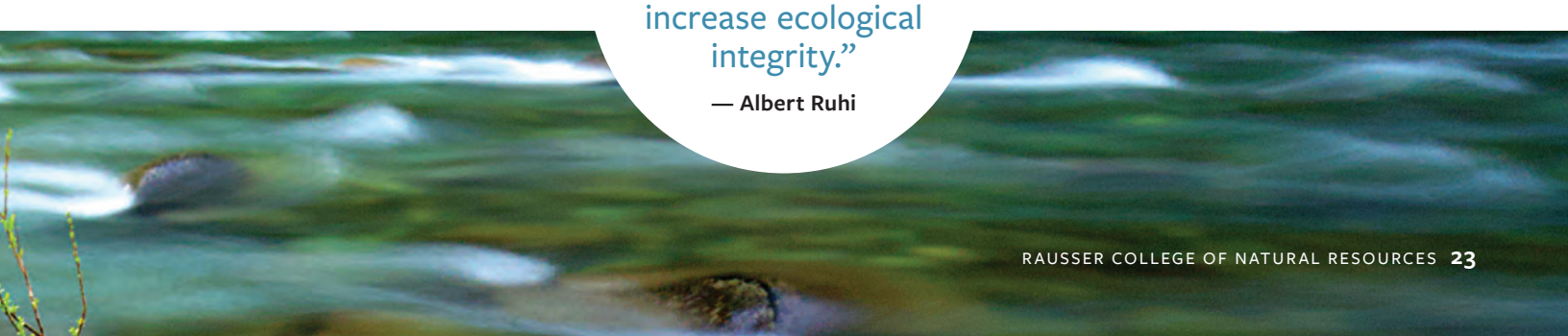
Similarly, a renewed focus on life-history diversity in fishes is informing a more holistic approach to the management of California's freshwater ecosystems. Carlson says that there is increasing recognition that diverse life-history portfolios contribute to the ability of salmon populations to survive environmental variability. "While much effort has gone into restoring rivers and streams to increase the amount of habitat available to fish species, there is potential to build on these efforts—to not only increase the number of fish but also increase their resilience," she says.

Grantham's research and outreach work focuses on identifying how policymakers can incorporate ecological principles in water management. "One of the most important things that state lawmakers could do is to formally recognize environmental water needs," he says, "but California continues to prioritize human consumptive uses—especially for agriculture—over ecosystem health."

Like California's newly implemented groundwater management plans (see page 10), Grantham says watershed-level planning may help stakeholders hash out how to sustainably allocate water under unpredictable and variable conditions. "There will still be politics and conflicts over these decisions, but a formalized process for community-driven water allocation planning would be a helpful step forward in our state."

> "Even when rivers are significantly altered, we can still increase ecological integrity."
>
> **— Albert Ruhi**

Albert Ruhi



Q&A

Water as a Human Right

INTERVIEW BY JULIE GIPPLE

Two Rausser College researchers discuss the political, social, and economic factors that cause inequities in access to safe and affordable water.

Isha Ray

Professor, Energy and Resources Group

Isha Ray's projects focus on access to clean water and sanitation for the rural and urban poor, and on how technology improves or hinders sustainable development and social equity. Ray frequently serves as an expert group adviser to UN Women and the United Nations Educational, Scientific and Cultural Organization (UNESCO). She is a member of the *Lancet* medical journal's Commission on Water, Sanitation and Hygiene, and Health (WASH), which aims to reimagine and reconstitute WASH as a central pillar of public health and a pathway to gender equality and environmental justice. In July, Ray will complete three years of service as Rausser College's Associate Dean for Equity and Inclusion.

What led you to study water and sanitation?
While studying the economics and governance of irrigation early in my career, I lived in a village in western India for 11 months while conducting primary fieldwork. I lived without a bathroom—something many people experience all their life. Water was scarce. During extreme shortages, we had to rinse our plates into a clean bowl and then drink that water. About that time, I started to shift my research focus to water as a human right—a daily necessity for quality of life, dignity, and well-being. My work incorporates social, economic, and philosophical perspectives on water and sanitation.

