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Agriculture and Natural Resources

JANUARY–MARCH 2019 • VOLUME 73, NUMBER 1

Special issue: Research to policy

News and opinion

EDITORIAL

NEWS


Evett Kilmartin

Research and review articles

COVER: *Top*, UCCE Advisor Lenya Quinn-Davidson consults with a fire crew in preparation for a controlled burn near Bridgeville, Humboldt County; *middle*, UCCE Advisor Tracy Schohr collects a water sample below the town of Paradise, which was destroyed in the Camp Fire; *bottom*, an Expanded Food and Nutrition Education nutrition class in Fresno County. *Photos: Evett Kilmartin, Ryan Schohr, Elëna Zhukova.*

EDITORIAL

Communication, engagement and science-based policy

Anne Megaro, Director of Government and Community Relations, UC Agriculture and Natural Resources

Anne Megaro

As a prospective graduate student, I applied to an animal science Ph.D. program knowing that I wasn't going to pursue a career as a bench researcher. This move was unconventional, but I had a plan: I wanted the knowledge, experience and credibility of a doctoral degree so that I could help bridge the communication gap between scientists and non-scientists. To achieve this goal, I would have to leave the laboratory and learn how to communicate with the public in a meaningful and effective way.

This desire led to a career in the realm that is the focus of this special issue of *California Agriculture*: the research-to-policy process — through which, ideally, scientific expertise informs the development of sound policies that further the public good.

As a congressional science and technology policy fellow, a consultant to the Agriculture Committee in the California State Senate, and now as the director of government and community relations for UC Agriculture and Natural Resources (UC ANR), I have experienced from multiple angles the lessons that Gupta, Campbell and Cole-Weiss articulate in their stage-setting article for this issue (page 11). That is, that the value that scientists — and, in particular, Cooperative Extension scientists — bring to the policymaking process is tied to their ability to communicate science effectively to many audiences and engage with a wide range of stakeholder groups.

I'd argue that UC ANR, and indeed Cooperative Extension nationally, is well positioned to expand this research-to-policy role.

First is the issue of communication. Helping and encouraging scientists to translate their work into something *accessible* to the general public is crucial. By accessible, I mean sharing science in a way that is relatable and in which people can understand and apply to their own lives. Cooperative Extension academics already excel at this skill. Their work by its nature involves delivering research into the hands and minds of practitioners and the public so that it can be applied immediately in the real world, in real time.

Cooperative Extension academics also tend to be expert relationship-builders. Their success as extension scientists is built on establishing trusted relationships with community groups, farmers and land managers. Those same skills can — and should — be applied to developing relationships with policymakers and others involved in the policymaking process.

This special issue — developed with guest editors Clare Gupta and Leslie Roche, both UC Cooperative Extension Specialists at UC Davis — emerged from the work of the UC ANR Research to Policy Program Team. This group has created a community of practice and provided a forum for sharing policy work, bringing together UC ANR academics and staff to learn from colleagues how to overcome challenges and implement best practices for policy engagement.

The articles in this special issue illustrate some of the many ways in which UC ANR research and extension work continues to inform and develop evidence-based policy in California. They document how good science coupled with communication and engagement have helped to expand the safe use of prescribed fire in forests, limit the water quality impacts of dairy farms, better manage our streams and rivers, improve nutrition standards and policies, and increase the efficiency of water use in urban landscapes.

As you read these articles, I invite you to think about how you can be involved in public policy, whether you are a researcher or member of the public. How do you bridge the gap between scientists and policymakers? What can you, as an individual, do to engage in evidence-based policymaking? CA

Anne Megaro is the Director of Government and Community Relations for UC Agriculture and Natural Resources. She helps bench and field researchers spread the good news of their work by sharing their story with policymakers and community stakeholders. She earned a Ph.D. in animal science from Cornell University and was a 2010–2011 AAAS Science and Technology Policy Fellow in the U.S. House of Representatives. Prior to her current role, she most recently served as Consultant for the Senate Agriculture Committee for the State of California.

Prescribed fire gains momentum

In recent decades, California has made sparing use of fire as a land management tool. But policy changes, partnerships and attitude shifts are creating conditions for expanded use of prescribed fire.

As Californians know too well, the 2018 wildfire season was historically severe. But for *prescribed* fire — fire set deliberately to achieve management objectives — 2018 was historically important.

California's fire management regime needed change — a strong conviction to that effect had developed in state government by 2018. The previous year's fire season had been unusually fierce, with the wine country fires rampaging in the north and the Thomas Fire, the state's largest-ever wildfire until that time, raging in the south. Leaders throughout state government recognized that climate change was exacerbating the state's perpetual wildfire problem — and would continue to do so. So it was that advocates for prescribed fire found the Legislature and former Gov. Jerry Brown broadly receptive to policy proposals that might mitigate the wildfire crisis. "Conversations were wide open," says Nick Goulette, former chair and current member of the steering committee at the Northern California Prescribed Fire Council. "Committees said 'Anything is on the table. What do we need to do?'"

In September 2018, the Humboldt County Prescribed Burn Association conducted a burn at the McBride Ranch near Cape Mendocino in Humboldt County, targeting about 350 acres of coyote brush that had invaded coastal rangelands.

Lenya Quinn-Davidson

They did a lot. It started in May, when Gov. Brown issued an executive order on forest health that, among its many provisions, instructed the California Department of Forestry and Fire Protection (Cal Fire), as well as the California Air Resources Board (CARB), to increase opportunities for projects in prescribed fire (Brown 2018). Then in September, the Legislature passed and the governor signed four pieces of legislation related to fire and forest health. One law, Senate Bill (SB) 901, provides Cal Fire $1 billion over five years for forest heath and fire prevention activities — including $35 million a year for prescribed fire and other fuel reduction projects (the $1 billion in funding is generated by California's greenhouse gas cap-and-trade program). The same law specifies that Cal Fire and UC Cooperative Extension (UCCE) will cooperate to deliver technical assistance on wildfire resilience to nonindustrial timberland owners. SB 1260 requires Cal Fire to cooperate on prescribed burns with public and private landowners. It also instructs Cal Fire to create a program for pre-certification of "burn bosses" — individuals who direct operations at prescribed fires — so that vetting of burn bosses needn't be conducted for each proposed burn. SB 1260 also, along with Assembly Bill 2091, aims to ease the way for prescribed burners to purchase private insurance.

In recent years, prescribed fire has played a very modest role in California's land management practices. It wasn't always so. Native American tribes conducted burns to manage resources long before Europeans arrived in the Americas. As recently as the 1980s, Cal Fire burned 30,000 to 65,000 acres a year (Quinn-Davidson 2018). In recent times, however, Cal Fire has burned fewer than 10,000 acres a year, and the acreage treated by all prescribed burners — Cal Fire, nongovernmental organizations, tribes, private landowners and so forth — has been inadequate to slow the ongoing buildup of fuels across California's forests and rangelands. Now, however, change is afoot — and the new laws and the executive order are only part of the story. To be sure, important policy changes now being implemented by Cal Fire are mandated by 2018 governmental directives, but changes at the agency also seem part of a cultural shift in attitudes toward prescribed fire. This cultural shift — which Lenya Quinn-Davidson, a Humboldt County UCCE fire advisor, has watched develop over her years as a prescribed fire practitioner — has itself been nurtured through partnerships established among stakeholders across the prescribed fire landscape. Today, prescribed fire seems on course to play a larger role in California's land management regime and — ideally

Lenya Quinn-Davidson

Jeffery Stackhouse, a Humboldt County UCCE livestock and natural resource advisor, participates in a restoration-focused prescribed fire in deciduous oak woodlands on a ranch in eastern Humboldt County.

— to reduce the risk that wildfire seasons such as the last two become a permanent phenomenon.

Why to burn (and why not)

Prescribed fires can be conducted to achieve a variety of management objectives. For example, they can reduce fuel loads in forests so that high-intensity fires become less likely. Prescribed fire can establish diverse ecosystems in which threatened species thrive. In other contexts, they can help control invasive species. A recent study involving researchers from UC Irvine and UC Merced suggests that burning off water-hungry vegetation in the Sierra Nevada could increase California's water abundance (National Science Foundation 2018; Roche et al. 2018). Prescribed burns may also, by reducing the overall severity of wildfires, decrease the potential for erosion and sedimentation after fires. Over time, because low-intensity fires produce much less air pollution than do infernos feeding on dense accumulations of fuel, prescribed fire could even improve average air quality (Long et al. 2017; Schweizer et al. 2017).

Prescribed fire, then, can be a powerful tool for land management. But for a formidable set of reasons described by Quinn-Davidson and Goulette, California has made only modest use of prescribed fire in recent years. According to the state's Forest Carbon Plan — a May 2018 document developed by state agencies that partially underpinned Gov. Brown's executive order — only 17,500 acres of nonfederal land in California have undergone "forest restoration and fuels treatment" in the average recent year. Moreover, "forest restoration and fuels treatment" includes not just prescribed fire but mechanical thinning as well.

The greatest impediment to prescribed burning in California is the climate — the state's hot, dry summers and damp winters allow "burn windows" only during brief periods at the beginning and end of each fire season, and during intermittent periods over the rest of the year (Quinn-Davidson and Varner 2011). Even when conditions would seem to allow prescribed burning, permits are required from Cal Fire during fire season (typically, from May 1 through October 31) and from air quality management districts at all times. Cal Fire has often been skittish about issuing permits because, according to Goulette, "they worry about liability. What if they don't put out [an escaped] fire you started?" Permits from air quality management districts, meanwhile, can be challenging to obtain because of the state's persistent air pollution problem — and permits can be rescinded at the last hour if CARB declares a "no burn" day. (In 11 of the state's air basins, local air districts issue permits for specific burns but CARB decides whether burning is allowed at all. In the remaining four basins, local air districts have authority to declare their own "burn" and "no-burn" days.) The state also suffers from a shortage of people trained in conducting prescribed burns. The bottom line is that, though California desperately needs to reduce fuel loads across its forests, the state has lagged far behind other areas — Quinn-Davidson points to the Southeast and the Great Plains — in its willingness to embrace prescribed fire.

Lenya Quinn-Davidson

A dog protects drip torches in the back of a truck. With prescribed fire, land managers can achieve objectives that range from reducing fuel loads in forests to establishing diverse ecosystems in which threatened species can thrive.

But things are changing fast — especially at Cal Fire, an agency that sits at or near the center of any prescribed fire discussion in the state. All prescribed fires on nonfederal land in California require a Cal Fire permit during fire season. Advocates for any policy change related to fire, Goulette says, must negotiate with Cal Fire. That's why prescribed fire supporters are glad that — according to Craig Thomas, the recently retired conservation director at Sierra Forest Legacy — "Prescribed fire is back in the realm for Cal Fire. They are regaining their burning skills." By November of last year, Ken Pimlott — the since-retired chief of Cal Fire — was telling the national radio program "Science Friday" that "Putting prescribed fire back out on the landscape at a pace and scale to . . . actually make a difference is a high priority" (Science Friday 2018). Indeed, in accordance with SB 901, Cal Fire is now establishing 10 year-round crews dedicated solely to prescribed fire and fuels reduction.

Thomas is grateful for the new crews — but he'd like to see more of them. "We need a robust Cal Fire prescribed burn crew," he says, "in every county with significant vegetation." Goulette, meanwhile, argues that Cal Fire should institute what he calls an "objective permitting process" to make permit issuance more predictable. Hugh Scanlon — Cal Fire's former unit chief for Humboldt and Del Norte counties — finds Goulette's permitting suggestion generally reasonable. He cautions, however, that any statewide permitting


Lenya Quinn-Davidson

Due to legislative action, an executive order and changes in attitudes toward controlled burning, prescribed fire seems set to play a larger role in California's land management practices.

process must be broad enough to account for the variable conditions — climatic conditions especially — that can exist across the state. Otherwise, a permit might be denied in one part of the state because conditions are wrong in a different part.

Burning together

The new laws, the executive order, the changes at crucial agencies — all of it seems bound up with the recent cultural shift that Quinn-Davidson discerns in California's attitude toward prescribed fire. The cultural shift in turn seems inseparable from partnerships established over recent years among key players in fire policy and practice. An example is the Northern California Prescribed Fire Council — the first organization of its kind in the West — which Quinn-Davidson cofounded in 2009 and directs today. A key element of the council's work, Quinn-Davidson says, has been building relationships among Northern California's large users of prescribed fire, including federal and state agencies, tribes, nongovernmental organizations and so on. A second key has been demonstrating to Cal Fire, among others, that prescribed fire enjoys widespread support in Northern California and in fact is already in use.

A more ground-level cooperative initiative is the Humboldt County Prescribed Burn Association, a group that Quinn-Davidson formed last year with Jeffery Stackhouse, a Humboldt County UCCE livestock and natural resource advisor. Prescribed burn associations are collectives of property owners who pitch in to burn one another's land. Burns conducted under this model produce all the land management benefits usually associated with prescribed fire and also provide burn training to nonprofessionals. In a state such as Nebraska, Quinn-Davidson reports, one encounters nonprofessional but well-trained individuals who have participated in as many as 200 burns through prescribed burn associations. In California, such associations are new. But Quinn-Davidson and Stackhouse are working to expand them — with help from a grant program administered by UC ANR and originating with the federal Renewable Resources Extension Act. Funds from the grant program have helped Quinn-Davidson and Stackhouse further their objectives with the prescribed burn association in Humboldt County — and also perform outreach efforts in other counties, where they have conducted prescribed fire programs that include a daylong indoor workshop and a day of real, live burning. This June, again with the help of money distributed through the grant program, the pair will host a prescribed fire training session in Humboldt County for UCCE advisors and specialists.

Another node of cooperation is known as the Fire MOU Partnership. This initiative, according to its underlying memorandum of understanding, focuses on cooperation among entities "to increase the use of fire to meet ecological and other management objectives" (USDA 2015). The partnership includes a broad range of organizations, from Cal Fire to the U.S. Forest Service to the Nature Conservancy; since its 2015 inception, the partnership has grown from 12 to 36 members. Thomas was the primary drafter of the memorandum of understanding, though the Forest Service, Cal Fire and Scott Stephens — the widely known UC Berkeley forestry expert — also provided input. "What's exciting," Thomas says, "is that the air districts are joining. Previously, the fire managers and the air quality regulators weren't as collaboratively engaged."

Collaboration will need to flourish if California, so often ahead of national trends but lagging other regions in controlled burning, is to take full advantage of prescribed fire's benefits. "We always think we know best," Quinn-Davidson says of her state and its people — but "we're gaining some humility, which we need to do. We've got a lot to lose." CA

—Lucien Crowder

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Do it yourself: UCCE workshop eases reporting of water diversions

For ranchers and farmers in remote locations, monitoring water diversions can present special challenges — that a new course helps overcome.

In recent years, California has tightened rules for reporting diversions of water for agriculture and other uses. One key challenge has been establishing workable standards for the collection of reliable data on relatively small and remote diversions — such as those for far-flung farms and ranches. Under new legislation, a certification program run by UC Cooperative Extension (UCCE) is helping to solve that problem.

The State Water Resources Control Board views accurate diversion reporting as a key element of sound water management. "It's incredibly important to monitor how much water comes into and goes out of the system," says Kyle Ochenduszko, chief of water rights enforcement at the water board. Diversion reports are fed into a state database and support the orderly allocation of water resources by, for instance, enabling the board's Division of Water Rights to inform water users when new requests to appropriate water might affect their own supply.

Since 1966, the California Water Code has required diverters of surface water, with certain exceptions, to report their diversions to the water board. But in part because the water board lacked fining authority for many years, compliance was poor. In 2009, Senate Bill 8 gave the water board the authority to fine noncompliant diverters an initial $1,000, plus $500 for each additional day of failing to report.

Even so, SB 8 did not stipulate precisely *how* diversions were to be monitored. Rather, it required diverters to measure their diversions using the "best available technologies and best professional practices," unless they could demonstrate that such technologies and practices were not locally cost-effective. That is, the requirement left wide latitude for interpretation. So things remained until 2015 — when Senate Bill 88 became law. This piece of legislation, passed amid a historically severe drought, directed the water board to draw up emergency regulations regarding water diversions. The regulations, once completed, required diverters of at least 100 acre-feet of water per year to hire an engineer or appropriately licensed contractor to install all monitoring devices.

Now the requirements were clear. But the provision mandating installation by an engineer or contractor prompted an outcry from many smaller diverters, particularly those in remote areas of the state.

For most diverters near sizable towns — Redding, say — complying with the regulations was manageable, with expenses limited to the cost of a monitoring device and the services of an installer. But diverters in remote parts of Modoc County, for example, were looking at bigger bills, says Kirk Wilbur of the California Cattlemen's Association. For such diverters, compliance might require importing an engineer or contractor from far away, which would entail significant travel expenses. If a site lacked electricity, as many do, the costs would pile higher (electricity can be necessary in diversions that include a flow meter, or in data transmission from areas without cell service).

So how to reconcile the interests of the state's diverters with those of the state? How best to balance the public and the private good?

The answer, it turned out, was to empower diverters to install their own monitoring devices — with UCCE playing the empowering role. The idea originated with the Shasta County Cattlemen's Association. It gained

A diversion site in Modoc County. A 2017 piece of legislation allows water diverters who complete a course offered by UC Cooperative Extension to install their own monitoring devices.

Glenn Nader

A weir at the UC ANR Sierra Foothill Research and Extension Center in Yuba County. Once installation of a monitoring device for a weir is complete, water diverters need only read a staff gauge that shows the height of the water spilling over the weir's crest — and do a bit of math.

the support of the statewide Cattlemen's Association. It took shape as proposed legislation in 2017 and was shepherded through the Legislature by Assemblyman Frank Bigelow (R-O'Neals). It breezed through both chambers with no votes in opposition — not even in committee. "All parties realized," says Assemblyman Bigelow, "that Assembly Bill 589 would cut compliance costs and, as a result, increase compliance rates — which benefited both the regulators and the regulated community."

Essentially, AB 589 allows water diverters to install their own monitoring devices if they successfully complete a monitoring workshop offered by UCCE. Further, it directed UCCE to develop the workshop in coordination with the water board. Khaled Bali, an irrigation water management specialist at the Kearney Agricultural Research and Extension Center, took the lead in drafting the coursework. "Then we met with the [water] board and got feedback," Bali says. "We made changes until they said, 'This looks good.'"

Attendees at the workshops, which last three and a half hours, gain a solid foundation in the basic principles of diversion monitoring. They learn how to monitor flows passing through a ditch, over a weir or through a pipe — or gathering in a pond. They learn how to build or install measuring devices appropriate for each type of diversion and how to calibrate those devices to comply with the state's accuracy requirements. They learn how to navigate the water board's rather detailed reporting system.

Equipment for monitoring flows through open ditches might be limited to a tape measure, a timing device and a floating object. Installing a monitoring device for a diversion routed over a weir — a simple dam with an edge or notch that allows overflow — requires a bit more equipment. But once the installation is complete, the diverter need only read a staff gauge that shows the height of the water spilling over the weir's crest (and then do a bit of math). Diversions flowing through pipes must be outfitted with flow meters. Diversions feeding into a pond or reservoir can be monitored by tracking the depth of the water with a staff gauge, float or pressure transducer (provided that the depth and surface area of the pond or reservoir are known).

So far, UCCE has offered the course in about 15 locations, from Yreka to Bakersfield. According to Shasta County UCCE County Director Larry Forero — who teaches the $25 course along with Bali, Tehama County UCCE Advisor Allan Fulton and UC Davis–based UCCE Specialist Daniele Zaccaria — about 1,000 people had earned certificates of completion by early October. Even farmers and ranchers who divert less than 100 acre-feet per year are attending. "I've been floored," says Wilbur, "by the number of diverters who have attended the course even though they aren't required to — they want to better understand the regulations and make sure they're doing the right thing." It probably helps that the registration fee is a fraction of the cost of importing a faraway engineer. CA

—Lucien Crowder

LETTER

Re: Soil- and waterborne *Phytophthora* species linked to recent outbreaks in Northern California restoration sites by Matteo M. Garbelotto, et al. (vol. 72, no. 4, October–December 2018)

WHAT DO YOU THINK?

