OCTOBER–DECEMBER 2016 • VOLUME 70 NUMBER 4

California Agriculture

Rangelands

Wild horses
Beef cattle markets
The cost of weeds
Selenium supplementation
Restoration with nonnative species

Also:
Groundwater
Incubating rural innovation

University of California | Peer-reviewed Research and News in Agricultural, Natural and Human Resources

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University *of* California
Agriculture and Natural Resources

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COVER: Cattle graze in Lassen County. Rangelands cover between 31 and 57 million acres in California, depending on how "rangeland" is defined. This issue features articles on auction markets for beef cattle, wild horses, selenium supplementation, rangeland weeds and restoration practices. *Photo by Will Suckow*.

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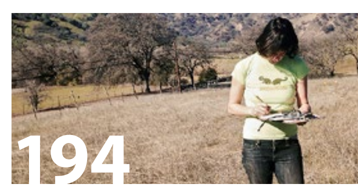
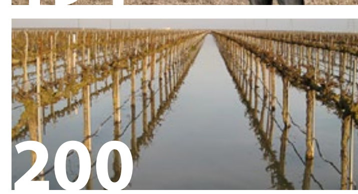




Unlocking the potential for innovation in rural California

Glenda Humiston, Vice President, UC Agriculture and Natural Resources

In my first editorial for *California Agriculture* one year ago, I made the case that UC ANR has for more than a century been in the business of what's known as "technology incubation" — providing infrastructure, tools and connections to help scientists and entrepreneurs turn innovative ideas into profitable, socially beneficial enterprises.

Glenda Humiston

Expanding ANR's role as an incubator in California is one of my top priorities as UC ANR vice president. It's also an area where the UC system and the state of California are investing more resources.

In May, Christine Gulbranson was hired as UC's first senior vice president of research innovation and entrepreneurship, reporting directly to UC President Napolitano. Gulbranson's position was created as part of the UC Innovation and Entrepreneurship Initiative, which received a major boost from the state in September when Gov. Jerry Brown signed Assembly Bill 2664, allocating $22 million to the expansion of infrastructure at UC campuses to support innovation and entrepreneurship.

These investments are being made because incubation has proven benefits. Probably the best example in the UC system is QB3, an incubator founded in 2000 with a focus on quantitative biosciences across three campuses — UC San Francisco, UC Berkeley and UC Santa Cruz. Under the guidance of founding director Regis Kelly, QB3 has helped to launch hundreds of companies that in turn have created thousands of jobs.

QB3's "Startup in a Box" and other services illustrate perfectly the many ways that a good incubator can support a new business — providing help with establishing the legal and financial structure of a new enterprise, managing intellectual property, pitching ideas to funders, applying for grants, connecting with other entrepreneurs and finding a physical space suitable for building a science-based business.

We want to use QB3 as a model. With that in mind, on August 30, Gulbranson and Kelly joined me and nearly 40 other leaders from agriculture, finance, business, government, technology and higher education for a daylong work session at the UC ANR building in Davis. Our goal was to develop an incubation strategy that capitalizes on UC ANR's unique strengths and serves unmet needs, providing QB3-type support where it isn't currently available.

At the meeting, we divided into eight-person groups, each with a mix of people from UC ANR, the UC campuses, state or federal government, funding institutions, incubators and industry. Our discussions focused on issues of innovation, geography, talent, stewardship and engagement. We used a set of questions as starting points: What exists now? Where are the gaps that need to be filled? Which of these gaps could UC ANR help to fill, either with partners or on its own? How could the work to fill the gaps be funded? And, how do we measure success?

It was a lively series of conversations. We recorded dozens of ideas for specific projects and other next steps. These are being synthesized into a public strategy document that we'll release in the coming months.

Two themes from the meeting stand out.

First, for UC ANR's incubation efforts to have meaningful impact, we need to find our niche, and that's likely to be in rural California. There's currently little or no incubator-type support in most areas outside of California's major urban centers — but there are definitely many innovative people and many market opportunities. UC ANR's unique network and long history of partnerships across California positions us very well to lead the development of a network of incubators to serve rural California. These incubators could also serve to help commercialize some of the many innovations developed within UC ANR each year. While the division runs on less than 1% of the UC budget, in recent years we have accounted for about 4% of all UC patent filings.

Second: partnerships — one of my guiding principles as the head of UC ANR — are going to be critical. We don't have the resources to build out a statewide incubation network on our own. Instead, we need to think of the division as a catalytic leader, working with like-minded partners to develop the needed infrastructure.