What's so critical about water?
When we think about the United Nations' 17 Sustainable Development Goals, there really aren't any that can be met without access to safe water. Yet water is a resource you can't control very well. It's always leaking and seeping where it isn't supposed to be—literally, figuratively, and metaphorically. And managing it is an environmental justice issue, because the mar-

ginalization of certain communities, more than physical scarcity, has led to a lack of access to safe water and sanitation. Water is connected to everything; it's not just a resource for people. All life forms depend on clean water.

How does gender fit into your work?
The burdens of inadequate water access and unsafe sanitation are disproportionately borne by women, especially low-income women who already experience a lot of suffering and deprivation. Around the world, water work—fetching, treatment, allocation, and management within the home and community—often falls to women as an unpaid chore. Many technologies that aim to increase access to affordable, safe water are often considered low cost, but that is because the labor upon which they rely is assumed to be free. While this discrepancy is generally known, it hasn't been fully incorporated into the evaluation of technologies or when accounting for labor costs. If we continue to promote these technologies as low cost, then we cement existing gender disparities.

Is access to safe water improving around the world?
Almost all countries have been on an upward trajectory for water access over the past few decades, but progress has not been equal. There are still many marginalized and deprived communities, whether that be in a poor village in the international context or in low-income African American urban communities or Latino farmworker communities in the U.S., to name a few. These deprivations are not a matter of chance, but rather the result of structural inequality bias.

Who is responsible for assessing that bias and for increasing access to safe water?
Historically, wherever nations have achieved near-universal access to water and sanitation, it has been with the strong presence of government investment or regulation. Of course, nonprofits and charities do important demonstration projects. Once in a while, such as with rainwater harvesting in Asia and Africa, these projects can even go to scale. Internationally, it's rare for the private sector to focus on the most underserved communities because delivering water and sanitation to poor people is not a highly profitable enterprise. And that isn't really the private sector's mandate. We don't ask the private sector to protect free speech or freedom of worship, or provide food stamps. Why would we leave it to them to provide water and sanitation for the poor? Governments have to take center stage, to the best of their capabilities.