The editorial staff of *California Agriculture* welcomes your letters, comments and suggestions. Please write to us at: 2801 Second Street, Room 184, Davis, CA 95618, or calag@ucanr.edu. Include your full name and address. Letters may be edited for space and clarity.

I am curious if any researcher has linked the inadvertent introduction of *Phytophthora* to restoration areas to the current practice of using dead plant tissue (compost) as part of the growing media.

If the plant material is grown in a sterile highly permeable mineral media, such as mined pumice, *Phytophthora* organisms will not be promoted.

Organic media eventually, if not immediately, promote *Phytophthora* when utilized as a growing medium. As organic substrate particles continue to decompose, the permeability of the medium decreases. The decomposition also consumes oxygen creating conditions perfect for *Phytophthora*.

In agriculture the hydroponic researchers realize the importance of promoting adequate oxygen levels in the rootzone. In floriculture the same concerns have been addressed. They are aware that dead (or alive) organic matter anywhere in the rootzone or irrigation system can result in oxygen levels that are too low for ideal root health.

Horticulture has to follow suit.

Gary Matsuoka
Laguna Hills Nursery

Matteo Garbelotto, UC Cooperative Extension specialist and adjunct professor at UC Berkeley, responds:

We published a paper in California Agriculture *in 2015 on the risks of using products that are in between true compost (which is normally truly* Phytophthora*-free) and mulch (see volume 69, issue 4; http://calag.ucanr.edu/archive/?article=ca.v069n04p237). Also, we have found that soil and mulch used for trail-making can be chock full of Phytophthoras, and we are alerting stakeholders about the risks of using these two media. Your comments were right on.*

RESEARCH ARTICLE

Cooperative Extension can better frame its value by emphasizing policy relationships

Cooperative Extension will be most relevant in policy circles if it embraces both its technical and relationship-based strengths.

by Clare Gupta, David Campbell and Alexandra Cole-Weiss

Cooperative Extension (Extension) prides itself on its technical expertise and its ability to disseminate research-based information; this is the basis of the story we often tell one another, as well as our funding partners, to justify our contribution to society (Peters et al. 2010; Peters and Franz 2012). Yet long-term disinvestment in the Extension system, along with public skepticism of science, threatens the system's ability to deliver the expertise and research-based information that it promises. In 1990, over 475 academics — both specialists and advisors — served California and its 58 counties through UC Cooperative Extension (UCCE). Today, that figure is approximately 280, representing a decline of about 40%. In response, Extension leaders have sought ways to more compellingly demonstrate Extension's public value (Franz 2011). Such efforts often rely on a familiar narrative framework, one that emphasizes the value of detached, objective science — and the ability of such science to shape evidence-based policy and practice. Against this backdrop, our research addresses two pivotal questions: Does this

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Abstract

Based on research-to-policy narratives provided by UC Cooperative Extension (UCCE) academics, we argue that current, effective Cooperative Extension (Extension) practices support a broader, more convincing account of Extension's public value than its leaders often articulate. This proposed account incorporates the familiar Extension narrative in which technical expertise and objectivity are emphasized. It also incorporates the insight, derived from our data, that Extension can achieve its greatest relevance in policy circles when it weaves together its ability to provide trustworthy technical knowledge with its capacity to influence policy dialogue, debate and practice across multiple settings and over the long term. In a policy world often marked by short-term thinking and polarization, Extension's ability to foster deliberative, context-sensitive and future-oriented policymaking is a critical contribution to society. Interview data reveals three approaches to effective policy-oriented relationship building: community-government partnership building; stakeholder-oriented experimental research; and community empowerment. Understanding these approaches can help reframe the story that we in the Extension system tell ourselves and the public about the public value we create.

Thomas Getts, left, UCCE advisor based in Lassen County, at the UC Davis Agronomy Field Headquarters. Providing trustworthy technical advice is a key part of Extension's mission, but the organization maximizes its public value when it combines technical knowledge with relational work.

Evert Kilmartin

traditional narrative adequately convey Extension's actual practices and their resulting public value? And if not, what alternative narrative can better frame our contributions to public policy and society?

To address these questions, we analyze data related to a competitive grant program that the UC Division of Agriculture and Natural Resources (UC ANR) initiated in 2011. The grant program aimed to catalyze rigorous, timely research that was relevant to high-profile issues of state policy — and thus to garner greater visibility and funding for UC ANR. In 2015 UC ANR contracted with us to evaluate the grant program's policy impacts. Our evaluation included document review as well as 30 interviews with grant recipients and their policy partners. The interviews were intended to elicit answers to three research questions: (1) What was the nature of the Cooperative Extension activities funded by the grant? (2) What tangible products and policy outcomes resulted? (3) What approaches, mechanisms and processes contributed to producing the observable policy impacts?

The data reveals practices that can form the basis for a fuller, more convincing account of Extension's public value than Extension often offers on its own behalf. This broader narrative incorporates the familiar, narrow Extension narrative that emphasizes technical expertise and objectivity but also extends well beyond it. Our data shows that when Extension weaves together its ability to provide trustworthy technical knowledge with its capacity to influence policy dialogue, debate and practice across multiple settings and over the long term, it can achieve its greatest public value. In a policy world often marked by short-term thinking and polarization, Extension's ability to foster deliberative, context-sensitive and future-oriented policymaking is a critical contribution to society. Our research, by examining successful cases of Extension's research-to-policy practice — and by analyzing how such projects weave together technical and relationship-building work — contributes evidence that can inform decisions about better facilitating, supporting and promoting such work.

Literature review

Our research is informed by two primary literatures. The first literature, rooted in public policy studies and science and technology studies, describes relational dynamics in the research-to-policy process. The second literature illuminates debates over the meaning and purpose of Extension and raises questions about *who* we serve and *how* we relate to the public.

Relationships, research, policy

Several studies in science and technology find that the utilization of research in policy arenas depends on robust relationships and strategic networking (Graffy 2008; Jasanoff 2009). Relational ties, embedded in social networks, serve as channels through which research is communicated, debated, utilized and developed (Morton 2015; Nutley et al. 2007; Weiss 1979). The shared premise of these studies is that research users engage actively and selectively with research, using and reusing it within specific contexts to create impact (Morton 2015). Influence on policymaking rarely results solely from presenting objective scientific evidence. Instead, research becomes meaningful when (1) its creators and users strategically deploy language, objects and acts that establish greater validity for certain knowledge claims than for others (Pearce et al. 2014); (2) it is attentive to local contexts, lay knowledge and political demands (Campbell and Feenstra 2005; Pearce et al. 2014); and (3) it is embedded in relationships and interwoven with the priorities, cultures and contexts of organizations and institutions (Best and Holmes 2010).

While effective knowledge transfer depends significantly on timing and context (Murdock et al. 2013), certain practices have been shown to facilitate the research-to-policy process. For example, the involvement of research users from the beginning of a research project, along with the coproduction of knowledge during the project, increases research utilization (Murdock et al. 2013; Patton and Blaine 2001). López Cerezo and González García (1996) argue that expert knowledge by itself is not sufficient for exerting policy influence because this knowledge is constrained by social, political and economic factors. They propose the idea of "negotiated expert knowledge," which uses public voices and deliberation to gain new perspectives and incorporate useful information. This concept helps avoid the expert versus layperson dichotomy and instead establishes a more nuanced view of knowledge creation (Collins and Evans 2007). In general, the literature suggests the need to rethink the relationship of expertise to "situated knowledge," defined as information — about impacts, problems, contributory causes, unintended consequences and so forth — that members of the public know because of their lived experience (Epstein et al. 2014).

This literature emphasizes the idea that researchers are less detached than, in traditional research-to-policy narratives, they appear to be. Indeed, the ideal of policy shaped by sound science often confronts the reality that decision-making arenas are characterized by multiple parties, contested values and power imbalances. Simply understanding how researchers relate to government policymakers is inadequate; instead, one must realize that both are part of a larger knowledge-action system in which knowledge is coproduced by multiple parties and in which researchers must navigate and shape complex "knowledge governance" arrangements (Clark et al. 2016; Muñoz-Erickson 2014).

Framing Extension's engagement

The meaning of the land-grant ideal has always been contested. Historians of land-grant universities note a split between those who emphasize the development and dissemination of technical knowledge and those who emphasize the public work of building common values, social capital and active civic engagement (Peters et al. 2010; Putnam 2000). In their pure forms, these competing conceptions imply very different Extension roles and practices. A conception emphasizing technical knowledge implies that Extension will focus on providing technical solutions to problems as researchers see them. A conception emphasizing values, social capital and civic engagement implies that Extension will help communities define and solve their own problems, with assistance from university researchers. Supporters of the latter approach use the dictum "researchers on tap, not on top" to differentiate their preferred emphasis from the other camp's technical emphasis — but previous research suggests that both views oversimplify a complex reality. Cash (2001) views Extension as a "boundary organization" that nurtures trusting relationships and navigates tensions between science, politics and policy. Extension professionals engage with the public by coordinating public meetings or interacting with advisory groups (Frederick 1998), by listening to public perspectives to inform policy development (Morton 2002) and by working with and through community coalitions to facilitate pooling of resources, sharing of information and coordination of efforts (Smathers and Lobb 2015). Extension agents Patton and Blaine (2001) distinguish

between Extension's roles as content expert and process expert — with the former focused on applied research capacities and the latter on the ability to frame an issue in public terms and facilitate public deliberation and issue resolution. Often, Extension professionals find themselves juggling their content and process roles — that is, they insert science into public discussions that they themselves have convened. Overall, the research suggests that Extension can be particularly effective at building well-functioning stakeholder and community networks precisely because of its identity as a trusted source of information and technical assistance.

Methods

In the competitive grant program we studied, grants were awarded to proposals that demonstrated both technical competence and the potential to impact high-priority policy issues of immediate relevance to California decision-makers. Because UC ANR contracted with us to evaluate the program's policy impacts, we had access to program documents.

To select a sample of projects for in-depth analysis, we reviewed all 52 projects that had gained funding through the grant program's competitive process during the three initial funding cycles (2011 through 2013). We read each project's initial proposal, its yearly progress reports and, if available, its final report. We then selected as case studies 11 projects that had been more successful than the other funded projects in terms of policy engagement. We used the following criteria to guide our selections:

- Did the project influence the design of a policy?
- Did the project influence whether a policy was adopted or not?
- Did the project influence how a policy was implemented?
- Did the project reports indicate significant engagement with policy-oriented audiences?

While the term "policy" has multiple meanings, our focus was primarily on public policy as established through governmental decision-making processes — and secondarily on the policy or policies of industries or organizations whose impact on issues of public importance is significant.

Of the 11 projects we selected as case studies, seven had been completed and four were ongoing. For each project, we interviewed the principal investigator (PI), co-PI or key collaborator; and one or more of these individuals' key policy partners. We conducted 30 interviews between April and July 2015, with a minimum of two interviews for each case study. Most interviews were taped and transcribed; in a few cases, the interviewer instead took detailed notes. The interview protocol included questions about the background of each research project and its policy environment; the policy impacts of the project; unique or particularly successful features of the project; challenges encountered in linking research to policy; and lessons learned. Transcribed interviews and related notes were uploaded into NVivo software for qualitative analysis and then content-coded so recurring themes could be identified.

To generate findings, we conducted three rounds of qualitative coding. First, we coded directly for responses to the questions asked; this allowed us to compare respondent answers. Second, we coded for themes that recurred across multiple interviews. (The thematic coding scheme we created was derived from notes taken during and immediately after each interview. We refined these codes as we read the full transcripts and performed multiple iterations of coding — in some cases collapsing categories and in others adding more specific subcodes for topics that occurred frequently or seemed particularly relevant to our research goals and questions.) Third, we performed a more interpretive round of coding that identified underlying approaches to research-to-policy work. This part of the analysis used a comparative method akin to what Weick et al. (2005, 409) term "sensemaking," a process that "occurs when a flow of organizational circumstances is turned into words and salient categories." In pursuing this approach, we compared each case to each other case, looking for categories that could be used to parsimoniously describe underlying similarities in approach.

We worked with a graduate student researcher on the first two rounds of coding. In these rounds, at least two people read each interview transcript more than once, after which all team members engaged in iterative


Aziz Baameur

Participants in an urban agriculture project analyzed for this research get their hands dirty at WOW Farm in Richmond, Contra Costa County. The project's policy outcomes included governmental support for local urban agriculture ordinances.

Elise Gornish, left, then a UCCE specialist, inspects a restored section of Stemple Creek in Sonoma County. A separate creek restoration project analyzed for this research focused on carbon sequestration.

conversation at coding sessions until they reached final agreement on applicable codes. The third, more interpretive round of coding work was conducted by the authors specifically for the analysis that we now present. Various methods have been proposed for ensuring the quality of qualitative research findings (Reynolds et al. 2011); the primary method we have used is peer validation. UCCE personnel, including those we interviewed, have had the opportunity during multiple UCCE-sponsored presentations and training events to review and comment on our categorization scheme.

Results and analysis

The case study evidence suggests that Extension's research-to-policy work has particular public value when it combines technical *and* relational activities — when it provides a space for deliberative and reflective policy conversations over time.

The research-to-policy approaches utilized by the UCCE professionals in our sample fall into three broad categories — which can be described as community-government partnership building, stakeholder-oriented experimental research, and community empowerment. In the community-government partnership building model, researchers work directly with both government and other intermediary partners (such as nonprofits) to serve as conveners of a policy dialogue, while also providing their partners relevant research data. In the stakeholder-oriented experimental research model, researchers partner with a community entity to conduct experimental, proof-of-concept research, which provides data to inform implementation of an existing policy. In the community empowerment model, researchers partner with a community group to provide data that the group then uses on its own to engage with decision-makers.

All 11 of our cases fit (to varying degrees) within one or more of these three models. Table 1 summarizes the case data, noting each project's name; the research-to-policy approach used; project outputs (tangible products); delivery method; project outcomes (demonstrated impact on policy); and the stage of the policy process that the work impacted. The last category uses a standard set of stages first codified by Jones (1984) to distinguish among (1) how issues come to attention and get on the policy agenda (agenda setting); (2) how policy goals and intentions are developed and specified (formulation); (3) how these goals and intentions become codified into laws, regulations or other formal policy statements (legitimation); (4) how enacted policies are then turned into working procedures and processes and are supported by public resources to create tangible impacts (implementation); and (5) how those impacts, both intended and unintended, are assessed by various stakeholders or objective observers (evaluation). As the table makes clear, the 11 projects collectively address all five stages of the policy process, and many individual projects address multiple stages. Below, we use case examples to characterize the three broad research-to-policy approaches found in our data.

Partnering with intermediaries

In four projects, researchers used intermediary groups such as nonprofits or government agencies to expand the influence of their research. In all four, researchers played dual roles as knowledge providers (focusing on content) and dialogue facilitators (focusing on process). For example, the Oak Woodlands project team addressed a Northern California group's concerns that policies governing timber harvesting privilege conifer protection over oak conservation, despite the key ecosystem function played by oak woodlands. Researchers responded by assessing, through primary data collection, levels of encroachment on oak woodlands — but they also took leadership to promote stakeholder dialogue on policy changes, such as amendments to current policies. They sponsored field trips to oak woodland sites for the Forest Practice Committee (part of the California Board of Forestry and Fire Protection); presented research briefings; and later organized a series of in-person meetings, workshops, monthly conference calls and public tours in which stakeholders considered legislative changes.

In a similar fashion, the Sierra Forest Restoration project team used its research to create dialogue between the U.S. Forest Service and civil society groups interested in environmental conservation. Working with partners from nonprofit organizations over time can seed policy relationships that Extension researchers might not be able to foster on their own. In the words of one researcher on the Sierra Forest Restoration team:

> *I've always thought of [Sierra Forest Legacy, a large environmental nonprofit] as very, very engaged. They read our papers even more carefully sometimes than we do. They talk to us a lot. I'm happy to talk [because] they have [a focus on] real policy implications. They know Senator Feinstein well. I've always thought that policy development is working with these engaged publics . . . that connection with individuals on a particular forest, and in the region, too — that is huge. It's [rare that] a new research paper comes out and it's like, "Oh, this is going to change the way we*

TABLE 1. Key features of 11 research-to-policy case examples

Project	Approach(es)	Project output	Delivery method	Policy outcome examples	Policy process stage(s)
Urban Agriculture	Community empowerment	Urban Agriculture web portal; Urban Agriculture policy brief; implementation guide for AB 551 (Urban Agriculture Incentive Zones Act)	Urban agriculture advocates deliver information from Urban Agriculture web portal to city- and county-level policymakers	Governmental support for local urban agriculture ordinances; adoption of AB 551	Agenda setting; legitimation; implementation
Putting Youth on the Map	Community empowerment	Putting Youth on the Map mapping tool	Organizers from East Oakland Building Healthy Communities use mapping tool for youth mobilization around Prop. 47	Project informs planning efforts around crime prevention allocation from Prop. 47 implementation (converts nonviolent offenses to misdemeanors)	Agenda setting; implementation
Comanagement of Food Safety and Ecosystem Services in Fresh Produce	Community empowerment	Information sheets on comanagement; online training modules; videos on comanagement for food safety and conservation	Farmers use information sheets in conversations with food safety auditors to explain and legitimate on-farm comanagement strategy	Comanagement language incorporated into the Food Safety Modernization Act	Formulation; legitimation; implementation
Shaping Healthy Choices	Stakeholder-oriented experimental research	Integrated school wellness program	Formal presentations of results (task forces, conferences); informal sharing of results through relationships within education policy networks	School wellness advisory councils; Dept. of Public Health rollout of Shaping Healthy Choices program in other school districts (pending)	Implementation; evaluation
Interpreting the Value of Working Landscapes	Community empowerment	Information sheets on benefits of rangeland grazing in parks	Partner with park staff on signage to educate public about value of cattle grazing in parks	Policy of grazing on public lands is maintained	Agenda setting; implementation
Disturbance and Vegetation Dynamics in Northern California Oak Woodlands	Community-government partnership	Dataset on disturbance and vegetation dynamics in Northern California oak woodlands	California Board of Forestry and Fire Protection uses dataset to campaign for rule amendment to address conifer encroachment	California Board of Forestry and Fire Protection made aware of need to change policy; data supports congressional change in U.S. Forest Service rules (pending)	Agenda setting; formulation
Creek Carbon Restoration	Stakeholder-oriented experimental research; community-government partnership	Dataset on carbon sequestration dynamics of creek restoration and conservation	Partnerships with local government actors to use data to inform local climate plans	Conservation work included in county climate plans; path to develop state-level protocol for greenhouse gas mitigation (AB 32)	Agenda setting; formulation; implementation
Informing Sierra Nevada Forest Restoration	Community-government partnership	Dataset on historical forest conditions	Partnerships with U.S. Forest Service; engagement with nongovernmental organizations	*Ongoing project* (likely to impact development and implementation of U.S. Forest Service restoration policy)	Formulation; implementation
Asian Citrus Psyllid	Community-government partnership	Geospatial map of disease prevalence; economic analysis of disease costs	Engagement with Citrus Research Board, California Department of Food and Agriculture and local task forces	*Ongoing project* (likely to impact state prioritization of funding for disease control)	Agenda setting
Soil Survey Decision Support Tools	Community empowerment	SoilWeb app (decision support tool providing info about soil qualities)	Engagement with USDA Natural Resources Conservation Service (and possibly with growers, state water boards and other state agencies)	*Ongoing project* (likely to impact state zoning and conservation program implementation)	Implementation
Groundwater Banking	Stakeholder-oriented experimental research	*Ongoing project* (to provide evidence of groundwater banking's effectiveness)	*Ongoing project* (TBD)	*Ongoing project* (likely to impact implementation of Sustainable Groundwater Management Act)	Implementation

do everything." It's really about having a good relationship with people and then using that to bring forward the new information.