I'm excited about the progress we're making in this critically important area. It's already expanding our network of partners, and I believe that it will position us well to amplify the benefits we provide to Californians, empowering more people in more places to solve the state's most important problems.

Unanswered questions for implementation of the Sustainable Groundwater Management Act

Michael Kiparsky, Director, Wheeler Water Institute, Center for Law, Energy & the Environment, UC Berkeley School of Law

California is grappling with the implications of the Sustainable Groundwater Management Act (SGMA), a visionary and potentially revolutionary law that could profoundly change the way water is managed in the state.

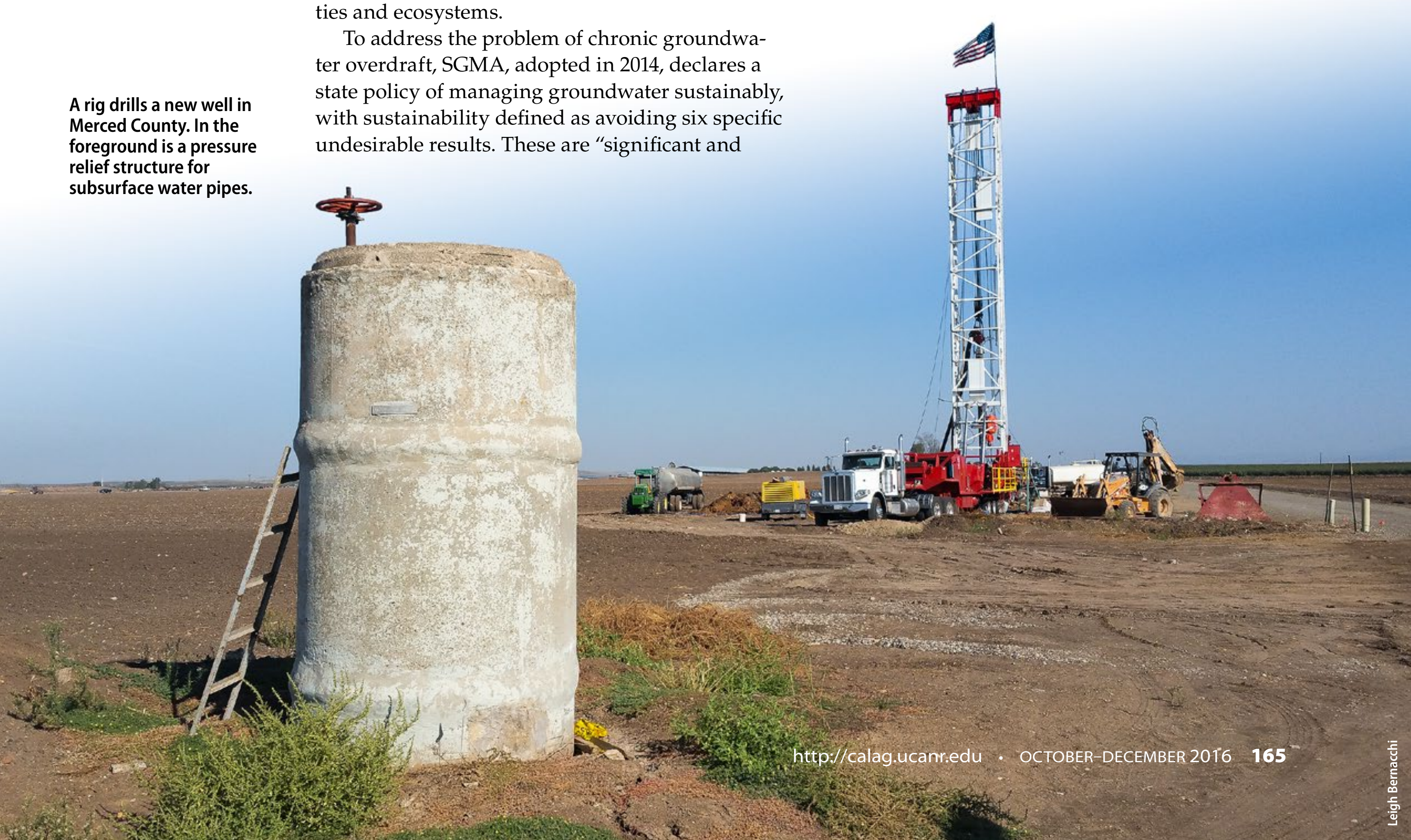
The nature of the revolution, however, is not yet clear. Whether and how SGMA achieves its goals hinges on open questions about its implementation.