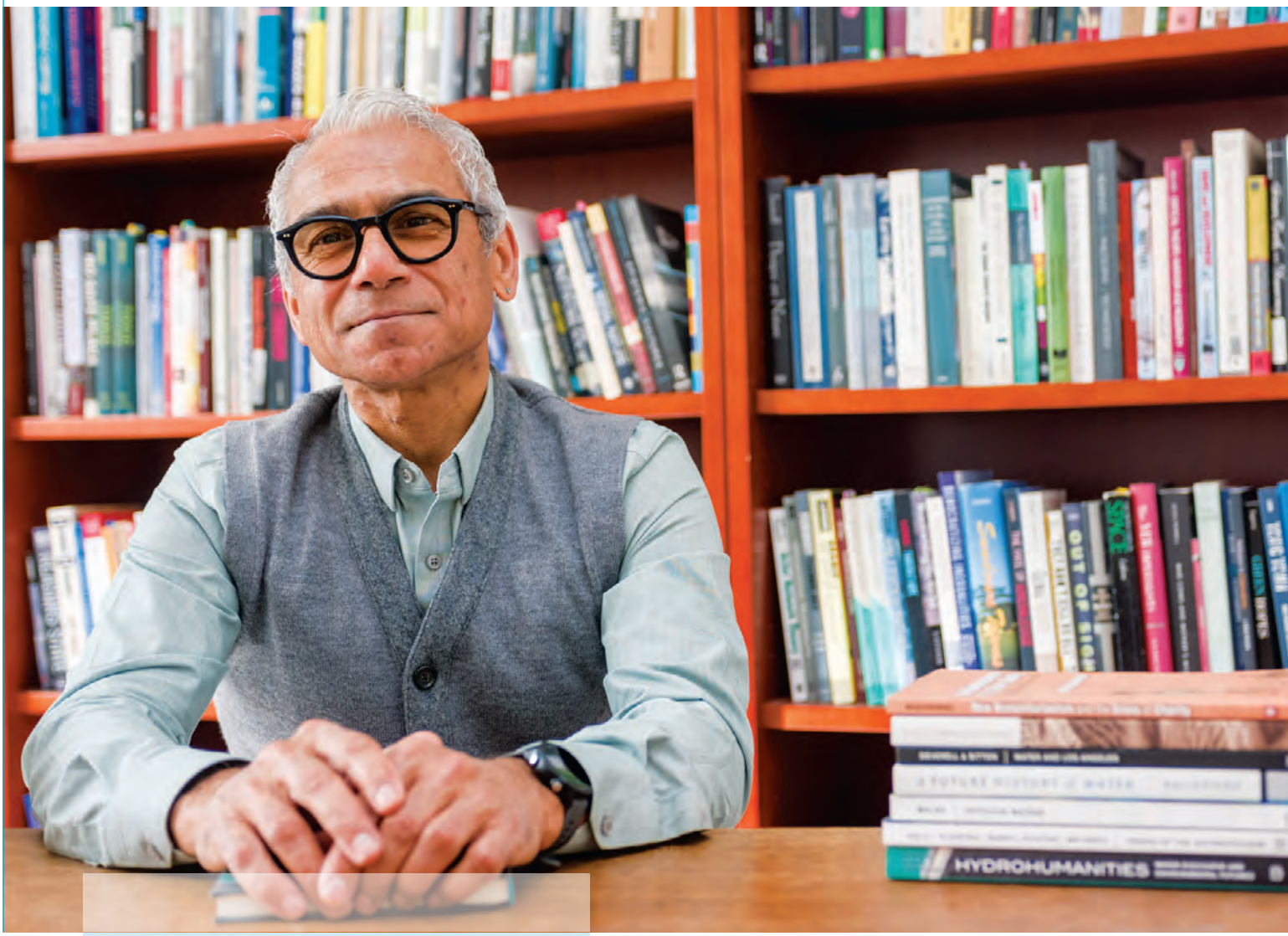
How can academic research encourage governments to take action?
Governments need to acknowledge that basic water and sanitation services are part of the social contract they have with their citizens. Concerned citizens and scholars like myself can assess and reveal existing disparities and hold states accountable for fulfilling their social contract. Researchers can also help develop scalable, sustainable, technological solutions for expanding water access and think creatively about how to finance those projects.

Women and children often walk miles to collect water from public taps like this one in Uttarakhand, India.

Moving closer to home, can you discuss your recent research on arsenic in water in California?
Our recent paper was a collaboration with Energy and Resources graduate student **Jenny Rempel**, **Alasdair Cohen** (PhD '16 Environmental Science, Policy, and Management; MPH '16 Public Health), and others. We analyzed 20 years of water quality data from Kern Valley State Prison and three nearby Central Valley communities where many groundwater aquifers contain unhealthy levels of naturally occurring arsenic. At all four locations, the study found instances of arsenic levels in the water supply above regulatory limits for months or even years at a time.

In addition to typical rural communities, we wanted to include a carceral community because water is a right for all humans, including humans in prisons. We also wanted to point out the flawed way in which the Safe Drinking Water Act monitors arsenic contamination. We monitor running annual averages of the concentrations of arsenic. Since arsenic varies in concentration, there could be many days where it goes above the maximum contaminant level, even if the annual average remains below the threshold. Human bodies are drinking every day, so it could be that the cumulative impact of arsenic contamination is being understated. We're strongly proposing additional monitoring measures to assess the number of days in which a system is out of compliance.

UC Regents (Ray); Alasdair Cohen (water collection)



Michael Mascarenhas

Professor, Department of Environmental Science, Policy, and Management

Michael Mascarenhas is an environmental sociologist who examines connections between racism and environmental injustices, particularly inequities in access to water for historically marginalized populations. He has written books on water resource access for First Nations people in Canada, environmental justice, and the privatization of humanitarian aid following disasters. His forthcoming book examines the water crises in the cities of Flint and Detroit, Michigan. Mascarenhas was an expert witness at the Michigan Civil Rights Commission on the Flint Water Crisis.

What led you to study water and inequity?
I first recognized the value of water as a child. As a new immigrant to Canada, I struggled to integrate. I found myself playing in our small town's rivers, listening to their flow, and traversing their banks. My uncle and I fished from the riverbanks, sharing stories as well as the fish we caught. To this day, those intimate experiences with water helped galvanize my appreciation for water's meaning and value.