To create reports that would be useful in policy discussions, researchers with the Sierra Forest Restoration project went beyond the common conclusion that "this merits further research" and deliberately drew out the policy implications of their research. As a policy partner in the U.S. Forest Service explained:

When they did the research, they could have just said "Here's the data, here's what it shows." But they took it one step further. They said "Here are the impacts, the implications"; they brought it back to what it means to us as public managers. Doing this draws a distinction between them and other researchers.

The project team focusing on citrus disease management also played a convener role, bringing together growers and government agencies to create evidence-based policies for containing the spread of the Asian citrus psyllid, a highly destructive pest. The researchers, to guide both industry and public policy responses, worked actively to present findings at Citrus Research Board meetings, the California Department of Food and Agriculture and relevant task forces.

The Creek Carbon Restoration project developed out of a local collaborative, the Marin Carbon Project, which examined the role of local agricultural lands in mitigating greenhouse gas emissions. The Creek Carbon Restoration project used a research study of on-farm carbon sequestration — which provided evidence that riparian restoration along streams in farmland could enhance carbon sequestration — to inform dialogue around state and local policy on climate change and to bring together agricultural groups, elected officials and government agencies. As the project's PI noted:

The fact that this [project] came from and continues to support a local partnership has been helpful. It is keeping us focused on [applying research] and not getting lost in research that is not as directly relevant on the ground. As a partnership, we could divide tasks and prioritize something in one year, like research, and then shift to some policy engagement the next year, moving resources to capitalize on each other's time and expertise.

A key take-away from all four projects using the community-government partnership approach is the complementarity of Extension's content and process roles. Deploying solid research in combination with convening and facilitating partnerships and policy dialogue is a common theme in these research-to-policy success stories.

Real-world experiments

Three projects set out to understand the empirical basis for proposed or recently adopted policies. In these proof-of-concept projects, researchers worked with field-based partners to set up real-world experiments. For example, researchers involved in the Groundwater Banking project worked with alfalfa farmers to develop field trials in which farmers could see for themselves the impact of experimental flooding. These trials provided evidence that groundwater banking shows good potential as an implementation mechanism for the Sustainable Groundwater Management Act.

In another example, researchers involved in the Creek Carbon Restoration project worked with farmers to evaluate the carbon sequestration benefits of existing on-farm stream restoration practices — and to show how those practices could fit into efforts to mitigate greenhouse gas emissions, as mandated under AB 32, California's legislation to reduce such emissions. Data from this project has informed county climate action plans in Marin County.

The Shaping Healthy Choices project, building on a loosely worded school wellness policy mandated by the California Department of Education, developed a multicomponent program that improved schoolchildren's diets and reduced obesity as measured by body mass index. Researchers, partly by spending extensive time developing school wellness committees, developed a program that teachers and principals would "buy into" and that could be implemented effectively. Strategic relationship building ultimately led to widespread recognition of the program's success. The U.S. Department of Agriculture (USDA) and the California Department of Education subsequently expressed interest in replicating the program.

The time spent building relationships was a critical component of all three projects, as described by one researcher:

The first six months before the grant even started, we already started working with growers — trying to reach out and engage them and make them interested in the project. That phase of building trust with people is really essential, and it needs time. You can't force that process.

This approach is time intensive. But it is often effective at influencing policy because, with the help of community partners, it uses real-world settings to show how a proposed policy could be implemented to produce desired outcomes.

Community empowerment

In five of the 11 cases, researchers partnered with community groups to provide policy-relevant data, but then stepped back as the groups used this data in policy advocacy. Interviewees noted that this process required a certain degree of "letting go" and a willingness to approach partners with an open mind about what data they might find useful. For example, in the Putting Youth on the Map project, the goal was to equip end users — primarily youth-serving organizations — with existing data, presented in a digestible format, that could inform policy agendas. As a project team member explained:

What we were really interested in doing was providing tools to people who are well positioned to be developing and driving policy agendas. Our work was really around [creating] this framing and scaffolding to support those kinds of discussions and activities.

The Urban Agriculture project pursued concerns about information availability that had been raised in a community needs assessment:

[People] didn't know where to go find out about the policies, or what the details were, or how they could access it. . . . [The information is] not transparent, it's not easy to find, it's not easy to understand. . . . If there are rules and regulations. . ., how do you find out about [them]?

The researchers responded by providing a synthesis of rules, regulations and literature articulating the benefits of urban agriculture.

Using this information, urban agriculture stakeholders were able to make legible their on-the-ground practices and to better advocate at the state legislature for policies friendly to urban agriculture.

The Soil Survey Decision Support project developed the SoilWeb app tool, which brings together information that land managers can use to influence decision-making about land use. The tool has been used by the USDA National Resources Conservation Service and the U.S. Forest Service to influence agenda setting and policy implementation in environmental resource management arenas (e.g., determination of land values and taxes, placement of conservation assistance programs and selection of reforestation techniques). The app also supports implementation of the Williamson Act, a California law that provides tax breaks to landowners who keep farmland in production if the land's soils meet certain productivity class ratings.

The Comanagement of Food Safety and Ecosystem Services project addressed a key problem for farmers who implement environmental conservation techniques: that they are sometimes penalized later by third-party auditors for violating federal food safety codes. Relying on existing data, the team created materials that growers could show auditors, including a policy brief, short video presentations and individual conservation resource sheets. The information provided justification for farming practices such as planting cover crops and hedgerows or maintaining wetlands. In the words of the project's PI, the information helps auditors:

> *. . . recognize that what they are seeing in the field is an accepted, appropriate conservation practice in the agriculture environment — why it's there, what it's doing, what [the] food safety concerns are and what strategies can be used for risk reduction associated with that practice. . . . [T]here continues to be this need to go back [and] look at the research to actually balance food safety and sustainability in the field. The research is happening. The process of developing implementation strategies is not there. As a land-grant institution, we should be doing that.*

Discussion

As the narrative accounts summarized in this article reveal, aspects of the policy engagement generated by Extension projects are often hidden or poorly understood. The narrative accounts reveal a disjuncture between the language that Extension leaders and academics often use to describe and emphasize their policy roles and the complex, multifaceted activities evident in successful examples of Extension policy engagement. Our data thus points toward a necessary reconsideration of the story that the Extension system tells itself and the public about its policy role and work. Our research points toward a different story — one that embraces both technical and relational work and that communicates the ways in which, in concrete settings, we weave those types of work together.

At an elementary school in Sacramento County, a child harvests produce grown as part of the Shaping Healthy Choices project. The project was an example of stakeholder-oriented experimental research.

In terms of the literature reviewed earlier, the narratives we have analyzed suggest that Extension is particularly well situated to play a critical public role in the research-to-policy process. But this will only be possible if Extension exhibits a clearer understanding and stronger embrace of recent scholarship in science and technology studies — scholarship that emphasizes the social and political embeddedness of research. Extension will be most relevant in policy circles if, instead of embracing a narrower understanding of itself as a provider of evidence-based solutions, it embraces both its technical and democratic strengths — if it informs the content of policy options while also participating, with respect and a certain humility, in the social and relational processes by which policy is shaped.

Aspects of the policy engagement conducted by Cooperative Extension projects are often hidden or poorly understood.

Our case evidence provides tentative support for three generalizations about how we conceptualize and support research-to-policy activities at land-grant universities. First, we need to reconsider what counts as policy relevance. A typical current pattern is to focus on research with the potential to shape decisions on issues already on the policy agenda because of pending legislation, pending regulation or other factors. In contrast, our case narratives show (table 1) how Extension engagement can occur at multiple stages of the policy process, from agenda setting to formulation to legitimation to implementation to evaluation (Jones 1984). As one PI noted:

Policy work doesn't only involve passing [formal] laws. Policy work also is . . . the community organizing and the base building and the capacity building and the political education that can then help people engage in [the] policy realm. So I think there are a lot of things that are policy-relevant that are outside of, or lead into, the formal policy world.

As our case examples show, Extension can help reveal issues; bring them to the attention of policymakers; frame alternative solutions; and aid in implementing and evaluating policies once they are enacted. Regarded from this viewpoint, a broad range of Extension activity can be considered policy relevant. This reality should inform how we talk about Extension's public value.

Second, our evidence suggests that policy impact and public value are seldom a matter of short-term engagement with policymakers, conducted from a detached vantage point. Rather, policy impact and public value proceed from Extension personnel making it a point to embed themselves in policy networks over time. Network relationships, nurtured in countless small and large conversations and encounters, are critical to the ability of Extension personnel to inform and shape policy. One practical implication of this insight is that, if the goal is policy relevance, awarding grants through a short-term competitive process may be less useful than providing adequate funding and support for the "boots-on-the-ground" capacity of the Extension system. A further implication is that policy-related work — including the patient relationship building that is critical to the long-term success of such work — must be accounted for and valued in Extension's merit and promotion processes. Publications often receive emphasis because they are easy to count and evaluate, but published research without relational underpinnings is less likely to achieve public impact.

Third, our evidence indicates that the settings and spaces in which policy work occurs are more varied than is often depicted. For most researchers, the word "policy" conveys an image of formal governmental decision-making venues. But as the literature and our cases demonstrate, policy work takes shape not only in legislatures and agencies but also in complex governance systems characterized by multiple individual and institutional players, shifting coalitions, diverse values and ongoing power relations. Providing sound, technical information to inform particular decision-makers will always be important, but so is the ability of Extension to develop, convene and nurture high-functioning knowledge-action networks in which knowledge coproduction is the norm.

By combining its technical expertise with its ability to foster deliberative dialogue within diverse communities and networks, Extension can make, and is making, a major contribution to society. The three models of effective policy-oriented relationship building that we describe in this paper — community-government partnership building, stakeholder-oriented experimental research, and community empowerment — demonstrate ways in which this synthesis is already present in Extension practices. Future research might helpfully explore how the three approaches we have found are relevant in other contexts, or ways in which they might overlap in the context of a particular policy intervention or a particular Extension agent's career. Research might also explore and discover additional approaches that did not appear in our relatively small sample. In the meantime, Extension leaders should rethink the narrative that they use to explain and justify their institution's public value. CA

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RESEARCH ARTICLE

UC ANR research informs, influences and strengthens fruit and vegetable programs and policies

UC Nutrition Policy Institute research has helped guide state and national policies that improve child and family health.

by Patricia B. Crawford, Wendi Gosliner, Kenneth Hecht and Lorrene D. Ritchie

Increasing intake of vegetables and fruit is key to improving health. The scientific basis for the important role that vegetable and fruit consumption plays in lowering the risk of obesity, heart disease, diabetes, stroke and some cancers is well established in the Dietary Guidelines for Americans (USDHHS, USDA 2015). Increases in vegetable and fruit consumption could also reduce national health care expenses. One study estimated that the annual health care costs and lost productivity associated with inadequate vegetable and fruit intake in the United States totaled over $63 billion in 2012 (Allen 2015). Further, if the population transitioned to more plant-based foods, it would help reduce greenhouse gas emissions and mitigate climate change (Hallström et al. 2017).

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Abstract

Vegetable and fruit consumption plays an important role in lowering the risk of obesity, heart disease, diabetes, stroke and some cancers. Yet, only 20% of the population eats the daily recommended amount of produce, and 10% of children do not consume any vegetables or fruit on a daily basis. To increase vegetable and fruit intake across the population, which can extend lives and reduce health care expenditures while also enhancing demand for California agricultural products, the UC Nutrition Policy Institute has conducted research to guide public policy and institutional and community programs. The institute has studied produce consumption among children and families in child care settings, emergency food systems, schools and federal nutrition assistance programs. Conducting research to support policymakers in deciding on effective nutrition programs and policies involves partnering with community organizations and decision-makers from the outset, collecting qualitative as well as quantitative data, and sharing research findings with those who can act upon them.

Currently, only 20% of the U.S. population eats the daily recommended amounts of vegetables and fruits. One study estimated that the annual health care costs and lost productivity associated with inadequate vegetable and fruit intake in the United States totaled over $63 billion in 2012.

Lance Cheung, USDA

Currently only 20% of the population eats the daily recommended amounts of vegetables and fruit: 2.5 cups of vegetables and 2 cups of fruit for a typical adult consuming 2,000 calories per day. Ten percent of all children do not consume any vegetables or fruit on a daily basis (USDHHS, USDA 2015). The need to improve vegetable and fruit intake is clear.

Changing physical and social environments

UC Cooperative Extension (UCCE) has been a long-standing leader in educating children and families about healthy diets. More recently, it has paired its conventional healthy eating educational efforts with efforts to change physical and social environments. Environmental change approaches include improving access to vegetables and fruit in places where families live, work, learn and play. The goal is to make healthy choices normative by ensuring they are available, affordable and appealing. Because changing food environments often calls for broad population-level public policy efforts, it is important to understand ways in which academics in UCCE can interact with the policy process. Clearly, research evidence is needed to identify and support the policy and environmental changes that are most effective in changing population behaviors.

The Nutrition Policy Institute (NPI), located in UC's Division of Agriculture and Natural Resources (ANR), was created in 2014. NPI's goal is to conduct and disseminate research to inform food and nutrition policy and programs that promote nutritional health and prevent obesity and chronic disease. Based upon its research and that of others, NPI provides recommendations to policymakers, administrators, health care providers and community organizations.

The socio-ecological model (fig. 1), which describes multiple circles of influence on the behavior of individuals and families (institutions, community and public policy), can be used to guide planning and evaluation of interventions to improve population nutrition (McLaren and Hawe 2005). To improve vegetable and fruit consumption in California and across the nation, NPI's research targets all three circles of influence: institutions, such as schools and child care facilities; community programs, such as food banks and pantry programs; and government programs, such as the federal food programs.

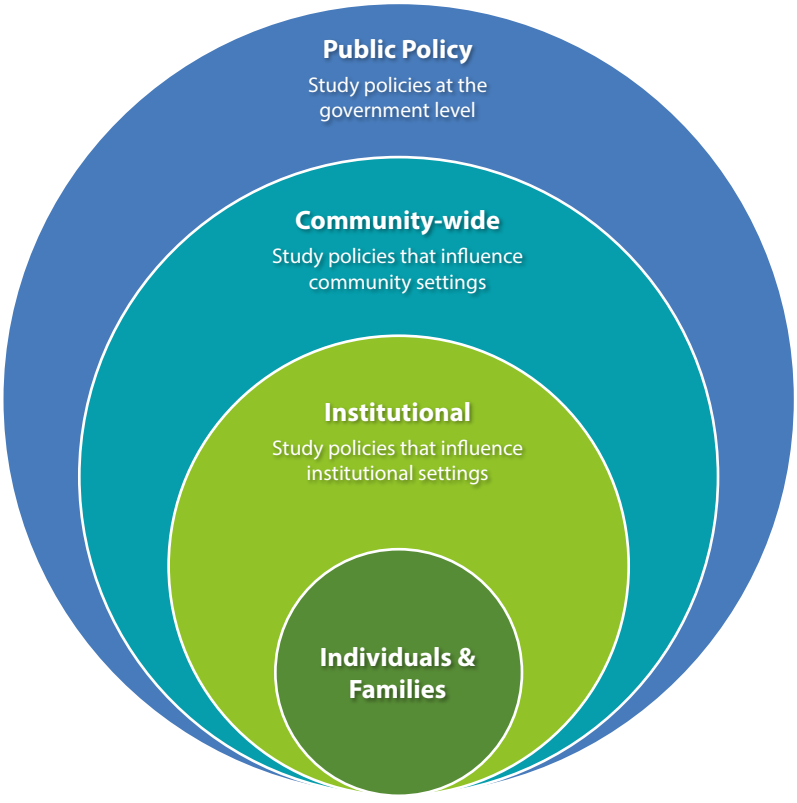

FIG. 1. Socio-ecological model of applications for policy-relevant research.

School and child care studies

Local school systems and early childhood educational settings provide an important opportunity for traditional nutrition education to influence behavior. In addition, they can be ideal venues for institutional interventions to change the food environment.

School Lunch Initiative

One early study by NPI researchers was among the first to demonstrate the effectiveness of combining school nutrition education and hands-on school gardening and cooking programs, and revamping the school meal offerings and dining environment (Wang et al. 2010). It assessed the impact of the School Lunch Initiative, established in the early 2000s by the Berkeley Unified School District in partnership with the Chez Panisse Foundation and the Center for Ecoliteracy. Changes in children's knowledge, attitudes and behaviors were compared according to how often they participated in the educational, gardening and cooking programs.

NPI found that students who participated more often in the educational, cooking and gardening elements of the program increased their consumption of vegetables and fruit by one-third of a cup per day. The study was the first to observe that students in such a program also increase their vegetable and fruit intake during nonschool hours. This research was used to support continued program funding by the Berkeley Unified School District, and it was welcomed by other school districts and advocates across the country as it provided rigorous evidence that well-implemented, comprehensive interventions incorporating menu changes, school gardens and cooking and nutrition education can significantly impact students' produce consumption and, by extension, their health.

School breakfasts

NPI researchers have also examined the comparative nutritional quality of breakfast at school versus

breakfast at home. Perhaps surprisingly, the evidence suggested that school breakfast participants ate more fruit than their home-eating counterparts, a finding that has supported the work of the federal School Breakfast Program and has encouraged California legislators to retain a small subsidy for the federal School Breakfast Program (Au et al. 2016).

In addition, the research showed vegetable and fruit intake was related to *how* the school breakfast was served. Children who attended schools where breakfast was served in the classroom at the start of the school day (as opposed to in the cafeteria before school began or during the first recess after school began) consumed significantly more total fruit, whole fruit, and greens and beans, a category of vegetables that tends to be inadequately consumed by children (Ritchie et al. 2016). This NPI research provides a strong rationale for the classroom breakfast model.

A longer lunch period

Another study by NPI researchers identified additional factors associated with increased vegetable and fruit consumption at school. A longer lunch period, the presence of a salad bar, better-quality fruit and student involvement in food service decision-making were all associated with increased produce consumption at school (Gosliner 2014). These findings were used as scientific evidence to support a bill, California AB 292 (Santiago 2015–2016), to increase the time public school students are allotted for eating lunch. While the bill has not yet passed, the issue continues to be on the policy agenda. Collectively, these school-based studies identified a number of program, policy and environmental changes that schools can take to maximize students' consumption of vegetables and fruit.

Child care nutrition

Reflecting concern about the alarming rates of obesity among our youngest children, NPI has made early childhood nutrition a high priority for its research. In 2008, at a time when almost nothing was known about the food-related policies and practices in early childhood settings, NPI partnered with California Food Policy Advocates to conduct the first statewide survey of nutrition in licensed child care facilities in California (Ritchie et al. 2012).

Included in the study were over 400 child care sites ranging from Head Start centers and state preschools to private centers and home-based programs. Some of the centers and homes (including Head Start and state preschools) participated in USDA's Child and Adult Care Food Program (CACFP), the child care equivalent of the National School Lunch Program.

Results demonstrated that CACFP sites in general, and Head Start centers in particular, served more vegetables and fruit than child care sites that did not participate in CACFP. The study findings provided much-needed evidence to support efforts to provide better nutrition to all children in child care and were influential in informing the first major updates to the CACFP nutrition standards, which went into effect in October 2018.


Peter Howard, USDA

Researchers with the UC Nutrition Policy Institute found that childcare sites participating in the federal Child and Adult Care Food Program served more fruits and vegetables to young children than sites not participating in the program.