Groundwater accounts for between one-third and two-thirds of California's water use in a given year and serves as a lifeline when surface water runs low during drought. In part because of California's historical lack of groundwater use regulation, this crucial resource is threatened. In some areas, declining groundwater levels have caused the land surface to subside at a rate of more than one inch per month, damaging roads, canals and pipelines. Falling water tables are driving a well-drilling race that threatens farms, communities and ecosystems.

To address the problem of chronic groundwater overdraft, SGMA, adopted in 2014, declares a state policy of managing groundwater sustainably, with sustainability defined as avoiding six specific undesirable results. These are "significant and unreasonable" (1) lowering of groundwater levels, (2) reduction in groundwater storage, (3) seawater intrusion, (4) water quality degradation, (5) land subsidence and (6) impacts on beneficial uses of interconnected surface waters.

In concept, this forward-thinking framing aligns the requirements of the law with the impacts of unsustainable groundwater use and the actions needed to address those impacts.

To accomplish these objectives, SGMA relies primarily on local control, with an enforcement backstop provided by the State Water Resources Control Board. New local entities called groundwater sustainability agencies (GSAs) will do the bulk of the work of implementing SGMA by developing, implementing and updating groundwater sustainability plans (GSPs). A GSP provides the template for achieving sustainable groundwater management in a GSA's jurisdiction within 20 years. GSAs must be formed by 2017 and GSPs completed by 2020 or 2022.



A rig drills a new well in Merced County. In the foreground is a pressure relief structure for subsurface water pipes.

Leigh Bernacchi

Given this framework, much about how SGMA will be implemented has yet to be determined. In the next few years, decisions about these details will be made that will have major implications for whether SGMA succeeds in achieving groundwater sustainability.

We may not know for decades whether and where sustainability has been achieved. Among many questions about SGMA's implementation, the following seven may help us consider important unknowns about California's water future under SGMA.

1. Governance

How will GSAs be structured? Decisions about governance and institutional design are being made now, so immediate attention to this question is imperative. In a recent report (Kiparsky et al. 2016), my collaborators and I developed nine criteria for fair and effective GSAs; three stand out at this juncture.

Scale is a crucial element. In most cases, the jurisdiction of a management agency would ideally match the scale of the resource being managed. But efforts to match jurisdictional scale to groundwater basins appear to be rare in the 127 groundwater basins affected by SGMA. Many basin maps could end up looking more like GSA patchwork quilts. In this experiment, transaction costs or ultimately even management effectiveness may be at stake.

Human capacity is also essential for GSAs. Funding, technical ability, legal expertise and management skills are essential for GSAs to be capable of handling the difficult tasks ahead of them. Two examples: To understand basin conditions and develop robust sustainability indicators and plans, managers will need in-house technical expertise, regardless of support lent by the state or consultants. Further, substantial administrative, policy and legal expertise will be required to develop funding for GSA activities through appropriate groundwater extraction fees, particularly given constitutional provisions such as Proposition 218 that circumscribe public agencies' authority to collect funds.

Finally, broad and meaningful *public participation and representation* are essential to the development of effective programs that account for the range of interests affected by a GSA's actions. In many areas, ensuring effective participation of stakeholder groups that would otherwise lack the resources to engage may require active support by the GSA, the state or third parties.

2. Translating sustainability goals into practice

How will the sustainability goals specified by SGMA translate, where necessary, into reductions in net groundwater extraction?

Broadly speaking, there are three approaches to changing the water balance in a groundwater basin:

- Groundwater users can reduce groundwater use;
- Groundwater users can replace some groundwater use with alternative supplies, such as imported surface water or recycled water; or
- Groundwater users or managers can recharge aquifer systems with stormwater, peak flood flows, recycled water or imported surface water.

Combinations of these strategies will vary, influenced by basin conditions, basin politics and other local factors.

In many areas, limitations on groundwater pumping will be required to avoid undesirable results.

A groundwater pump at the Russell Ranch Sustainable Agriculture Facility near UC Davis.

Will Suckow

A groundwater pumping system in Merced County.

Determining extraction caps and allocating them among competing interests will be both technically challenging and controversial. SGMA does not specify how much groundwater may be withdrawn in a given basin; rather, sustainable yield is defined in terms of avoidance of undesirable results, which are locally specific and will be defined in large part by GSAs. Politically, we can expect resistance from groundwater users accustomed to unfettered access to the resource. Defining effective and efficient pathways through technical controversies, stakeholder negotiations, public participation processes, financing issues and other inevitable challenges will test the skill of all involved.