What's so critical about water?
Water is the conduit for so many other things. Manufacturing, industry, development—these cannot succeed without water. Everything that makes the modern nation state possible is because of governments' or nation states' ability to control and manage other people's access to water—something that is often accomplished by force, coercion, or other means. But beyond the economics of it, the simple fact is we need water to survive. For example, if you do not have access to safe, potable water you cannot drink, cook, or bathe. Life without water becomes very precarious.

Mathew Burciaga

John Palechor

Water insecurity can lead to housing insecurity. If your house is condemned because the water is contaminated or cut off, this is an environmental injustice that can create intergenerational harm. Families can be broken apart as children are moved to a place with safer water.

Your first book studied the racialized consequences of water policy in Ontario. Can you tell us about that?
Where the Waters Divide is about the privatization and liberalization of environmental policy around water and how those policies have made it more difficult for First Nations communities to find access. When I was writing that book in 2012, water was a real problem for First Nations in Canada. On any given day, there were about 95 boil water advisories across 633 First Nations communities. In contrast, there was one boil water advisory in the urban center in Vancouver during that time. I was part of a group of academics that, together with community groups, lobbied hard for regulations to guarantee safe drinking water on First Nations reserves, and there are now standards for drinking water quality. But, 20 years later, there are almost just as many boil water advisories reported in these communities. Despite more awareness and better water quality methods and policy, things are not changing enough.

Can you tell us about your forthcoming book on racial capitalism and water injustices in Flint and Detroit, Michigan?
Poison and Thirst provides an ethnographic analysis that weaves together the multiple strands of racial capitalism, including fiscal austerity, and Michigan's Emergency Management Law that resulted in profound environmental injustices in Flint and Detroit. The book spans beyond the realm of water to include white supremacist attacks on the public infrastructure of these predominantly Black cities, including housing, education, collective bargaining rights, and Black political power. So much has been written about the so-called Flint/Detroit Water Crisis. My goal with this book is to focus on the racist underpinnings of the seemingly mundane, taken-for-granted workings of fiscal austerity, and to draw attention to the ways in which its implementation in Michigan has stripped away Black assets and democratic autonomy for the benefit of white political and economic elites.

How do the lessons learned in Michigan relate to other parts of the country or the world?
Advancing environmental and social justice depends largely on who has access to clean, safe, and affordable water. Beyond Michigan, there are so many places in this country facing water contamination and lead poisoning, including the cities of Pittsburgh, New Orleans, Washington, D.C., and Jackson, Alabama, to name just a few. These are all majority Black and brown cities. In California, more than one million people don't have access to safe and affordable drinking water, and extreme drought conditions exacerbate the issue. If we don't think about policies in terms of their impact to marginalized communities, we're going to make things worse in these already segregated environments.

Your research involves collaborating with people, communities, and governments. How does that work?
Most of my work is ethnographic and collaborative with people and communities, combined with archival research. For *Poison and Thirst*, I learned from pastors, community leaders, artists, and organizations like We the People of Detroit and the People's Water Coalition. They are calling on governments, scientists, and academics to take responsibility and demonstrate accountability for environmental injustices and racism.

You've also written about humanitarian efforts to increase water access and other basic needs. Can you tell us about that?
In *New Humanitarianism and the Crisis of Charity*, I examined how corporations and philanthropists shape water charity efforts in Africa and Asia. In many places around the world, people don't get water from a tap powered by publicly funded infrastructure. In some places philanthropy plays a big role, and nonprofit organizations are almost governmental: they're providing things that states used to do, like military training, public education, and water infrastructure. The book analyzes the new conditions that influence humanitarian efforts like access to drinking water. Today, these efforts are primarily influenced by the good intentions of the charitable-industrial complex rather than the immediate needs of those without basic human rights.

Mascarenhas and colleagues on a recent research trip in the Colombian Massif mountains, an area that includes the headwaters of the Magdelena and Cauca Rivers and is the source of 70 percent of Colombia's water.