The study results also formed the basis of California AB 2084 (Brownley 2010), the Healthy Beverages in Child Care Act, which contains the country's strongest nutrition standards for what children drink in child care. Further, the drinking water requirement in AB 2084 was incorporated in the Healthy, Hunger-Free Kids Act of 2010 (HHFKA). HHFKA is the federal law reauthorizing CACFP and the other child nutrition programs; thus, NPI's research informed the law that now ensures that children in child care anywhere in the country are guaranteed access to free, fresh drinking water throughout the day.

Food bank nutrition studies

Outside of school and child care, produce availability in other community settings can affect family consumption patterns. Food banks and their associated pantries are an important community resource. As more families, even those with working adults, struggle to make ends meet financially, local food banks have grown to meet the need. Currently, emergency food organizations help to feed approximately 14% of all people in the United States annually, including 12 million children (Feeding America 2014).

The Food Bank of Central New York (FBCNY), an agency at the forefront of food banks concerned about the nutritional impact of the food distributed, asked NPI to evaluate its 2006 policy to decline donations of sodas, snack foods and candy. Many stakeholders in food banking felt client choices should not be limited in that way. NPI gathered food preference information from clients of FBCNY's food pantries to inform potential revision of the food bank's soda and candy policy.

Results showed that pantry clients overwhelmingly preferred to receive vegetables and fruit as well as meat, poultry and fish over soda, candy and snack foods (Campbell et al. 2011). Altogether, 90% or more reported that vegetables and fruit were very important or important to receive at a pantry, and

more than 85% reported that soda, candy and snacks were only somewhat or not important. As a result of this study, FBCNY strengthened its policy prohibiting donation of sugary beverages and snacks, and it demonstrated the substantial reduction in distribution of these products by monitoring the annual inventory over a 4-year period. NPI's research has helped to galvanize food banks across the country to enact similar policies.

In California, NPI monitored fresh vegetable and fruit donations using inventory data from six food banks between 2007 and 2010. During this period, produce donations increased to make up over 50% of the weight of total foods in the food banks' inventory, with fresh vegetables and fruit becoming the largest source of produce (Ross et al. 2013).

To help other food banks mirror the successes of the New York and California food banks, Kaiser Permanente funded NPI to provide technical assistance to 20 food banks across the country (including 11 in California) to develop and implement nutrition policies that emphasized the need for increased produce and discouraged donations of sugary beverages and snack foods. All of these food banks now have such policies in place, confirmed by a follow-up process evaluation conducted by NPI.

Finally, to widely disseminate technical assistance and support for food bank nutrition policies, Kaiser Permanente funded the development of a free massive open online course, or MOOC (Campbell et al. 2015). To date, thousands of people across the country, including UCCE advisors and staff, have participated in this course and have downloaded the resource guides produced. The MOOC promotes healthful offerings at food banks and pantries by detailing the steps necessary for adopting nutrition policies. This course has helped to change the culture of food banking — from focusing on the distribution of the maximum poundage of any food to focusing on the distribution of nutritious food that supports health.

The MOOC . . . has helped to change the culture of food banking — from focusing on the distribution of the maximum poundage of any food to focusing on the distribution of nutritious food that supports health.

Federal program evaluations

Changes to government programs and policies have had a significant impact on improving dietary behaviors; they impact large segments of the population and can profoundly impact vegetable and fruit intake. NPI's numerous studies of federal food programs, including the Special Supplemental Nutrition Program for Women, Infants and Children (WIC), CACFP, National School Lunch Program, and School Breakfast Program, have contributed to these changes.

WIC food package changes

NPI's work with WIC demonstrates how research can affect policy. WIC provides supplemental foods to qualifying low-income children and pregnant and postpartum women. It is a large program: More than half the babies born in California are enrolled in WIC. In addition to food, the program provides nutrition education, which includes teaching families why and how to eat more vegetables and fruit.

At the federal level, the package of supplemental foods available to WIC participants was slated to change in 2009, to add vegetables and fruit, among other improvements — the first such change to the program since its establishment in the early 1970s. To understand whether vegetable and fruit education would support participants in using the newly provided access to produce, NPI collaborated with PHFE-WIC (the largest WIC program in California) and the state WIC branch to evaluate educational sessions being provided by all California WIC clinics.

In 2008, a telephone survey was administered to a cross-section of more than 3,000 California WIC participants immediately before and 6 months after they received the produce-promoting education from WIC. Six months following the nutrition education, the women and caregivers reported increased recognition of the educational messages and increased family consumption of fruit (but not vegetables) (Ritchie et al. 2010). These results supported the policy changes to WIC foods and highlighted the effectiveness of the combination of educational and structural support.

NPI researchers also conducted other studies of the impact of the 2009 WIC food package changes. One study examined diet quality data from the National Health and Nutrition Examination Survey, which included a national sample of 1,197 preschool children, age 2 to 4 years, from low-income families before and after the food package changes. Increases in intakes of greens and beans were higher for WIC participants than those for non-WIC participants during a time when vegetable consumption seemed to decrease for children not participating in WIC (Tester et al. 2016). In a California study, random samples of children participating in WIC (3,004 children in 2009, 2,996 in 2010) were surveyed before and after the 2009 changes to WIC foods. The findings revealed small but significant increases in consumption of vegetables and fruit (Whaley et al. 2012).

For informing future directions, it's important not only to document the dietary impacts of policy change but also to understand the perceptions of those impacted. Thus, NPI evaluated participant satisfaction with the WIC food package changes. Although WIC participants reported being highly satisfied with all changes (more whole grains, lower-fat dairy, less juice and cheese), the addition of vegetables and fruit was among the most highly rated (Ritchie et al. 2014).

Taken together, these WIC studies documented that the new food package was well accepted and impactful.

This type of information can play a role in supporting program reforms and in informing members of Congress when they are considering WIC authorization or appropriations.

Fresh Fruit and Vegetable Program

In 2010-2011, NPI collaborated on a nationwide evaluation of the USDA Fresh Fruit and Vegetable Program (FFVP), a program in which schools with high numbers of low-income students are funded to provide free vegetable and fruit snacks to all students (Olsho et al. 2015). Schools participating in FFVP are encouraged to distribute a wide variety of fresh vegetables and fruit, at least two per week, including types to which students might not otherwise be exposed.

The study compared the intake of 4,696 elementary students at schools that did and did not participate in FFVP. The results showed that daily mean vegetable and fruit intake was one-third of a cup higher among students at schools participating in FFVP compared to the intake of those at nonparticipating schools. In addition, vegetable and fruit consumption increased outside of school. Evidence like this informs the policymakers whose decisions determine whether such successful nutrition programs will continue.

National leadership

Researchers can impact policy also by participating in efforts that shape national policies, such as serving on committees of the National Academy of Sciences, statewide commissions and similar influential bodies. NPI researchers have provided national leadership on ways to improve vegetable and fruit consumption by serving on the committee that recently contributed to the government's Healthy People 2020 initiative.

Healthy People 2020 provides science-based national objectives for improving the health of Americans. These objectives provide guidance for state and local public health planning and programming. Recently, NPI co-authored the Healthy People 2020 Law and Health Policy Project report on successful policy strategies to improve vegetable and fruit consumption (Crawford et al. 2018). The report contains examples of effective policy interventions that can help shape the environment to improve vegetable and fruit consumption. Examples of these include the use of tax revenues to support vegetable and fruit programs in schools that both educate and encourage students to try new kinds of vegetables and fruit and the use of state and local policies to alter the built environment to provide increased space for vegetable and fruit stands and mobile carts.

Scaled and combined interventions

These case examples highlight different types of research undertaken to inform, influence and strengthen policy and programs related to vegetable and fruit consumption in the various circles of influence in the socio-ecological model. Research-based action in more than one circle is critical because it has the greatest chance of success in expanding vegetable and fruit demand and consumption (IOM 2012). Connections between circles of influence can be explicit or discovered over time. For example, changing public policy by modifying the WIC food package or school meal regulations has driven changes in community food environments, and local institutions have responded by implementing additional supportive interventions. The more changes that support increased vegetable and fruit consumption, the more likely they are to lead to the desired outcomes: improved consumption among individuals and families, better population health and expanded markets for California-grown produce.

Although the dietary impact of a single intervention will not likely be large, if interventions are scaled and combined, the impact can be dramatic (IOM 2012). Even an increase in vegetable and fruit intake of one-fourth cup daily can substantially impact population health and reduce health care costs while increasing demand for vegetables and fruit. For example, if all residents of California were to increase their daily vegetable and fruit consumption by one-fourth cup, Californians would purchase 3.6 billion more cups of vegetables and fruit every year. Further, if consumption levels increased enough to move any portion of the population from eating vegetables and fruit less than once to more than three times daily, those who improved their intake could see as much as a 27% lower risk of stroke, a 24% lower risk of heart disease and a 15% lower risk of all-cause mortality (Bazzano et al. 2002).

USDA

The more changes that support increased vegetable and fruit consumption, the more likely they are to lead to the desired outcomes: improved consumption among individuals and families, better population health and expanded markets for California-grown produce.

Lessons on using research to create change

Throughout more than a decade of policy-relevant research, NPI has learned important lessons that can be applied in other fields and on topics other than vegetable and fruit consumption. These include the value of providing research-based guidance to advocates and

policymakers in clear and actionable ways. Documents such as the Healthy People 2020 Law and Health Policy Project report provide a wide variety of research-based strategies by which local and state government and nongovernment agencies can work to improve vegetable and fruit access. Translating findings using reports, briefs and fact sheets and presenting results and recommendations directly to advocates and policymakers can facilitate the use of research to create positive change.

While quantitative data often are beneficial for informing policy debates, qualitative data also are influential. Qualitative data that capture the voices of those impacted by change provide illustrative insights and important context for interpreting quantitative data. Sometimes, a compelling anecdote that makes a personal connection can influence policymakers more than the most rigorous scientific findings. Under contract with the California Endowment, NPI interviewed kindergarten children on what they thought of afterschool meal standards that had increased vegetable and fruit offerings. From the mouths of children came "We love the new purple and green foods." Complete stories, with the numbers linked to an anecdote or quote, are the most compelling to policymakers.

The science that UC ANR brings to policy debates is fundamental, but the right research questions must be developed to supply the information that policymakers need. NPI has learned to work closely with agencies and participant populations to identify critical areas that can benefit from research that is both scientifically valid and policy relevant. In this way, the research provides a bridge between academia and the world at large and is facilitated by partnerships, which is an ANR goal. Partnering with community organizations from the outset helps to ensure that the research questions posed are relevant and that the answers can offer realistic and practicable solutions.

Finally, NPI has learned that discussing the research study findings at meetings with stakeholders, including policy- and decision-makers, is important. It provides an opportunity for stakeholders to identify meaningful solutions, and for researchers to learn of the policy-relevant questions that have the highest priority and need answering next. In sum, we've learned that conducting policy-relevant research involves collaboration throughout the entire process — partnering from the outset with community organizations and decision-makers, collecting and collaboratively evaluating qualitative as well as quantitative data, interpreting results with consideration of policy relevance, and sharing results and recommendations with those who can act upon them. CA

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RESEARCH ARTICLE

UC ANR research and education influences landscape water conservation and public policy

For more than 30 years, UC has tackled the obstacles that inhibit widespread landscape water conservation, with new science, trainings and contributions to state policy.

by Janet S. Hartin, Lorence R. Oki, David W. Fujino, Karrie Reid, Charles A. Ingels, Darren L. Haver and William N. Baker

For nearly three decades, California has mandated practices to improve landscape water use efficiency and conservation. The goal of state policies has been to ensure a steady and reliable water source while maintaining healthy sustainable landscapes. Strategies have included the adoption of landscape irrigation standards, water budgets and tiered water rates favoring conservation, and also increased education to the landscape industry and the public.

UC has been influential in developing and providing credible science-backed information to inform legislative actions. It has also reduced the obstacles that were inhibiting widespread landscape water conservation: a lack of credible information regarding landscape water requirements, inadequate training across a large segment of the landscape industry, lagging irrigation system technology, and an inadequate supply of locally available drought-resistant landscape plants.

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Abstract

UC has been heavily involved in research and extension efforts impacting landscape water conservation legislation for over 30 years. In 1981, UC implemented the California Irrigation Management Information System, a network of weather stations that provides data for local estimates of plant water needs. Those estimates led to UC being able to advise the California Legislature on policies for maximum applied water allowances for residential and large landscaping projects. The allowances have been reduced significantly with UC guidance, and UC has helped landscapers to meet the increasingly restrictive requirements. Best practices that reduce water losses have been developed in collaboration with equipment manufacturers and landscaping specialists, and explained to end users. In addition, UC has developed the WUCOLS database, which classifies over 3,500 plants by their water needs. UC's involvement in landscape water conservation continues on many fronts, developing science and contributing to policy.

UCCE Advisor Chuck Ingels speaks to the press in Sacramento about water conservation. UC has developed a database that categorizes 3,500 plants by their water needs.

Lorence Oki

Between 40% and 60% of the potable water supply used in urban areas is applied to large-scale and residential landscapes (Kjelgren et al. 2000; St. Hilaire et al. 2008), and up to 60% of water applied by overhead sprinklers is lost due to runoff from soil surfaces, deep percolation below root zones and soil evaporation (Hartin and McArthur 2007; Hartin et al. 2017). With California's population expected to increase from 39 million to 60 million by 2050 (Dieter and Maupin 2017), water conservation in small residential landscapes and large landscaped areas, such as commercial sites, parks and school grounds, will remain critical, and temporary water restrictions imposed during drought are likely to become permanent in many parts of the state.

Water conservation will need to offset the growth in demand. Nearly one-half of the state's population growth since 2005 has occurred in inland Southern California and the Central Valley due to the lower housing costs in these areas (Hanak and Davis 2006). These inland properties require higher amounts of supplemental water than coastal areas due to warmer climates and larger landscaped areas.

Glossary

Evapotranspiration (ET): The water evaporated from soil around plants and the water taken up by plants through transpiration, expressed in inches per unit time.

Reference evapotranspiration (ET_o): An estimate of water used by a healthy, well-watered, full-covered surface of cool-season turfgrass maintained at 4 to 7 inches tall at a given location; determined by temperature, solar radiation, wind speed and relative humidity (real-time ET_o for approximately 140 weather stations throughout California can be found at cimis.water.ca.gov).

Plant factor (PF): Reflects the specific water need of a given plant species (usually a noncrop plant) expressed as a fraction of ET_o ($ET_c = ET_o \times PF$).

Crop coefficient (K_c): Reflects the specific water needs of a given crop plant grown in a monoculture ($ET_c = ET_o \times K_c$); in landscape settings, generally used solely for turfgrass and groundcover species.

Irrigation efficiency (IE): The portion of the total applied irrigation water taken up by the plant; low IE indicates a significant fraction of applied water is lost through runoff and evaporation from surrounding soil.

Evapotranspiration adjustment factor (ETAF): Ratio of PF or K_c to irrigation efficiency (ETAF = PF or K_c/IE); in California, landscape water demand standards are set according to a maximum allowable ETAF value, which recognizes that overall water efficiency depends on both plant species (reflected in the plant factor) and an efficient, well-maintained irrigation system.

Maximum applied water allowance (MAWA): The maximum amount of water needed to irrigate a specified landscaped area, expressed in gallons per year; based on the reference evapotranspiration (ET_o), evapotranspiration adjustment factor (ETAF) and the size of the landscaped area.

TABLE 1. Plant factors (PF)/crop coefficients (K_c) for established landscape plants in California

Plant type	Plant factor (PF)*/ Crop coefficient (K_c)†
Landscape plants with high water use	0.7–0.9*
Landscape plants with medium/moderate water use	0.4–0.6*
Landscape plants with low water use	0.1–0.3*
Landscape plants with very low water use	< 0.1*
Warm-season turfgrass (Bermudagrass, zoysiagrass, St. Augustinegrass, buffalograss)	0.6†
Cool-season turfgrass (tall fescue, Kentucky bluegrass, ryegrass, bentgrass)	0.8†

The science of landscape water use

Determining how much water is required by heterogeneous landscapes containing multiple species of plants is more complicated than determining the water needs of a field of a single crop species. It would be challenging and time consuming to assess the water requirements of the thousands of native and nonnative landscape plants that are suited to California's Mediterranean climate. Moreover, urban landscape plantings vary in density (plants per unit area), which can significantly alter the water needs of a landscape. In addition, the urban environment includes a variety of microclimates; shade by tall plant species and buildings and other factors commonly create microclimates that influence water needs (Nouri et al. 2016; St. Hilaire et al. 2008).

UC has been heavily involved in developing strategies that directly respond to these challenges (Hartin et al. 2018). In 1981, the pioneering California Irrigation Management Information System (CIMIS) weather station network was set up, a collaboration between UC and the California Department of Water Resources (CDWR). Today, there are more than 145 automated CIMIS weather stations in distinct climate zones throughout the state.

Most CIMIS stations record data on a collection of variables needed to determine the reference evapotranspiration (ET_o) at a given location, providing the basis for local estimates of plant water needs. Data from the CIMIS network also allowed UC to establish crop coefficient (K_c) values for turfgrass (Gibeault et al. 1985) and plant factor (PF) values for other landscape species (Hartin et al. 2018). K_c and PF values adjust reference evapotranspiration for a particular landscape species or mix of species (table 1). (See the glossary for definitions of terms.)

A major finding by UC was that the health of most landscape plants generally is not impaired when plants are irrigated somewhat below their evapotranspiration rate, a practice known as deficit irrigation. This knowledge led to the identification, through replicated field trials, of minimum irrigation requirements for several species of landscape trees, shrubs and groundcovers (Harivandi et al. 2009; Hartin et al. 1993; Oki et al. 2016; Pittenger et al. 2001; Pittenger et al. 2009; Reid and Oki 2008, 2013, 2016).

UC also has been a major developer and extender of credible information on landscape water use through peer-reviewed publications; presentations to industry decision-makers at workshops, seminars, conferences and field days; and the UC Agriculture and Natural Resources (UC ANR) Master Gardener program. This work has been instrumental in implementing the multiple pieces of landscape water use legislation that California has adopted since 1990.

AB 325: Water Conservation in Landscaping Act (1990)

The Water Conservation in Landscaping Act of 1990 required CDWR to convene an advisory task force to develop a Model Water Efficient Landscape Ordinance (MWELO), which was adopted by the legislature in 1993 (State of California 2010). Central to MWELO was the establishment of a maximum applied water allowance (MAWA) based on the size of the landscape and the climate zone.

The formula for calculating MAWA includes an evapotranspiration adjustment factor (ETAF) based on plant factor and irrigation efficiency. MWELO set a maximum ETAF of 0.8 for new commercial and residential landscapes irrigated with potable water. To not exceed this standard, landscapes generally needed to include plants with low and very low water requirements and well-designed, functional irrigation systems. Each jurisdiction is required to either adopt MWELO or update its own landscape ordinance to be equally effective in conserving water.

UC's role

MWELO required that local jurisdictions categorize plants based on water needs and climate zones. The CDWR and U.S. Bureau of Reclamation provided funding for UC, under the direction of Emeritus UC Cooperative Extension (UCCE) Advisor Laurence Costello, to oversee the development of such a database. WUCOLS (Water Use Classification of Landscape Species) categorized thousands of species of landscape plants in six climate zones (North Central Valley, Central Valley, South Coastal, South Inland Valley, High and Intermediate Desert, and Low Desert) by their water use: very low, low, medium, and high. The work relied on the consensus of 36 experts from the public and private sectors, including UC.

Since the inception of WUCOLS in 1992, additional species have been added, with major updates in 1994, 1999 and 2014. Currently, WUCOLS includes more than 3,500 plants (Costello and Jones 2014); and several teams of UC scientists are engaged in assessing the minimum water requirements of additional landscape species, to add them to the database. The WUCOLS database greatly supplements information from the

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Well-designed landscapes with efficient irrigation systems and drought-resistant plants help ensure water budget compliance.

relatively small number of replicated field studies (which are likely more valid but much lengthier and more resource intensive) that have directly measured the water use of individual landscape plant species.