3. Groundwater–surface water interactions

How will SGMA influence surface water, and vice versa? One of the most promising, and potentially most fraught, aspects of SGMA is that it calls out the interactions between groundwater and surface water. Although hydrologists and water managers have long recognized that surface flows and groundwater conditions are tightly linked, California water law reinforces artificial distinctions between the two.

Sustainable management under SGMA will include consideration of impacts on surface water (the sixth "undesirable result", above) in two ways. The first is avoiding significant and unreasonable harm to surface water rights holders — implying a need to maintain groundwater levels sufficient to support interconnected rivers and streams. The second is avoiding significant and unreasonable harm to groundwater-dependent ecosystems — rivers and streams, but also wetlands and springs.

The challenge for GSAs will be making decisions that are technically sound and ecologically meaningful, while balancing the tensions these choices may create among different users and uses of groundwater and surface water.

4. The role of markets

How can, and how should, market mechanisms be used as part of SGMA implementation? Where SGMA compliance requires reduced pumping, it will affect the economics of groundwater. Many water agencies already augment water supplies by buying water from within or outside their basins. SGMA explicitly authorizes groundwater transfers as one potential tool for achieving sustainability, but does not provide specific guidance about such transfers or the markets they imply.

Markets can be excellent tools for improving efficiency in that they can help redistribute water to higher-value uses. However, poorly designed markets also can create externalities (impacts to third parties or the environment). Further, poorly designed markets can exacerbate inequity, potentially raising legal concerns.

Whether effective and fair groundwater markets develop will depend on GSAs' ability to design and enforce appropriate market rules, as well as on unanswered questions about how groundwater rights law influences the development of extraction allocations and their transferability.

5. The role of data

What data will be collected and shared by GSAs? SGMA empowers, but does not require, GSAs to collect groundwater extraction data from individual wells, and it requires only aggregated extraction data to be shared and reported to the state. Even if GSAs conduct appropriate monitoring and modeling, regulators and stakeholders may have to view the groundwater system within each GSA boundary as a black box, obscuring coordination, public participation and effective oversight.

SGMA promises unprecedented collection of data in California. But even so, data does not lead automatically to better management. Some GSAs will choose to collect and share copious data. Others may not. GSAs and the state should ensure that sufficient data are collected, made public, and used to aid planning, management and oversight. Creating a common data framework that is at once flexible, transparent, and effective will be an essential, and non-trivial, first step.

6. The role of the State Water Board

When and how will the State Water Resources Control Board (Board) enter the SGMA process? SGMA makes local GSAs primarily responsible for sustainable groundwater management. Recognizing that some

GSAs might not achieve, or even robustly pursue, that goal, SGMA gives the Board a vital "backstop" enforcement role.

This is a whole new area for the Board, and we don't know how it will approach the role in practice.

Some of the Board's intervention points are clear now: for example, there are clear deadlines for GSAs to be in place in medium- and high-priority basins. Others are less so: SGMA does not specify exactly under what conditions intervention based on GSP inadequacy will be warranted, for instance. Strong engagement by the Board will be needed.

7. "Significant and unreasonable"

What does "significant and unreasonable" actually mean? The core of SGMA is preventing undesirable impacts, but these impacts are not unambiguously defined or quantified in the law or its attendant new regulations. Rather, GSAs themselves will define — implicitly or explicitly — what they think significant and unreasonable impacts are, based on the thresholds and measurable objectives they choose to adopt.

GSAs will need to navigate these and other value-based choices in defensible ways. Ultimately, unresolved conflicts could lead to litigation. Then, the courts may play a role in clarifying what impacts meet the threshold of "significant and unreasonable." Where this happens, it may represent a departure from the principle of local control that is so central to SGMA.

The role of innovation

This extensive list of questions is not meant to suggest that SGMA is unlikely to succeed. The questions are not unanswerable, much effort is already underway to address them, and there are good reasons for optimism.

SGMA incentivizes innovation, simply by regulating groundwater for the first time, and by doing so in a flexible way. Our work on innovation in the water sector suggests that progress requires more than just new technology (Kiparsky et al. 2013). It also requires surmounting institutional barriers to bring new ideas into broader practice.

Here are two emerging innovations that SGMA is already helping to catalyze.