Surf and Sustainability

MATT STREIFF CHANNELS HIS LOVE OF SURFING AND FONDNESS FOR BERKELEY INTO SUPPORT FOR RAUSSER COLLEGE

BY MATHEW BURCIAGA

Despite growing up in inland San Diego County, **Matt Streiff** always had his eye on the coast. "Surfing was my favorite thing to do—it still is," he says. "I would beg, borrow, or do whatever I needed to do to get people to take me to the beach." In addition to riding the waves, Streiff, BS '97 Environmental Economics and Policy, spent his childhood playing tennis and soccer, and traveling to Baja California.

The strong affinity Streiff has for the "classic" Southern California lifestyle made his decision to attend UC Berkeley a little surprising. Surfing in the Bay Area can be tough; conditions are not always hospitable, and the swell isn't always the most cooperative. But the diverse, cosmopolitan locale he encountered on his first visit to Telegraph Avenue was enough to convince the avowed Southern Californian to head north.

Matt Streiff and his son, Dylan, before hitting the surf on a recent trip to the Maldives.

At Berkeley, Streiff channeled his interest in economics and the natural world through multidisciplinary programs in the College of Natural Resources. He paired classroom lectures on international economics and environmental policy with hands-on experience in land management at Forestry Field Camp. Outside of class, Streiff and his friends regularly rooted for future NBA All-Star Jason Kidd at Haas Pavilion and future Pro Football Hall of Famer Tony Gonzalez at California Memorial Stadium.

Those moments followed Streiff to Paris, where he worked as a bartender after graduating; New York, where he attended Columbia Law and met his wife, Kimberlee; and back to Southern California, where he co-founded what would become American Healthcare REIT, one of the largest healthcare-focused real estate investment trusts in the country.

"It's amazing how much of an impact those four years had on me and my life today," Streiff says, remembering his time at Berkeley. "I have a lot of fondness for Cal; it played a very important role in my intellectual and social formation."

Streiff tries to return to campus at least once a year, typically to watch a football game with family and friends. He's shown his three children around the campus and taught them how to cheer on the blue and gold. His strong tie to Berkeley also influences his philanthropic priorities: he and his family make regular gifts to Cal Athletics and the Rausser College Fund for Natural Resources.

His firm belief in the importance of creating a sustainable future—which he classifies as one of the defining challenges of our time—aligns with Rausser College's mission. "The need for environmentally friendly practices in agriculture, energy production, and related fields is more present than ever," he says. "We need bright minds to focus on driving innovation because these challenges are not going away."

Streiff's support of the College now comes at a critical point: many companies and other private organizations have begun to prioritize the environmental, social, and governance impacts of their investments and activities. "But in some ways, they're catching up to what the College was thinking about when I was there almost 30 years ago," he says.

By giving back to Rausser College, Streiff hopes to strengthen student and faculty efforts to protect and steward our natural resources for future generations.

Mushroom Mosaic

PHOTOGRAPH BY ALIENOR BASKEVITCH

Plant and Microbial Biology graduate student **Alienor Baskevitch** arranged and photographed these fantastic fungi during a field excursion she led last fall as a graduate student instructor of the Biology of Fungi course. Baskevitch's ongoing interest in mushrooms was sparked as an undergraduate at Berkeley when she took a similar mushroom course taught by professor emeritus **Tom Bruns**. The annual trip to Mendocino is a long tradition in the beloved mycology courses and offers students the opportunity to find species they wouldn't have encountered on or near campus. "Foraging for mushrooms requires you to pay deep attention to the world in a way I find enriching and grounding," Basekvitch said. "It was gratifying to be able to help catalyze that same interest for my students as well."

Berkeley Rausser
College of Natural Resources

101 Giannini Hall #3100
Berkeley, CA 94720-3100

NONPROFIT ORGANIZATION
US POSTAGE
PAID
UNIVERSITY OF CALIFORNIA
BERKELEY

Want to receive only the online version of *Breakthroughs*? Send your name, mail ID, and email address to breakthroughs@berkeley.edu.

The Central Sierra Snow Lab tracks precipitation and snow water content in the Sierra Nevada, offering critical insight into California's most important water storage system. Learn more on page 3.

Photo: California Department of Water Resources