AB 2717: California Urban Water Conservation Council, stakeholders (2004)

AB 2717 further refined landscape water conservation legislation, using recommendations by a task force appointed by the California Urban Water Conservation Council (now called the California Water Efficiency Partnership, CalWEP). Task force members represented both public and private stakeholders. The final report — Water Smart Landscapes for California: AB 2717 Landscape Task Force Findings, Recommendations, and Actions — was submitted to the Governor and Legislature in December 2005 (CUWCC 2005). It included 43 recommendations regarding best practices to improve water use efficiency in new and existing urban landscapes. The top 12 recommendations are listed in table 2.

UC's role

UCCE's Laurence Costello and Janet Hartin were appointed to the task force along with 28 members representing CDWR, the California State Water Resources Control Board (SWRCB), the California Bay Delta Authority, the U.S. Bureau of Reclamation and also the landscape, equipment manufacturing, building and construction industries, and urban water suppliers, environmental advocacy and environmental justice groups, the League of California Cities and the California State Association of Counties. UCCE's Lorence Oki, Ali Harivandi (emeritus) and Robert Green (currently at California Polytechnic State University, Pomona) served as UC representatives on task force working groups.

TABLE 2. Top 12 of the 43 recommendations made by the AB 2717 task force

1.	Adopt water-conserving rate structures as defined by the task force
2.	Reduce the ETAF (landscape water budget) in MWELO and review it every 10 years for possible further reduction
3.	Enforce and monitor compliance with local ordinances and MWELO
4.	Require dedicated landscape meters
5.	Promote the use of recycled water in urban landscapes
6.	Require that local ordinances be at least as effective as MWELO
7.	Increase the public's awareness of the importance of landscape water use efficiency and inspire them to action
8.	Require smart controllers
9.	Adopt and enforce statewide prohibitions on overspray and runoff
10.	Provide training and certification opportunities to landscape and irrigation professionals
11.	Support upgrading CIMIS
12.	Adopt performance standards

A key topic of debate among task force members was whether new landscapes should be required to contain a minimum percentage of drought-resistant plants or if adequate water savings could be realized based on a water budget through a variety of other means. The task force ultimately recommended the more flexible latter approach, leaving plant selection to the property owner.

UC task force members and other groups represented on the task force (such as the California Landscape Contractors Association) supported exemptions from MWELO's mandated water budgets for "special landscape areas." These areas included recreational turf (sports fields and parks) and areas irrigated with recycled water. While synthetic turf is a viable water-saving alternative to natural turf in some instances, it can result in undesirable impacts such as high surface temperatures in inland and desert areas (Williams and Pulley 2003) and a greater number of player injuries (McNitt et al. 2008).

Several UC academics and other authors, led by Professor Emeritus Ken Tanji, compiled an extensive review of irrigating landscapes with recycled water in Southern California (Tanji et al. 2007) to reduce reliance on potable water. While irrigating landscape plants with recycled water is viable in many situations, salts tend to occur in higher concentrations in recycled water. Leaching these salts below the root zone to prevent plant damage can increase the net water requirement above 1.0 ETAF, the current MWELO allocation for special landscape areas. UC ANR specialists (Haghverdi and Wu 2018) recently published a white paper in support of increasing the ETAF above 1.0 for areas irrigated with recycled water, to provide enough water for leaching.

AB 1881: Water Conservation in Landscaping Act (2006)

AB 1881 required CDWR to update MWELO by enacting many of the recommendations from the AB 2717 task force. These included decreasing ETAF from 0.8 to 0.7 for new non-single-family developments with landscaped areas larger than 2,500 square feet "pending a study conducted by UC supporting this recommendation." Local jurisdictions were required by Jan. 1, 2010, to adopt the updated MWELO or adopt a local ordinance that was at least as effective in conserving water.

UC's role

Many of the recommendations developed by UC and other members of the task force were enacted in this bill. These included requiring selection of plants adapted to specific sites while not prohibiting or requiring specific plant species, encouraging the capture and retention of stormwater on-site and the use of recycled water, conducting on-site soil assessment and management to prevent erosion and water runoff, applying

mulch around shrub and tree plantings, endorsing education of water users on water conservation practices, and encouraging economic incentives to promote water conservation.

As importantly, the legislation encouraged landscape maintenance practices that lead to long-term water conservation, such as routine irrigation system audits, maintaining functional equipment, and minimizing landscape irrigation overspray and runoff. To that end, classes approved by the U.S. Environmental Protection Agency (US EPA) WaterSense program that increase water use efficiency and decrease water loss are regularly offered by the California Landscape Contractors Association, the Qualified Water Efficient Landscaper program, and Rain Bird. The classes promote the incorporation of water-efficient irrigation practices pertaining to irrigation system design, installation and maintenance, and they often include hands-on demonstrations of irrigation system audits. Attendees gain knowledge of best practices that promote healthy water-conserving landscapes and earn certificates of completion, which may provide career advancement opportunities.

The bill also required the California Energy Commission to regulate performance standards and labeling requirements for irrigation equipment to conserve energy and water. Examples of heightened performance standards include requiring matched precipitation rate sprinkler heads and other emission devices; separate valves for tree and turf irrigation whenever possible; and the use of original components (or their equivalents) for sprinkler repair.

Two UC studies funded by CDWR

Between 2003 and 2015, UC received CDWR funding to conduct two studies to further refine provisions within AB 1881. Both studies involved identifying the relative importance and impact of specific best practices — such as conducting sprinkler equipment performance audits and scheduling irrigations based on climate and plant water needs — that maintain the health, performance and aesthetics of large-scale public and private landscapes under reduced water budgets.

More than 70% of applied water was lost

The first study (Hartin and McArthur 2007) examined major causes of water loss on 30 park, school district, commercial and golf course sites in Los Angeles, Riverside and San Bernardino counties. Results identified that over 70% of applied water was lost, due mainly to leaks, sunken heads, improper head tilt, unmatched sprinklers, broken or worn parts, overspray, deflected spray, and improper pressure and line or head placement. The results validated the importance of including best practices targeting irrigation system installation and maintenance in water conservation legislation recommended by the AB 2717 task force. Results of this UC study were also included in a white paper published by CDWR that stressed the importance of best practices in landscape water conservation.

Determining validity of reducing ETAF to 0.7

The second CDWR-funded study (led by California Center for Urban Horticulture Director David Fujino and UC ANR's Loren Oki and Janet Hartin) was conducted by us, the authors of this article, in response to the legislative mandate for a UC study to determine the impact of reducing ETAF from 0.8 to 0.7 (a 19% reduction) on plant health, function and appearance. We monitored these factors and the water use of 30 large landscapes (parks, school grounds, private grounds, business parks and golf courses) with a wide variety of species, microclimates, densities, irrigation schedules and technologies in six climatic zones throughout the state. Of the 30 sites, 21 performed adequately at 0.7 ETAF after implementing best practices that improved irrigation system functioning and decreased water loss (Hartin et al. 2017; Reid et al. 2017), legitimizing the proposed ETAF reduction, which took effect Jan. 1, 2010.

Some of the greatest water savings in our study came from improving distribution uniformity and irrigation efficiency.

Some of the greatest water savings in our study came from improving distribution uniformity and irrigation efficiency. With those improvements, warm-season turfgrasses met the 0.7 ETAF standard without impairment to plant health, plant function or aesthetics. Warm-season turf species are more drought resistant than cool-season species; cool-season species did not meet the 0.7 ETAF standard since they are less drought resistant than warm-season species.

All 24 shrub sites used considerably less water than the turf sites, although 10 of them increased water use the second year (ETAFs of 0.58 and 0.61, respectively) due to malfunctioning valves and management turnover that led to a lack of continuity in site maintenance. Results suggest that drip-irrigated and mulched areas of plants with a mix of medium, low and very low water needs and small areas of warm-season turf can perform adequately at 0.7 ETAF.

The results of this study underscored the importance of the MWELO exemptions for special landscape areas. In the absence of an exemption for recreational turf, the options to meet the 0.7 ETAF include reducing the acreage of cool-season turf species, replacing cool-season species with warm-season species or irrigating the landscape with nonpotable water.

Another goal of the CDWR-funded ETAF study was to expand the number of plants listed in WUCOLS. In addition to CDWR, many organizations supported this effort, including the Association of Professional Landscape Designers, American

Society of Irrigation Consultants, American Society of Landscape Architects, California Association of Nurseries and Garden Centers, and the California Landscape Contractors Association. The most recent WUCOLS update, WUCOLS IV (Costello and Jones 2014), includes the water use classification of an additional 1,500 ornamental plants, bringing the total to 3,546 entries.

Analytical user data indicates high usage of WUCOLS. During 2014 there were 7,300 users and over 130,000 page views, which increased to over 25,000 users and 538,000 page views during 2016. There was a slight decrease in hits in 2017, perhaps due to an easing of the drought-related water restrictions that had been imposed by Governor Brown in 2015.

Outreach was a major component of the ETAF study. Between 2013 and 2017, our team reached over 7,000 landscape industry professionals through presentations at workshops, symposia, field days and conferences sponsored by UC and industry organizations such as the California Landscape Contractors Association, Irrigation Association, Western Chapter of the International Society of Arboriculture, California Association of Pest Control Advisers, and water districts. In addition, we authored several new UC ANR publications: Sustainable Landscaping in California (publication 8504), Keeping Plants Alive under Drought or Water Restrictions (publication 8553) and Drought Tip: Use of Graywater in Urban Landscapes in California (publication 8536).

Irrigation system malfunctions resulted in more water loss than could be saved by selecting drought-resistant landscape species.

Irrigation system malfunctioning

In both UC studies, irrigation system malfunctions resulted in more water loss than could be saved by selecting drought-resistant landscape species (Hartin and McArthur 2007; Hartin et al. 2017; Reid et al. 2017). This underscores the importance of proper selection, installation and maintenance of irrigation equipment. Having a landscape contractor firm provide hands-on training to demonstrate these recommended irrigation management practices to site managers significantly reduced water loss following the training in both UC studies (Hartin and McArthur 2007; Hartin et al. 2017; Reid et al. 2017).

Emergency drought legislation 2014

Beginning in 2014 (during our ETAF study), Governor Brown declared a state of emergency and signed consecutive executive orders to conserve water during the drought and beyond. On April 1, 2015, he imposed statewide mandatory water reductions due to the continuing drought. Important elements impacting urban landscapes included a mandated 25% statewide reduction in residential and commercial potable water use through Feb. 28, 2016 (based on usage in 2013); replacing 50 million square feet of turf with drought-resistant plants; prohibiting the use of potable water for irrigating turf on public street medians and on new landscapes not irrigated with drip systems; requiring urban water suppliers to enact pricing structures consistent with meeting statewide water restrictions; and requiring urban water suppliers to provide monthly information on water usage, conservation and enforcement permanently.

In addition, the 2015 order required CDWR to update MWELO to increase water efficiency in new and existing landscapes by using more efficient irrigation systems, gray water, and stormwater capture and by limiting turf. Using newer technologies such as precision irrigation hardware and software and renewable energy–powered desalination were also encouraged.

On April 7, 2017, Governor Brown lifted the drought emergency in all counties except four (Fresno, Kings, Tuolumne and Tulare, due to their reliance on groundwater) but maintained policies that support a core commitment to long-term water conservation through continued mandates on water use reporting, reducing water loss and decreasing the reliance on potable water for landscape irrigation.

Decrease in urban water use

While comprehensive results and impacts of public policy legislation aimed at increasing landscape water conservation have not been fully evaluated, recent data shows a decrease in urban water use. Total urban potable water use was 20% less in May 2017 than in May 2013 (an estimated savings of 124,537 acre-feet per month) (California Water Boards 2017). The U.S. Geological Survey reported a 17% reduction in urban water use throughout California between 2010 and 2015, driven in part by mandatory water restrictions in 2015 (Dieter and Maupin 2017). Perhaps more importantly, per-capita water use has fallen steadily over the past two decades, from 232 gallons per day in 1995 to 178 gallons per day in 2010, in response to long-term efforts at conservation, including reduced amounts of water applied to California landscapes (Mount and Hanak 2016). A blip occurred in 2015 when per-capita water use fell to only 130 gallons per day under mandatory conservation.

Input from many organizations and stakeholders impacted landscape water use policy and decreased water loss. While UC did provide policymakers with credible and objective research-based information, implementing MWELO and adjusting MAWA required a collaborative effort by a wide variety of groups and individuals vested in maintaining healthy, functional landscapes that perform acceptably under water reductions.

New landscape water use legislation

In May 2018, Governor Brown signed two bills (SB 606 and AB 1668) consistent with his 2017 Making Water Conservation a California Way of Life proposal. SB 606 focuses on landscape water use and AB 1668 focuses on rural and agricultural water use. Together they establish water use objectives and reporting standards for indoor and outdoor residential and commercial use; require SWRCB and CDWR to adopt long-term standards for efficient water use; update urban water management plans to include the reliability of the water supplies and strategies for meeting current and future water needs; require urban water suppliers to conduct a water supply and demand assessment and make water shortage contingency plans available to customers; and require water suppliers to declare emergency measures to ensure sufficient water for human consumption, sanitation and fire protection.

AB 2371 was enacted on Sept. 28, 2018. It continues to enforce many current landscape water conservation practices in and out of drought, including hydrozoning, water budgeting, stormwater collection, use of recycled water and irrigation equipment maintenance. In addition, it requires the Contractors State License Board to update the C-27 landscape contractors' exam as needed to include questions on new and emerging landscape irrigation efficiency practices; allows potential purchasers of housing units containing in-ground landscape irrigation systems to require irrigation system inspections; and requires the formation of a working group to examine and consider updating current consumer information on landscape water use. It also requires CDWR, following a public hearing every 3 years, to update MWELO or determine that an update is not needed and consider revising and updating the WUCOLS database.

UC continues policy role, advances science

UC continues to play a major role in providing objective information to policymakers as they formulate and update legislation on water conservation in commercial and residential landscapes. UC also continues to advance the science to conserve water and help ensure that legislative targets are met. Due to continued improvements in the efficiency of sprinkler and drip irrigation systems (which can decrease water loss), ETAF was further reduced in 2015 from 0.7 to 0.55 for residential landscapes (a reduction of 21%) and from 0.7 to 0.45 for commercial landscapes (a reduction of 35%). Conservation on this scale will rely heavily on implementing best practices that decrease water loss, identifying new species of drought-resistant landscape plants and improving irrigation system performance. In practice, many irrigation systems fall far short of the irrigation efficiencies (0.81 for drip devices and 0.75 for overhead sprinkler devices) used in the current MWELO.

Bijoor et al. (2014) found that smart irrigation systems were more effective at reducing water loss than irrigation systems operated by conventional timers and that the difference exceeded water savings realized from selecting a warm-season (more water-conserving) turf species over a cool-season species. Reid and Oki (2016) continue to screen a wide variety of landscape plants for their drought resistance to expand the palette of California-friendly landscape plants. Work by their team has already led to the identification of hundreds of drought-resistant plants included in MWELO.

Top, UCCE advisor Karrie Reid (center) with Green Gardener training participants in San Joaquin County. *Bottom*, a catchment can test measures irrigation system precipitation rate and distribution uniformity. Performing regular irrigation audits is a best practice recommended by UC researchers involved in water conservation research and extension.

UC ANR Specialist Amir Haghverdi is leading a project to further define water requirements of turf under deficit irrigation and reclaimed water regimes; evaluate the performance of soil moisture–sensing and ET-based smart landscape irrigation technologies on water use effectiveness under deficit irrigation; and monitor turf responses to multiple levels of water stress using multispectral (measures reflectance over a wide range of wavelengths) and thermal remote-sensing techniques.

David Fujino and the Western Center for Agricultural Equipment established the SmartLandscape project at UC Davis in collaboration with more than 20 organizations and companies. SmartLandscape provides workshops and on-site training for landscapers and students on new water-saving technologies. Several UC faculty, specialists and advisors (Alison Berry, A. James Downer, Janet Hartin, Darren Haver, Karrie Reid and Igor Lacan) are involved in various projects throughout the state alone and in cooperation with the U.S. Forest Service and other groups to determine the long-term durability of a wide variety of underused landscape trees under warmer, drier conditions due to climate change (Hanak and Lund 2012) and urban heat islands. CA

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RESEARCH ARTICLE

Stream flow modeling tools inform environmental water policy in California

The models have been used to assess patterns of stream flow modification, inform California's Cannabis Cultivation Policy and highlight shortcomings in the state's water accounting.

by Theodore E. Grantham, Julie K. H. Zimmerman, Jennifer K. Carah and Jeanette K. Howard

Over the past century, California has built an extraordinarily complex water management system with hundreds of dams and a vast distribution network that spans the state. This system generates electricity, provides flood protection, delivers reliable water supplies to 40 million people and supports one of the most productive agricultural regions in the world. Yet development of the state's water management system has come at a price. Damming waterways, diverting water from rivers and streams and altering natural flow patterns have transformed the state's freshwater ecosystems, leading to habitat degradation, declines of freshwater species and loss of services that river ecosystems provide, including high-quality drinking water, fishing and recreational opportunities, and cultural and aesthetic values.