The first is tapping the potential for groundwater recharge on farmlands using winter storm flows. In the same way that Apple assembled existing microprocessor, battery and display technologies and developed the iPhone, a number of researchers, including Helen Dahlke (UC Davis), Phil Bachand (Bachand & Associates) and others, are combining underutilized resources — winter flood flows, water conveyance infrastructure and off-season farmland — together to create something new (Bachand et al. 2013; Bachand et al. 2016; Harter and Dahlke 2014; O'Geen et al. 2015).

A second emerging concept is recharge net metering — an example of an innovation that builds on an idea from another sector. Photovoltaic net metering, widely used in the electricity sector, made it economically feasible for me to install solar panels on the roof of my house by allowing me to sell excess power the panels generate when the sun is shining and to buy electricity from the utility to use in the evening. The difference determines my annual electricity bill. In the Pajaro Valley, a partnership including Andy Fisher (UC Santa Cruz), the Resource Conservation District-Santa Cruz County and the Pajaro Valley Water Management Agency is working to develop an analogous scheme for aquifer recharge (PVWMA 2015). Landowners who invest in projects to infiltrate stormwater receive a credit against the fees they pay when pumping groundwater. What's exciting about this scheme is its potential to align the interests of landowners with the broader health of the aquifer and to provide another tool for addressing challenges in a common resource.

To be sure, a host of barriers remain to the diffusion of these innovations, including water quality, logistical, economic, legal and financing challenges. And neither is a magic bullet for groundwater management. But both illustrate how SGMA already is both forcing and enabling creative thinking.

This type of creative thinking will be critical for California to implement SGMA successfully and transform from a national laggard in groundwater management into an international leader. Thankfully, the state is rising to the occasion. State agencies are meeting milestones under extraordinary time pressure, and NGO, academic, and industry groups are producing timely analyses to point out problems and identify solutions.

As indicated here, the law presents significant challenges for both public and private sectors and requires tough decisions to be made under considerable uncertainty. Whether California can muster the leadership, scientific and engineering innovation, and administrative skill to meet these challenges will ultimately determine how revolutionary SGMA actually is. CA

This text is adapted from remarks in a keynote address (video: bit.ly/2bw63H0) to the 2nd International Groundwater and Agriculture Conference in June 2016 (ag-groundwater.org). Holly Doremus, Nell Green Nylen and Thomas Harter provided useful feedback. This work is a product of the UC Water Security and Sustainability Research Initiative (ucwater.org), supported by the UC Office of the President.

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The Sustainable Groundwater Management Act challenges the diversity of California farms

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Alyssa DeVincentis, Ph.D. student, Department of Land, Air and Water Resources, UC Davis
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Tomato field irrigated with well water. Russell Ranch, UC Davis.

Will Suckow

California's agricultural sector, a major groundwater user, finds itself in the midst of the implementation of the Sustainable Groundwater Management Act (SGMA).

The law mandates the formation of local groundwater sustainability agencies (GSAs) and adoption of groundwater sustainability plans (GSPs) for all overdrafted groundwater basins across the state by 2020. Each GSA will be unique, with its own governance structures and rules, including the size and composition of the governing board, mechanisms for representing different interests, opportunities for stakeholders to participate, and rules concerning the allocation of pumping "rights" and the use of economic instruments, such as pumping permits, pumping taxes or tiered pricing, to incentivize pumping curtailments (DWR 2016).

This new water management landscape may threaten the diversity of the state's farming operations

Farm diversity — in size, as a proxy for resources and capacity — has been shown to foster innovation, increase stability and resilience under changing climate conditions, and facilitate building knowledge and human capital to support future generations of farmers (Brummer 1998; Davidson 2016; Ericksen et al. 2009; Foley 2011).

Farms of all scales will be required to comply with SGMA and the management plans established by their local GSAs; however, farms of different scales have varying human and financial resources. As such, compliance with SGMA requirements is likely to be manageable for some growers but severely burdensome for others. Unless GSAs explicitly address this equity concern and consider all growers' water needs during the planning and implementation phases of SGMA, the law will threaten the future of the state's agricultural diversity.