The state aims to accommodate human water needs while maintaining sufficient stream flow for the environment. To support this mission, scientists from the U.S. Geological Survey (USGS), The Nature Conservancy (TNC) and UC have developed new techniques and tools that are advancing sustainable water

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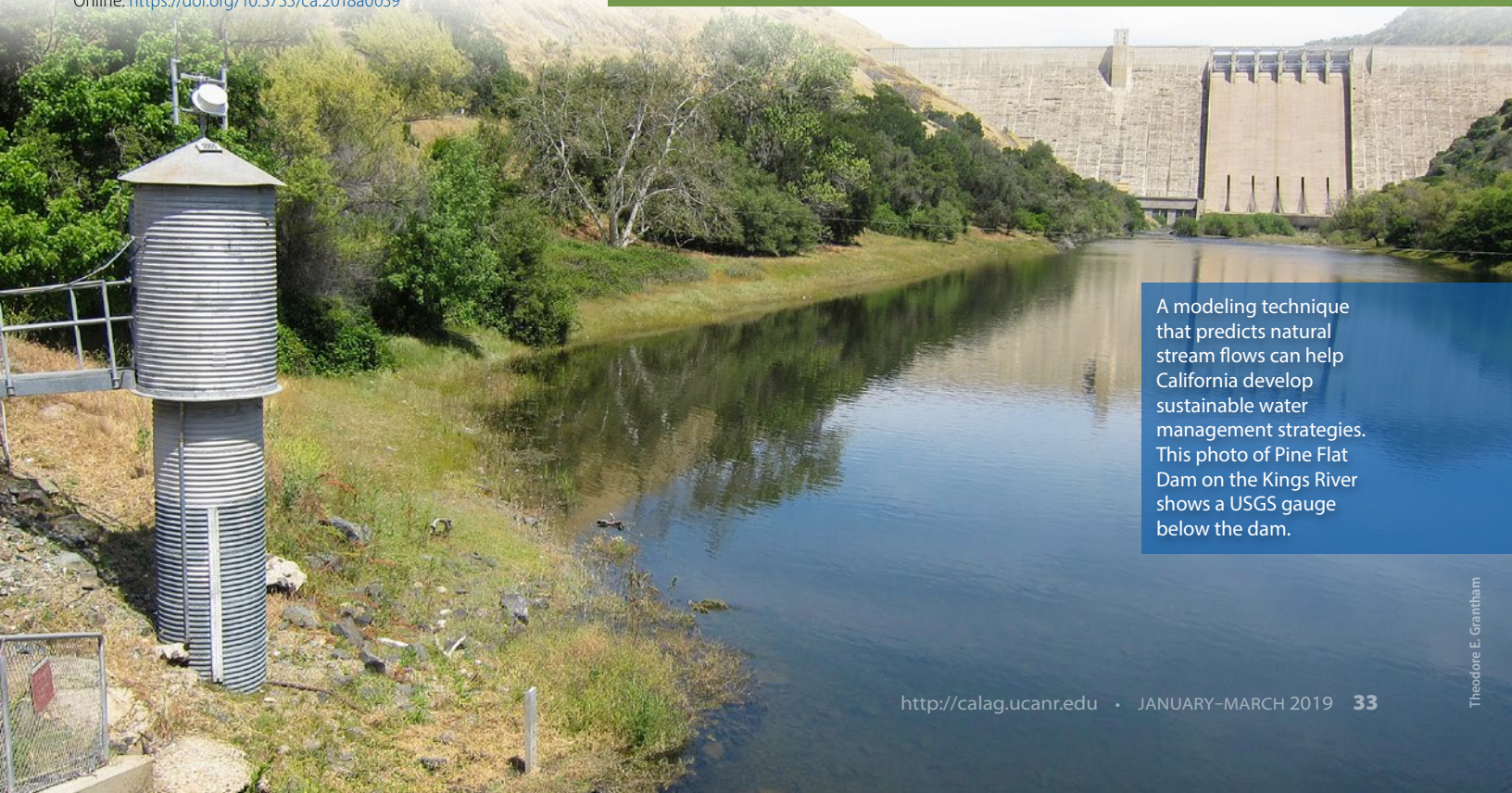
Abstract

Management of California's vast water distribution network, involving hundreds of dams and diversions from rivers and streams, provides water to 40 million people and supports a globally prominent agricultural sector, but it has come at a price to local freshwater ecosystems. An essential first step in developing policies that effectively balance human and ecosystem needs is understanding natural stream flow patterns and the role stream flow plays in supporting ecosystem health. We have developed a machine-learning modeling technique that predicts natural stream flows in California's rivers and streams. The technique has been used to assess patterns of stream flow modification, evaluate statewide water rights allocations and establish environmental flow thresholds below which water diversions are prohibited. Our work has informed the statewide Cannabis Cultivation Policy and influenced decision-making in more subtle ways, such as by highlighting shortcomings in the state's water accounting system and building support for needed reforms. Tools and techniques that make use of long-term environmental monitoring data and modern computing power — such as the models described here — can help inform policies seeking to protect the environment while satisfying the demands of California's growing population.



A modeling technique that predicts natural stream flows can help California develop sustainable water management strategies. This photo of Pine Flat Dam on the Kings River shows a USGS gauge below the dam.

Theodore E. Grantham

management in California. At the center of these new advances is the need to understand the natural ebbs and flows in the state's rivers and streams.

Natural patterns in stream flow are characterized by seasonal and annual variation in timing (when certain flows occur), magnitude (how much flow), duration (how long flows of certain levels persist) and frequency (how often flows of certain levels occur). California's native freshwater species are highly adapted to these seasonally dynamic changes in stream flows. For example, salmon migration is triggered by pulses of stream flow that follow winter's first storms, reproduction of foothill yellow-legged frogs is synchronized with the predictable spring snowmelt in the Sierra Nevada, and many native fish breed on seasonally inundated floodplains, where juveniles take advantage of productive, slow-moving waters to feed and grow.

When rivers are modified by dams, diversions and other activities, flows no longer behave in ways that support native species, contributing to population declines and ultimate extinction. Thus, understanding natural stream flow patterns and the role they play in supporting ecosystem health is an essential first step for developing management strategies that balance human and ecosystem needs.

Unfortunately, our ability to assess alteration of natural stream flow patterns, and the ecosystem consequences, is hindered by the absence of stream flow data. California's stream flow gauging network offers only a limited perspective on how much water is moving through our state's rivers. In fact, it's been estimated that 86% of California's significant rivers and streams are poorly gauged and nearly half of the state's historic gauges have been taken offline due to lack of funding (TNC 2018a). Of those gauges that are still in operation, most are located on rivers that are highly modified by human activities and gauge records prior to impacts are limited. These limitations can be partially overcome with modeling approaches to predict the attributes of natural stream flow expected in the absence of human influence. The predictions can then be compared to measured stream flow at gauging locations, or they can be used to estimate natural flow conditions in ungauged streams.

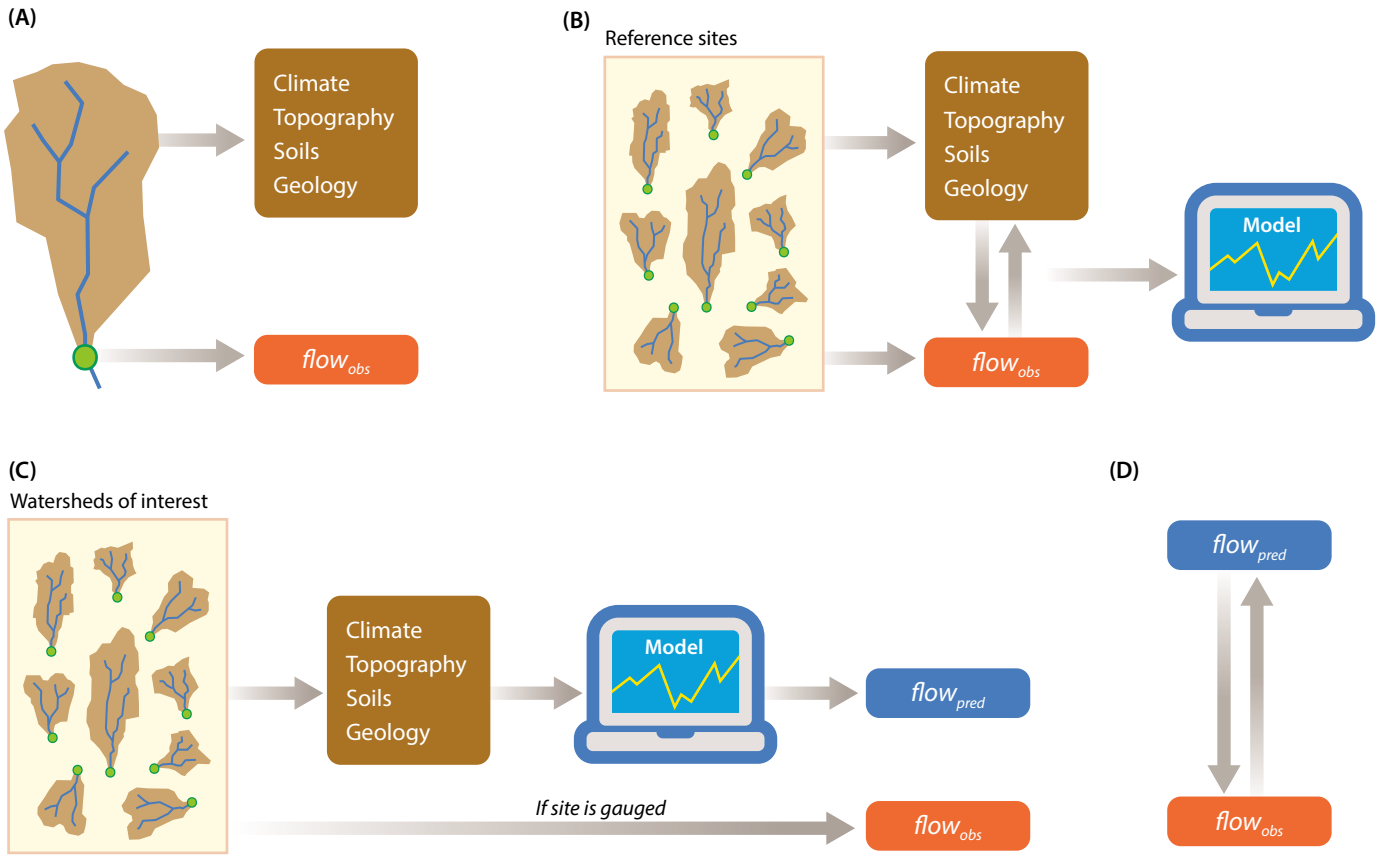


FIG. 1. Our flow modeling approach: (A) Reference flow gauges, located on streams with minimal upstream human influence, are identified and flow observations ($flow_{obs}$) and information on physical watershed characteristics compiled in a database. (B) Models are then developed that relate physical watershed characteristics to observed flows (e.g., September mean monthly flow), using data from all reference gauges in the region. (C) Once the models are "trained," they can be used to make predictions of expected natural flows ($flow_{pred}$) at any location for which the same watershed variables are calculated. (D) If predictions are made at altered (nonreference) gauged sites, comparisons between observed values and predicted values can be made to estimate the degree to which flows have been altered from natural expected conditions.

Developing stream flow models

In 2010, Carlisle et al. (2010) developed a modeling technique to predict natural attributes (such as magnitude, duration, frequency, timing and variability) of stream flow and assessed stream flow alteration at gauges throughout the United States (Carlisle et al. 2011). Soon after, UC and TNC scientists began using the approach to expand and further refine the technique for applications in California (e.g., Grantham et al. 2014; Zimmerman et al. 2018).

The models have evolved over time, but all rely on stream flow monitoring data from USGS gauges located on streams with minimal influence from upstream human activities. These are referred to as reference gauges. Some reference gauge data come from historical measurements made before significant modification of flows occurred, such as the years prior to the building of a dam. The remaining data are from reference gauges located in California watersheds that remain minimally altered by human influence.

Once reference gauges were identified and flow records obtained from the USGS web-based retrieval system, we used geographic information systems to characterize the watersheds above each reference gauge based on their physical attributes, such as topography, geology and soils (Falcone et al. 2010). We also assembled monthly precipitation and temperature climate data for the past 65 years for each watershed.

The watershed variables and climate data were then compiled and statistically evaluated in relation to observed flow conditions at the reference sites using a machine-learning approach (Cutler et al. 2007) that uses the power of modern computers to search for predictive relationships in large data sets. An advantage of machine-learning techniques is the ability to make predictions from multiple model iterations (i.e., alternate versions of the model trained with different subsets of the data), which tends to increase accuracy. Once we had developed and evaluated models using observed stream flow data from reference gauges, we could predict stream flow attributes for any portion of a stream or river in California for which the climate and watershed characteristics were known (fig. 1). Additional technical details of the modeling approach are provided in Carlisle et al. 2016 and Zimmerman et al. 2018.

Patterns of stream flow modification

In a study led by Zimmerman et al. (2018), we applied the machine-learning technique to assess patterns of stream flow modification in California. We did this by predicting natural monthly flows at 540 streams throughout California with long-term USGS gauging stations and comparing those predictions with observed conditions. We then assessed how observed flow conditions at the gauges deviated from predictions and recorded the frequency and degree to which flows were either higher (inflated) or lower (depleted) than natural expected levels, while considering the uncertainty of model predictions.

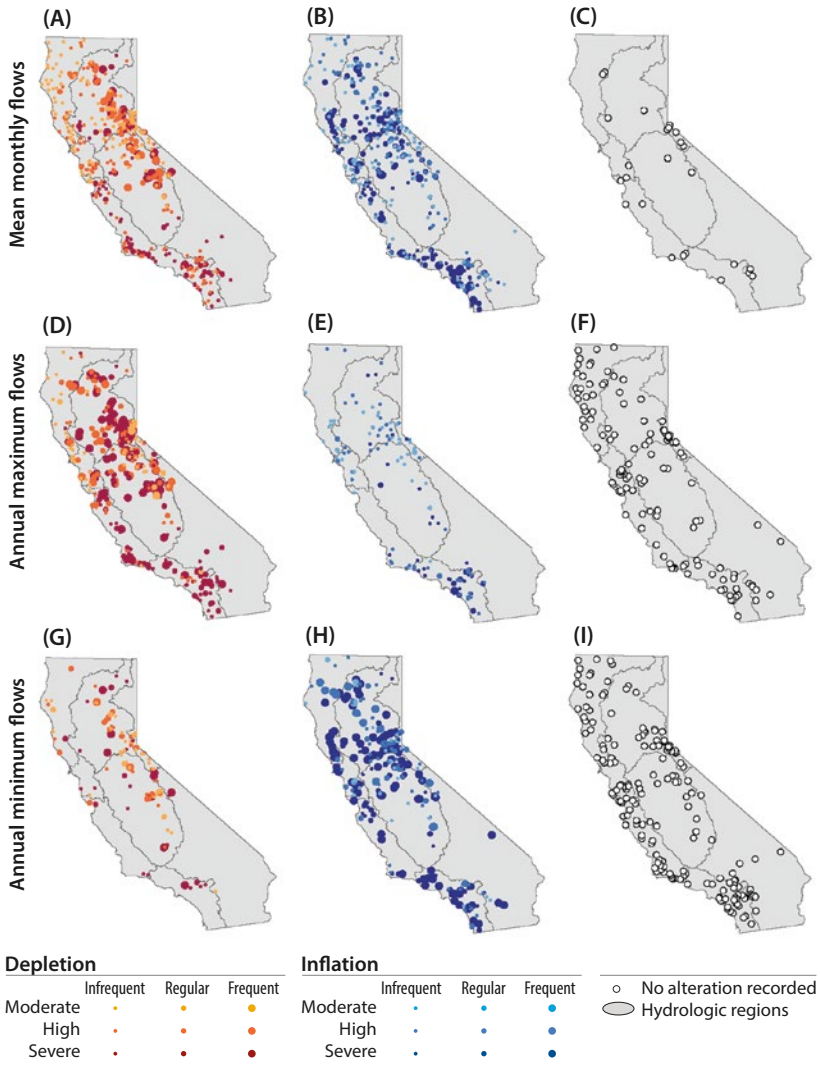


FIG. 2. Patterns of flow alteration magnitude and frequency for mean monthly (A–C), annual maximum (D–F) and annual minimum (G–I) flows. Alteration frequency is shown by symbol size and magnitude by color intensity for flow depletion (A, D, G) and inflation (B, E, H). Gauge locations with no alteration recorded are also shown (C, F, I). Reproduced from Zimmerman et al. (2018).

We found evidence of widespread stream flow modification in California (fig. 2). The vast majority (95%) of sites experienced at least 1 month of modified flows over the past 20 years and many sites (11%) were modified most of the time (≥ 66% of months over the period of record). When stream flows were modified, the magnitude of modification tended to be high. On average, inflated stream flows were 10 times higher than natural expected levels, whereas depleted stream flows were 20% of natural expected levels.

Overall, stream flow modification in California reflects a loss of natural seasonal variability by shifting water from the wet season to the dry season and from wet areas of the state to the drier south. Stream flow inflation was most common in dry summer months and for annual minimum flows. Conversely, flow depletion was most common in winter and spring months and for annual maximum flows. Unaltered sites tended to occur in places with relatively low population density

and water management infrastructure, such as the North Coast, whereas greater magnitude and frequency of alteration was seen in rivers that feed the massive water infrastructure in the Central Valley and the populated Central Coast and South Coast regions.

A key water management goal in California is to manage river flows to support native freshwater biodiversity. By estimating natural river flows and the degree to which they are modified, our work provides a foundation for assessing "ecological flow" needs, or the river flows necessary to sustain ecological functions, species and habitats. Assessments of ecological flow needs are generally performed at stream reach to regional scales (Poff et al. 2010), but rarely for an area as large and geographically complex as California.

In 2017, a technical team that includes scientists from UC, TNC, USGS, California Trout, Southern California Coastal Water Research Project and Utah State University began developing a statewide approach for assessing ecological flows. The team has identified a set of ecologically relevant stream flow attributes for California streams that reflect knowledge of specific flow requirements for key freshwater species and habitats (Yarnell et al. 2015). Our modeling technique (previously used to predict monthly and annual minimum and maximum flows) is now being extended to predict natural expectations for these new stream flow attributes.

Model predictions of the natural range of variability for these ecologically relevant stream flow attributes will provide the basis for setting initial ecological flow criteria for all streams and rivers in California by the State Water Resources Control Board (SWRCB) and other natural resource agencies. These ecological flow criteria will be based on unimpaired hydrologic conditions, but they can be refined in locations where management and ecological objectives require a more detailed approach. For example, refined approaches would likely be required in rivers that must be managed for species listed under the Endangered Species Act or in rivers where substantial flow and physical habitat alteration makes reference hydrology less relevant for setting ecological flow criteria, such as in the Central Valley or in populated watersheds of coastal California.

Our technical team also was involved in establishing the California Environmental Flows Workgroup of the California Water Quality Monitoring Council (State of California 2018). The mission of the Workgroup is to advance the science of ecological flows assessment and to provide guidance to natural resource management agencies charged with balancing environmental water needs with consumptive uses. The Workgroup is comprised of representatives from state and federal agencies, tribes, and nongovernmental organizations involved in the management of ecological flows. It serves as a forum to facilitate communication between science and policy development and to provide a common vision for the use of tools and science-based information to support decision-making in the evaluation of ecological flow needs and allocation of water for the environment.

Water accounting reforms

The modeling technique described above has also been used to evaluate statewide water allocations. Grantham and Viers (2014) analyzed California's water rights database to evaluate where and to what extent water has been allocated to human uses relative to natural supplies. They calculated the maximum annual volume of water that could be legally diverted according to the face value of all appropriative water rights in the SWRCB's water rights database. Water rights were distributed according to their location of diversion, and the permitted diversion volumes were aggregated at the watershed scale to estimate a maximum water demand for each of the state's watersheds. These permitted


Carson Jeffres

By estimating natural river flows and the degree to which they are modified, the authors' modeling technique enables scientists to assess "ecological flow" needs, or the river flows necessary to sustain ecological functions, species and habitats. This includes the amount needed to maintain adult salmon passage and spawning and winter rearing conditions for juvenile salmon.

water diversion volumes were compared with modeled predictions of average annual supplies to estimate the degree of appropriation of surface water resources throughout the state (fig. 3).

The study found that appropriative water rights exceed average supplies in more than half of the state's large river basins, including most of the major watersheds draining to the Central Valley, such as the Sacramento, Feather, Yuba, American, Mokelumne, Tuolumne, Merced and Kern rivers. In the San Joaquin River, appropriative water rights were eight times the volume of estimated natural water supplies (Grantham and Viers 2014). The volume of water rights allocations would be much higher if pre-1914 and riparian water rights had been included, but these data were not available at the time. The analysis also revealed that water rights allocations poorly represent actual water use by water rights holders. For example, comparisons of allocations with water use suggest that in most of California only a fraction of claimed water is being used.

In a well-functioning water rights system where allocations are closely tracked and verified, an excess of water rights relative to supplies is not necessarily a problem. During water shortages, holders of junior appropriative rights would be required to curtail their water use. When water is abundant, most water rights holders should be able to fully exercise their claims. Uncertainty in when, how and where water is being used, however, threatens the security of water rights — particularly when water is substantially overallocated relative to natural supplies. During the 2012–2016 drought, for example, the SWRCB issued notices of curtailment to water rights holders to protect endangered fish species within priority watersheds. Less controversial targeted cutbacks to individuals might have been sufficient if the agency had more accurate information on how water rights were being exercised.

As the 2012–2016 drought progressed, flaws in the state's accounting system for tracking water rights became more apparent. This study, together with other policy reports (e.g., Escriva-Bou et al. 2016), articulated the need for water accounting reforms, raised public awareness and helped to mobilize support for new legislation in 2015 (Senate Bill 88), which significantly increased water-use monitoring and reporting requirements for water rights holders. The new regulations also extended reporting requirements to senior water rights holders (pre-1914 appropriative and riparian water rights holders), which are among the largest individual water users in the state.

Flow thresholds for cannabis water diversions

The legalization of recreational cannabis in 2016 with passage of State Proposition 64 prompted state agencies to develop new policies to regulate the production, distribution and use of the plant. For example, California Senate Bill 837 directed the SWRCB to establish a new regulatory program to address potential water quality and quantity issues related to cannabis cultivation.

The subsequently enacted California Water Code Section 13149 in 2016 obliged the SWRCB, in consultation with the California Department of Fish and Wildlife, to develop both interim and long-term principles and guidelines for water diversion and water quality in cannabis cultivation. As a result, in 2017, the SWRCB adopted the Cannabis Cultivation Policy: Principles and Guidelines for Cannabis Cultivation (SWRCB 2017). The Cannabis Cultivation Policy's goal is to provide a framework to regulate the diversion of water and waste discharge associated with cannabis cultivation such that it does not negatively affect freshwater habitats and water quality.

A key element of the Cannabis Cultivation Policy is the establishment of environmental flow thresholds, below which diversions for cannabis irrigation are prohibited (fig. 4). During the dry season (April 1 to Oct. 31), no surface water diversions are permitted for

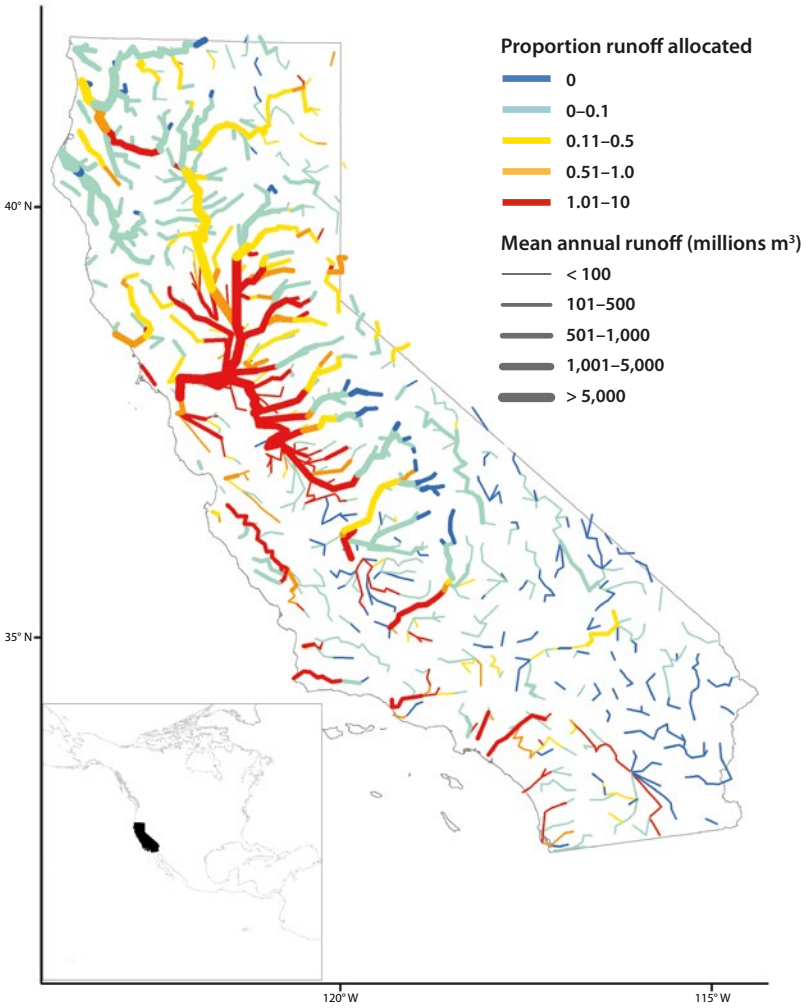


FIG. 3. Cumulative volumetric allocations of water rights relative to mean annual runoff for all major watersheds in California. The width of the lines corresponds to the mean annual runoff (in millions of cubic meters). Reproduced from Grantham and Viers (2014).

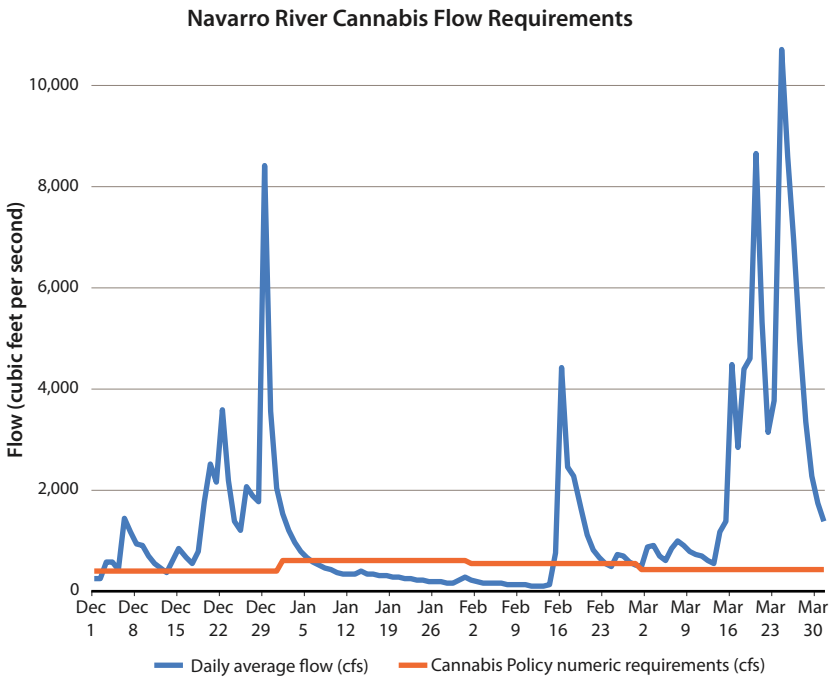


FIG. 4. Daily average flow, in cubic feet per second, for 2011 for the Navarro River at a USGS gauge (USGS 11468000 Navarro R NR Navarro CA) plotted against the Cannabis Cultivation Policy numeric requirements for diversion. For dates where there are flows above the orange line (e.g., March 1 to 31), diversion would be allowed. For dates where there are no flows above the orange line (e.g., Jan. 6 to Feb. 14), no diversion for cannabis cultivation would be allowed, to protect flows for salmonid passage, spawning and rearing.

The SWRCB's Cannabis Cultivation Policy establishes regulations and guidelines for water use by cannabis farms, including the timing, volume and rate of water diversions from rivers and streams. Environmental flow thresholds are based on the modeled predictions of natural flows at the nearest USGS gauge.

cannabis cultivation. Diversions from surface water sources to off-stream storage are allowed between Nov. 1 and March 31. However, water may only be extracted from streams when flow exceeds the amount needed to maintain adult salmon passage and spawning and winter rearing conditions for juvenile salmon. Environmental flow requirements for the winter diversion season were determined by an approach known as the Tessmann Method (Tessmann 1979), which uses proportions of historical mean annual and mean monthly natural flows to set protective thresholds.

Because flows are not measured continuously in most streams in California (TNC 2018a), including at most points of diversion, the Cannabis Cultivation Policy instead relies on using the predictions of natural flows from the models described above. Predicted natural mean monthly and annual flows are used by the SWRCB at compliance gauge points to calculate the Tessmann thresholds. Cannabis cultivators seeking a Cannabis Small Irrigation Use Registration permit from the SWRCB are assigned a compliance gauge near their operation and can legally divert water only when flows recorded at the gauge meet or exceed the Tessmann thresholds during the diversion season (fig. 4).

Next steps

The motivation for developing natural stream flow models and data rests on the premise that rivers and streams can be managed to preserve features of natural stream flow patterns critical to biological systems while still providing benefits to human society (e.g., water supply and hydroelectric power) (Arthington et al. 2006; Poff et al. 2010). For any stream of interest, balancing the needs of humans and nature requires an understanding of its natural flows, whether observed conditions are modified relative to natural patterns and what degree of modification harms its health.

As noted in the examples above, this work has both direct and indirect implications for policy and decision-making. A database of natural stream flows developed by machine-learning models was used to help define cannabis policy to set minimum flow targets — a direct application of the technique. However, this work also influenced policy and decision-making in more subtle ways, including building awareness of shortcomings in the state's water rights accounting system. This form of engagement with government agencies and the broader public helps define the agenda early in the policy-making process (Jones 1984), although quantifying the degree to which our research contributed to policy

outcomes such as SB 88 is difficult. The future impact of our work on environmental flow management remains unclear, but early engagement with state and federal agencies through the Environmental Flows Workgroup suggests that our flow modeling tools and data will have an important role in future policy development.

Recognizing there are likely other applications for our modeling tools, we have been working to make the data available to the public. Model predictions have now been generated for every stream in California, including values of mean monthly, maximum and minimum monthly flows and confidence intervals for California's 139,912 stream segments in the National Hydrography Database (Horizon Systems 2015). The dataset is being hosted by The Nature Conservancy at rivers.codefornature.org, where it can be accessed and downloaded through an application programming interface (API). A more dynamic spatial mapping tool has been developed to explore the data in individual rivers, watersheds or regions. An online interactive visualization tool is also available that allows a user to select one or several stream gauges and generate the corresponding hydrograph of observed and expected monthly flows (TNC 2018b).

An immediate next step for this project is to expand the natural flows dataset to include predictions of additional stream flow attributes that are relevant to environmental water management. This will support the Environmental Flows Workgroup's goal of defining ecological flow criteria in all rivers and streams of the state and can help inform a variety of programs including, for example, water transactions and stream flow enhancement programs.

Other direct applications of the natural flows data may be in hydropower project relicensing, which requires consideration of environmental flow needs. In addition, under the Sustainable Groundwater Management Act (SGMA), groundwater sustainability agencies (GSAs) are required to avoid undesirable results including depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water. Because environmental flow criteria have not been established for most streams in California, GSAs are rightfully confused as to the standards they are expected to meet. Statewide environmental flow criteria may help to define management targets required for SGMA implementation.

Statewide environmental flow criteria may help to define management targets required for SGMA implementation.

Looking to the future, society will continue to face challenges in balancing environmental protections with the demands of a growing population. Tools that make use of long-term monitoring data and modern computing power, such as the models described here, can help inform policy and management intended to achieve this balance. CA

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RESEARCH ARTICLE

UC-industry-agency partnerships influence and help implement dairy water quality policy

More than 94% of dairy producers were in compliance with new regulations to protect water quality after a carefully staged, collaborative plan to support the transition to new practices.

by Deanne M. Meyer, Betsy M. Karle, Jennifer M. Heguy, David J. Lewis, Jeffery W. Stackhouse and D. Denise Mullinax

Abstract

For 50 years, UC Agriculture and Natural Resources (UC ANR) has contributed to dairy water quality policy in California and helped, with partner organizations, to implement it in the dairy industry. When conditional waivers for waste discharge requirements expired in 2003, UC ANR shared research and best professional practices as regional water quality control boards developed new orders. UC ANR academics then worked with water quality control boards' staff and dairy industry representatives to develop feasible, staged implementation plans. Collaboratively, more than 50 hours of workshop curriculum were developed and disseminated, helping dairy producers to accept scientifically sound management practices that are more protective of groundwater. Research by UC ANR to better understand system dynamics, nitrogen management and practices to minimize the impact of manure application on groundwater quality continues, as does a program in environmental stewardship.

Passage of the Porter-Cologne Act, California's water quality regulation, in 1969 and the addition of point source regulations to the federal Clean Water Act in 1972 created a path to reduce the impacts of livestock operations on water quality. Water is an important resource for Californians. In the dairy industry, water is used directly for animal consumption, milk harvesting hygiene and sanitation, milk cooling, animal cooling and also for on-site forage production. Two important ways in which dairies conserve water are the use of manure-based fertilizers for on-site forage production, and the use of feeds that are byproducts of human food production (almond hulls, distillers grains, cottonseed, etc.). The human edible outputs from the industry are milk and meat. The industry also produces solid manure and process wastewater (very dilute manure), which require management to minimize the potential impact to surface water and groundwater sources.

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Manure management practices based on UC ANR research and delivered through educational workshops have helped hundreds of California dairy farmers comply with regulations designed to protect water quality.

Steve Quirt

In the 1970s, the State Water Resources Control Board (SWRCB) worked to incorporate the 1972 Clean Water Act requirements for concentrated animal feeding operations into the Porter-Cologne Act. The SWRCB requested information from UC Agriculture and Natural Resources (UC ANR) on manure generation on dairies and best practices for manure management. Since that time, UC ANR has worked collaboratively with the SWRCB, regional water quality control boards, industry organizations and dairy owners, providing research and educational programs to generate science-based policy and guide its implementation.

Contributing science to regulatory framework

UC ANR's earliest work with the SWRCB, on identifying better practices for manure management, was used during the decade leading up to development of statewide regulations adopted in 1984 (previously Chapter 15: §2560-2565, now located in Chapter 7, subchapter 2, Article 1 §22560-22565) (California Code of Regulations). Technical information was provided on soil qualities important for dairy pond structure (§ 22562) and the importance of having manure storage structures contain at least 10% clay and not more than 10% gravel or other impermeable material. Also, technical information was provided on manure nutrient use in crop production systems (§ 22563): "The application of manure to crop lands shall be at rates reasonable for the crop, soil, climate, special local situations, management system, and type of manure."

In response to the statewide regulations adopted in 1984, regional water quality control boards were tasked with developing Conditional Waiver of Waste Discharge Requirements (CWWDR) or Waste Discharge Requirements (WDR). WDR were developed with or without the federal Clean Water Act National Pollutant Discharge Elimination System permits, depending on local needs. Beginning in the late 1970s, UC ANR advisors convened local groups of dairy owners and operators to discuss the implications of the new regulations, identify alternative manure management practices and engage in local monitoring to benchmark and document progress.

The state's regulatory process for issuing water quality permits changed in 2003 with the passage of Senate Bill 293, which mandated a sunset to the existing CWWDR. In practice, this required that each regional water quality control board reissue its conditional waivers on a 5-year cycle or issue WDR. Both processes required intensive public input.

As change agents, UC ANR (UC Cooperative Extension) advisors and specialists were actively engaged with stakeholders to provide science-based information to staff at regional water quality control boards as they developed and adopted WDR for dairies. Technical questions arose prior to and during the policy development process. Research findings and best professional understandings provided by UC ANR academics informed policymakers during the 2-year process of drafting the Central Valley (RB5) Dairy General Order (CVRWQCB 2007; CVRWQCB 2013). UC ANR also provided scientific input during development of dairy regulatory processes by the North Coast (RB1) (NCRWQCB 2012) and San Francisco Bay (RB2) (SFBRWQCB 2015) regional water quality control boards.

Building partnerships

The California Dairy Quality Assurance Program (CDQAP) Environmental Stewardship module was founded in 1997, a partnership between dairy industry groups; federal, state and regional government agencies; dairy science researchers and UC ANR. Its first project was to collaboratively establish a mechanism to certify dairies in environmental stewardship. It was proactive in addressing environmental concerns, setting up the voluntary certification project before the adoption of water quality regulations that targeted nitrogen management (CVRWQCB 2007; CVRWQCB 2013; NCRWQCB 2012; SFBRWQCB 2015). In addition to joint work between UC ANR and CDQAP, active participation from U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS), resource conservation districts and regional boards' staff members remains important to the success of the programs.

The project received a grant in 1999 from the U.S. Environmental Protection Agency in support of its goal to encourage dairy operators to adopt more environmentally sustainable management practices to manage manure and protect water quality. Practices needing attention included managing production areas prior to winter rains to maximize collection of rain runoff from solid manure containing areas, conditioning corrals to minimize erosion during rain events, evaluating liquid manure storage capacity, using water more efficiently and carefully timing application of nutrients to soil during growth of winter and summer crops to more closely match crop nitrogen needs. Enhanced management helps to prevent erosion and retain nitrogen nearer to crop root zone for use.

The requirements for becoming certified in environmental stewardship include attending a 6-hour UC ANR dairy environmental stewardship course (dairy water quality and dairy manure management). Also, the dairy operator or owner needs to document compliance with local, state and federal regulations pertaining to environmental stewardship and successfully complete an on-farm evaluation by an independent third party with no previous ties to the facility or affiliation with facility management. UC ANR academics were deeply involved in developing the on-farm evaluation

UC ANR has worked collaboratively with the SWRCB, regional water quality control boards, industry organizations and dairy owners, providing research and educational programs to generate science-based policy and guide its implementation.

tool to delineate compliance with water quality regulations and to evaluate probability of compliance based on infrastructure available for manure management and management capabilities. The evaluation checklist was finalized through a series of ten 3- to 5-hour meetings by staff from the SWRCB, regional water quality control boards, US EPA, California Department of Food and Agriculture, dairy industry representatives and UC ANR.

Central Valley Dairy GWDR

In 2000, the Central Valley Regional Water Quality Control Board (CVRWQCB) asked UC ANR to address technical questions posed by its staff on manure nitrogen distribution, atmospheric nitrogen losses, nitrogen application rates, phosphorus and potassium concentrations in manure, salts in dairy manure and the effects of applying manure to land (Chang et al. 2006). A committee of UC ANR experts on these subjects was convened. The findings of the committee's report, specifically that nitrogen application rates of 1.4 to 1.65 times the nitrogen removal rates in harvested crops are protective of groundwater quality, served as the foundation of the GWDR (for existing milk cow dairies [CVRWQCB 2007, 2013]) nitrogen application restriction developed in 2007.

Many of the experts on the committee also worked on the USDA NRCS Comprehensive Nutrient Management Plan guidance development process. This process brought together technical experts from UC ANR, dairy industry stakeholders and NRCS staff to develop guidance for many aspects of nutrient management involved with dairy operations. Together, the group worked with stakeholders and CVRWQCB staff to identify logical, methodical ways that producers could effectively implement changes to their operations to be more protective of groundwater quality and meet compliance needs.

In 2003, after the mandatory sunset of conditional waivers, the CVRWQCB began to develop dairy-specific GWDR for existing milk cow dairies through a series of stakeholder meetings. Included were concerned citizen groups, USDA NRCS state experts, UC ANR academics, dairy industry representatives and county regulatory agency staff.

The primary focus of the dairy GWDR was better management of all forms of nitrogen to minimize nitrate leaching through soil. Existing knowledge (in industry, UC ANR and USDA NRCS), findings from then-current research (from UC ANR) and identification of standard practices (from USDA NRCS, industry, UC ANR) were integrated to establish a staged implementation process for the dairy GWDR (CVRWQCB 2007).

The trust developed during the initial years of the environmental stewardship program was invaluable. Stakeholders who knew one another provided scientific input during numerous dairy stakeholder working group meetings with dairy program staff at CVRWQCB. UC ANR academics provided written and oral public comments and contributed research publications and findings during working group meetings. Once the dairy-specific GWDR program was finalized, the next hurdle was delivering it to the dairy industry in a way that would result in positive management change by dairy owners and operators. They were required to change from doing what they had been doing for decades to, for example, maintaining detailed water quality records and submitting annual reports. UC ANR collaborated with its partners in CDQAP to develop workshops for dairy operators and their consultants. UC ANR led the workshop curriculum development and dissemination processes.

UC ANR contributed research on the infiltration of nitrate-nitrogen into groundwater below fields farmed for forage crops to be fed to dairy cows (Harter et al. 2002; Harter, Davis et al. 2001; Harter, Mathews et al. 2001; Mathews et al. 2001). It was key to dairy producers making nitrogen management a priority.

The final 6-stage implementation plan for complying with the dairy-specific GWDR was a methodical approach to managing nitrogen applications. It consisted of (1) identifying current facility infrastructure and nitrogen application and water management capabilities; (2) evaluating sufficiency of existing infrastructure for more detailed needs of a future system; (3) determining a feasible implementation plan to get from current structures to future needs in a limited time frame (as defined in the GWDR); (4) completing retrofits as needed; (5) evaluating effectiveness and (6) making additional improvements.


David Lewis

To help dairy operators estimate manure storage pond capacity needs, workshop leaders set up office hours where they provided one-on-one assistance with site-specific calculations.

In fall 2005, UC ANR and CDQAP delivered a workshop in the Central Valley to dairy operators. The primary focus of this workshop was introducing pending changes in the regulatory process and providing an opportunity for each dairy facility owner to identify the facility is in operation and exists (a California Environmental Quality Act process).

In 2006, UC ANR published California Dairies: Protecting Water Quality, which summarized practical approaches and technologies to protect water quality and aid dairy producers in positioning their facilities to comply with the impending regulations (Ristow et al. 2006). For dairies with irrigated cropland, recommended management practices included assessing farm nitrogen balance and improving manure recordkeeping systems, upgrading liquid manure distribution systems to quantify application rates, exporting manure nitrogen off-site, increasing storage capacity by reducing the volume of water generated in the milking parlor, applying nitrogen (manure and nonmanure sources) at agronomic rates and modifying irrigation systems to improve water use efficiency and distribution uniformity.

UC ANR advisors and specialists worked with their CDQAP partners to create educational programming for Central Valley dairy operators under the jurisdiction of the regional board. Starting in 2007, the 3-hour workshops and outreach meetings held throughout the Central Valley, altogether more than 33 hours of curriculum, presented technical and agricultural science knowledge to help dairy operators and consultants start to implement the GWDR and information on its detailed regulations. When the dairy GWDR was adopted, the CDQAP environmental stewardship program was 7 years strong. Though farmers knew that change was coming, they were unprepared for the GWDR's 125 pages of regulatory text, and few understood the nuances of compliance.

The workshops were held at 6-month intervals beginning in fall 2007, after the GWDR was adopted, for the first 2 years and then annually. Grants from the California Dairy Research Foundation offset costs for workshop materials. Attendees were provided with UC publications on management practices to protect surface water quality (Long et al. 2005; Meyer and Robinson 2007) and to use flowmeters (Hansen and Schwankl 1998; Schwankl et al. 2003) to quantify water and nutrient use for dairy forage crops. An online series of nine presentations on irrigation water management specific to dairy and liquid manure was created for dairy operators (Schwankl 2008). A compliance assistance binder was created (CDQAP-RB5 2007).

In the compliance assistance materials created for dairy operators and consultants were board-approved sampling protocols required by the GWDR, which also specified proper laboratory methods for analysis of the samples. The protocols were developed by UC, based on UC science and best professional understandings (Miller et al. 2018; Miller et al. 2019). The protocols help dairy producers obtain representative soil, solid and liquid manure, plant tissue and irrigation water samples for precisely managing nutrient applications and nutrient removals from land where manure was applied (Campbell Matthews and Frate 2008; Davy et al. 2009; Frate and Campbell Matthews 2008; Harter and Meyer 2007; Meyer and Mullinax 2008; Meyer 2008; Meyer et al. 2008; Meyer and Price 2011; Mueller and Putnam 2009; Pettygrove and Campbell Matthews 2008). A laboratory methods manual following US EPA methods was developed and went through stringent review by laboratory managers from other land grant universities familiar with these materials and the need for quality assurance (Holstege et al. 2010).

Fewer workshops were needed as dairy operators became more familiar with the GWDR, but the need continued for technical assistance on the detailed field-by-field nutrient management plans required. These were to be prepared under the consultation of a certified crop advisor or technical services provider, and at the time, educational opportunities for these professionals did not address managing manure as a nutrient, so UC ANR again stepped up to fill the gap. UCCE specialists and advisors developed presentations on sample collection and handling, targeting nitrogen application to crop needs based on crop stage of production, and irrigation water management to reduce deep percolation of nitrate, as well as programs in backflow prevention related to potential cross contaminations on dairy operations.

The GWDR had a component related to mandatory groundwater monitoring. The Central Valley Dairy Representative Monitoring Program was developed to meet the groundwater monitoring requirements. Currently, many UC ANR specialists and advisors work with the Central Valley Dairy Representative Monitoring Program to provide technical advice on both the mandated groundwater monitoring program and the development of next-generation manure management practices more protective of groundwater. Ongoing development and dissemination of continuing education by CDQAP partners provides timely "news you can use" to dairy operators on manure management and water quality topics.

North Coast, Bay Area dairy orders

As the North Coast and San Francisco Bay Area regional boards approached the time to reissue conditional waivers for dairies, UC ANR and their partners in the CDQAP environmental stewardship program were engaged in the process, prior to the dairy orders being adopted in January 2012 and July 2015, respectively (NCRWQCB 2012; SFBRWQCB 2015). Once they were finalized, CDQAP organizations worked collaboratively to deliver workshops in Petaluma, Point Reyes, Ferndale and Rohnert Park to help dairy operators understand and meet compliance needs. These workshops, and also office hours, were held at least

Regulation of un-ionized ammonia, which is toxic to fish and other aquatic life, is particularly important in watersheds like Stemple Creek that have a documented history of supporting (*left*) steelhead trout (*Oncorhynchus mykiss*) and (*right*) California freshwater shrimp (*Syncaris pacifica*).

In Stemple Creek/Estero de San Antonio watershed, there has been a more than 95% reduction in un-ionized ammonia concentrations.

twice annually during the first 2 years. Annual meetings are now held prior to the submission deadline of annual reports.

Unique needs in the North Coast and San Francisco Bay regional water quality control board jurisdictions included concerns about waterborne pathogens and toxic un-ionized ammonia from dairy enterprises entering aquatic habitats. In the case of pathogens, indicator bacteria are used as water quality constituents to protect water quality for shellfish harvesting and recreation. Un-ionized ammonia can be acutely toxic to cold water fishery species, including coho and steelhead trout, which are listed as endangered and threatened, respectively, on the North Coast.

Drawing upon work of UC ANR academics, systems understanding of bacteria fate and transport on area dairy farms was provided (Lewis et al. 2005) with specific management practice recommendations to reduce pathogen delivery from pastures that receive manure (Lewis et al. 2010) and high-use areas (Lewis et al. 2009). Additionally, recommendations for residual dry matter levels (Bartolome et al. 2002) served as guidelines for managing more extensively grazed areas of dairy farms.

The Animal Resource Management Committee, founded more than 30 years ago and responsible for monitoring and improving water quality in streams adjacent to dairy and animal operations in Sonoma and Marin counties, provided key organizational capacity. Staff from regulatory agencies and resource management agencies, dairy producers and technical service providers continue to meet monthly during the winter storm season. They share and discuss water quality data collected by surface water group monitoring programs and any regulatory agencies and work with the agricultural network to address identified problems through water quality planning and conservation practice implementation.

In Stemple Creek/Estero de San Antonio watershed, one of the watersheds covered by the committee, there has been a more than 95% reduction in un-ionized ammonia concentrations (fig. 1). Un-ionized ammonia is regulated on a concentration basis to prevent acute and chronic toxicity in surface water. Regulation is particularly important in watersheds like Stemple Creek that have a documented history of supporting steelhead trout (*Oncorhynchus mykiss*) and California freshwater shrimp (*Syncaris pacifica*).

Manure is a source of un-ionized ammonia and its direct delivery to streams and rivers. Using collected data to inform management, practices were

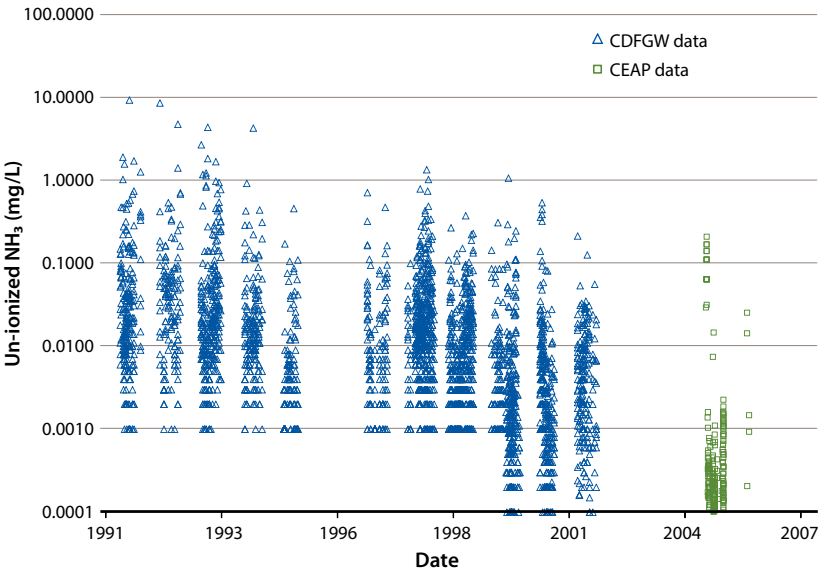


FIG. 1. Un-ionized ammonia concentrations in Stemple Creek watershed. Values are from unpublished data from the California Department of Fish Game (now California Department of Fish and Wildlife) sampling and analysis program from 1991 through 2001 and the Conservation Effects Assessment Program (CEAP) Study in 2005 and 2006 (Bingner et al. 2008). In 2000, a change in the analytical detection limit resulted in the reporting of lower limit values from that point on.

implemented on watershed dairies that resulted in un-ionized ammonia concentrations decreasing from maximum values of nearly 10 milligrams per liter to less than 1 milligram per liter. The decrease was sustained through years of high precipitation, such as 1998, with 72.81 inches of rainfall, and through low rainfall years, like 2001, with just 23.54 inches (fig. 2).

Once the dairy orders were adopted, CDQAP again used a collaborative process for record keeping and reporting template development, review and approval. Compliance assistance binders were created and populated throughout a series of educational workshops (CDQAP-RB1 2012; CDQAP-RB2 2015); content included the work of UC ANR academics in pasture-based systems to address the specialized needs of pasture-based systems to be protective of water quality (Bartolome et al. 2002; Lewis et al. 2005). UC ANR worked to develop and deploy the workshops with dairy industry stakeholders (trade association and creamery representatives) and staff from other organizations: the two regional water boards, USDA NRCS and local resource conservation districts. Grants from the California Dairy Research Foundation and USDA Risk Management Agency offset costs for workshop materials and delivery.

Impacts, lessons learned

The record-keeping templates for dairy operators were an important outcome of these efforts. They helped operators to meet the regulatory requirements for documentation of facility evaluations before and after major storm events as well as other facility management needs. They gave regulatory agency staff confidence that producers were maintaining records about required practices. Workshops were also a key component of the education and outreach strategy, providing up-to-date technical information and answering detailed site-specific questions. Some of the more unique questions were forwarded to the appropriate regional boards' staff and served as the basis for question and

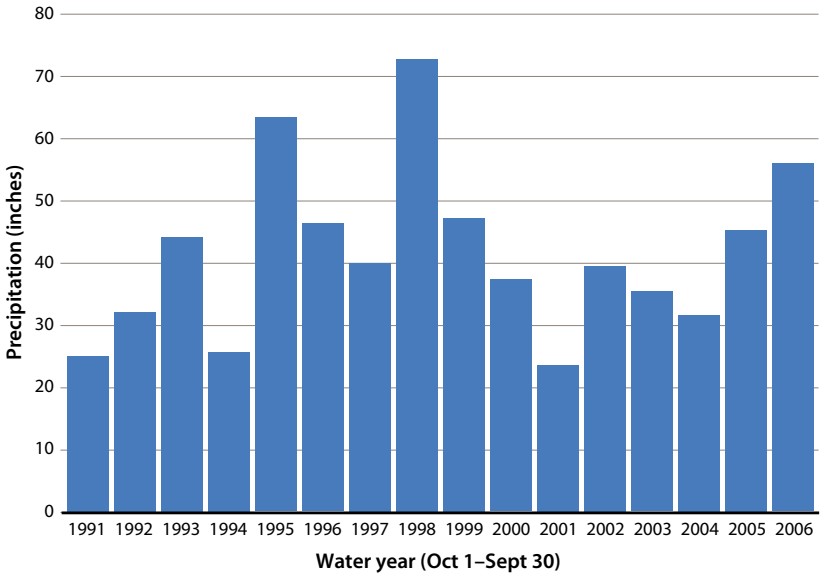
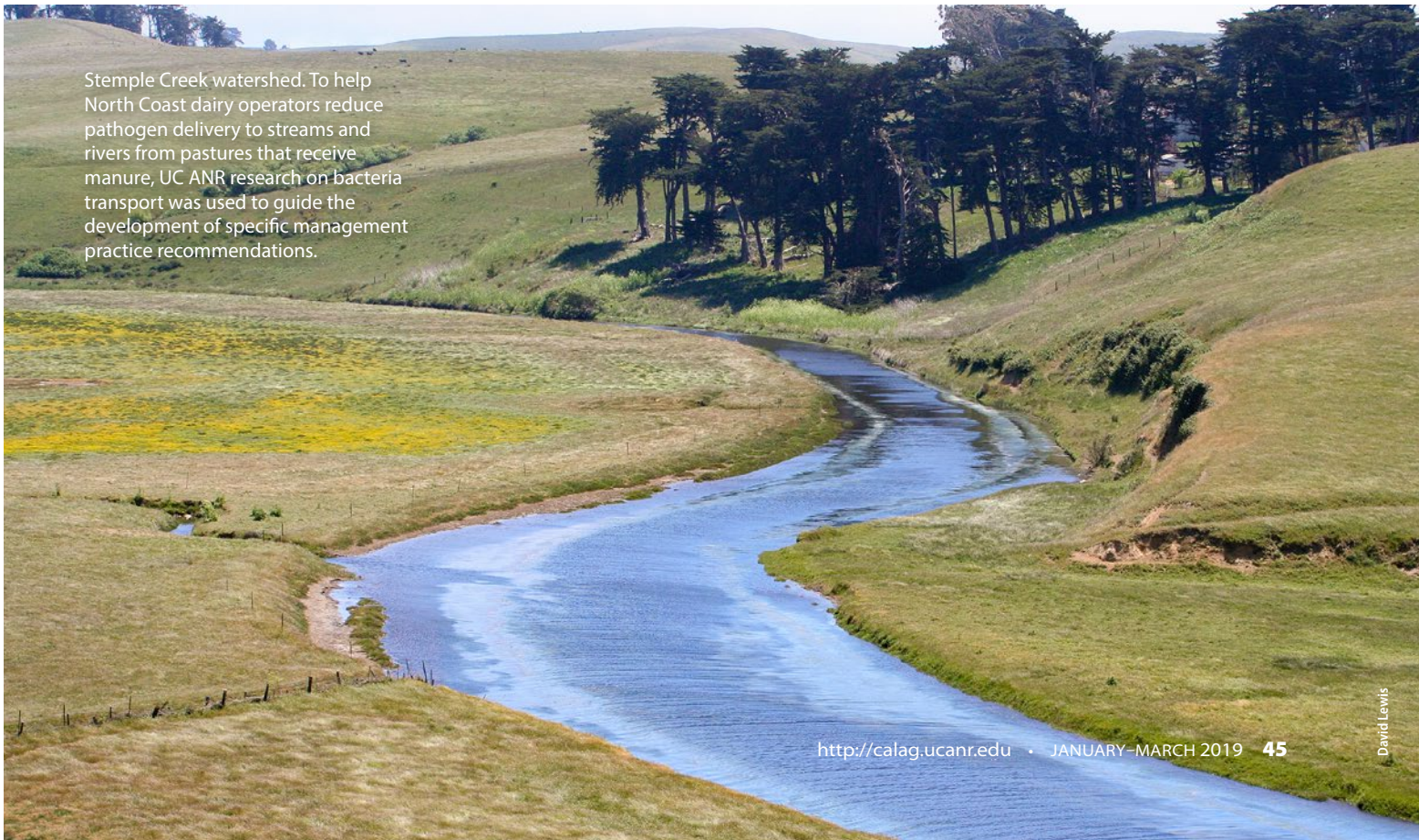


FIG. 2. Cumulative annual precipitation from 1991 through 2006 from Point Reyes Station, a coastal location approximately 10 miles south of Stemple Creek watershed, representative of the Point Reyes–Bodega Bay coastal region. Precipitation data are not from the studied Stemple Creek watershed because a continuous precipitation record is unavailable for that watershed.



Stemple Creek watershed. To help North Coast dairy operators reduce pathogen delivery to streams and rivers from pastures that receive manure, UC ANR research on bacteria transport was used to guide the development of specific management practice recommendations.

David Lewis

View across Tomales Bay to the east shore, where grass-covered hills provide pasture for area dairies. The bay and its watershed support shellfish production and harvesting and are habitat for a diversity of wildlife.

answer (Q&A) documents on the board website. Surveys conducted at the end of workshops showed that dairy operators appreciated the opportunity to learn about the regulatory process.

Of greatest importance to the regional board staff was the compliance rate. More than 94% of Central Valley operators and 95% of North Coast and San Francisco Bay producers submitted required documents at each of the submission deadlines. This was far more than anticipated. Central Valley GWDR covered more than 1,400 dairy operations, and thereby was the largest number of permittees ever adopted by RB5 under one GWDR. The North Coast CWWDR applied to 126 facilities and the San Francisco Bay CWWDR applied to fewer than 50 facilities (including sheep and goat dairies). This high compliance rate allowed board staff to conduct compliance inspections instead of tracking down paperwork and educating dairy operators one-on-one about compliance needs.

In the Central Valley, facilities certified in the CDQAP environmental stewardship program are inspected less frequently (every 5 years rather than every 3 years) by board staff because they are also evaluated by a CDQAP contractor. Facilities certified under a state- or county-approved quality assurance program receive a 50% WDR fee reduction (SWRCB 2016), a savings of up to $6,624 per dairy annually.

Early in the process the workshops for consultants were improved by including a presentation on the emotional aspects of change, because consultants were reporting that some of their clients were exhibiting various stages of grief (denial, anger, bargaining, depression). Feedback was unanimous that the presentation provided consultants with insight to better understand why dairy producers were reacting as they were to the regulatory changes.

Some workshops experienced bumps and provided the workshop leaders opportunities to regroup. After attempting a classroom delivery to estimate manure storage pond capacity needs, they quickly identified that an alternative approach was needed. Office hours were set up at local sites near dairy operators so producers could work through the needed, site-specific calculations with one-on-one assistance.

Delivery of educational workshops and scientific information to dairy farmers and their consultants was important for a greater understanding of regulatory requirements. UC ANR has worked with regulatory boards and hundreds of dairy farmers and dozens of consultants while navigating a multitude of production systems (from 20 to 10,000 cows, organic and conventional, pasture-based and confinement facilities) and regulatory environments (regional board requirements, county building requirements, county animal permitting requirements and air management districts regulations). As additional regulations take shape, UC ANR will continue to deliver scientific information and work with its partners to influence the state's water quality policy.

Improved dairy manure management practices to maintain or improve surface water or groundwater quality are achieved through incremental steps. UC ANR involvement at the local and state level has provided invaluable research into subjects critical to specific water quality needs. Analysis of management practices to improve nitrogen management, minimize nonpoint source impacts to surface waters, and evaluate manure treatment technologies takes time and much repetition to represent different geographic areas. On-farm and regional research is ongoing to better inform policymakers developing water quality policy. Change in management practices and ultimate improvements to surface water and groundwater quality comes when individual dairy operators modify practices. Through collaborative efforts, UCANR and CDQAP have been leaders in the development and delivery of award-winning outreach programs to improve environmental management and sustainability at dairies with owner/operator participation. CA

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Lawrence Berkeley National Laboratory scientists want to hear directly from growers and water suppliers about their experiences with the energy needed to pump groundwater. The grower survey can be accessed at https://gwenergy.lbl.gov/growers, and the water supplier survey at https://gwenergy.lbl.gov/id.