Farm scale and SGMA

In April, the authors and other graduate students in the National Science Foundation Climate Change, Water and Society Integrated Graduate Education

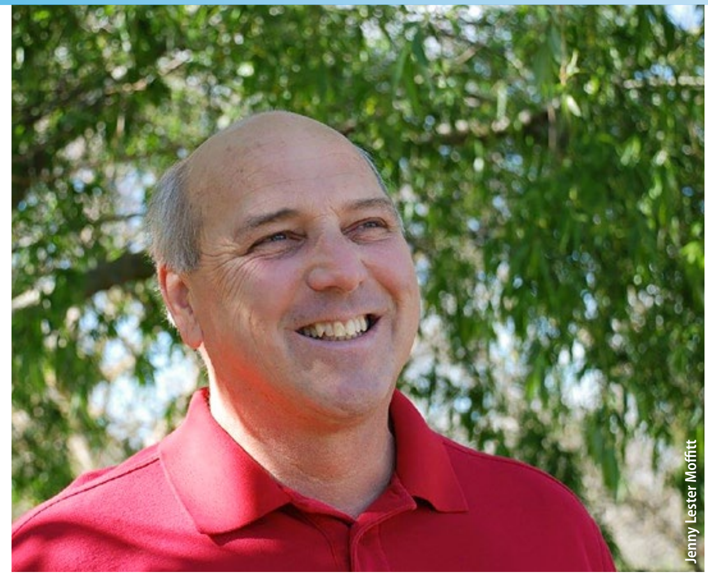
Research Traineeship Program hosted a conference — "Weathering Change" — at UC Davis to discuss the implications of SGMA for California. One panel featured three growers — Don Cameron, Russ Lester and Emma Torbert — who illustrate the breadth of farm scales across the state (figs. 1 and 2). Here, we summarize the perspectives they shared and explore the challenges they have already begun to experience in relation to the equitable implementation of SGMA, including: (i) producing and accessing pertinent surface-groundwater information, (ii) financing new infrastructure and (iii) representing varied water users and resource needs.

Don Cameron

General manager of 6,000-acre Terranova Ranch Inc. and chair of the state's Environmental Farming Act Science Advisory Panel, Don Cameron grows 26 crops near Fresno. Terranova Ranch receives some Kings river water through a mutual water company, but relies on groundwater for more than 95% of its irrigation, using 45 metered wells that are pumping from approximately 600 feet deep. Cameron has been a leader in water conservation for decades: he was an early adopter of drip irrigation technologies in the 1980s and is currently partnering with UC Agriculture and Natural Resources to experiment with groundwater recharge practices, including on-farm flood capture.

Don Cameron, Terranova Ranch Inc.

Cameron has been extensively involved in local SGMA planning, sometimes attending three GSA meetings a week. Even though this participation has placed significant strain on human resources, Cameron explained that having a voice in SGMA implementation is not only a responsibility for growers like himself, but a priority. He appreciates that smaller farmers are not able to spend the same time away from their fields, and explained that his region has attempted to build representation of agriculture and rural communities' diverse interests into their GSA boards. He said that he is optimistic that SGMA's mandate for development of new institutions and plans for reducing groundwater overdraft will initiate needed changes to protect groundwater resources well into the future, but acknowledges the challenges that lie ahead, particularly with respect to implementing and enforcing pumping restrictions.



Russ Lester, Dixon Ridge Farms

Russ Lester

Owner of 1,400-acre Dixon Ridge Farms in Solano County, Russ Lester grows organic walnuts, processing tomatoes, wheat and edible dry beans, and also operates one of the largest organic walnut processing and marketing operations in the state. Like many farmers in the Central Valley, he is shifting from annual to perennial crops, and is currently experimenting with wine grapes, almonds, olives and prune trees, which has hardened his water demand. Dixon Ridge Farms has riparian rights to surface water from local creeks, but approximately 90% of operations rely solely on groundwater. Lester is concerned that groundwater levels in his region are in jeopardy, experiencing well-level drops on his own properties in recent years. As a result, he has invested in deeper wells and installed monitoring meters on all new pumps.

Lester has been an active leader in speaking for the basin's heterogeneous agricultural interests (i.e., many crops, different water sources, variable groundwater conditions across the large basin) and is organizing some of the small to mid-sized growers in his region to work together to ensure that they have a collective voice in the Yolo and Solano county GSAs, particularly in determining how pumping restriction rules will be designed and enforced. He also stressed the need for assistance in developing good information on surface-groundwater interactions.

Emma Torbert

Co-manager of The Cloverleaf Farm, Emma Torbert grows 4 acres of organic fruit trees and mixed vegetables near Davis. Cloverleaf Farm has no surface water access and relies on a single 200-foot well for irrigation. Over the past 5 years, Torbert has experimented with reduced irrigation schedules in her orchard, cutting back water use by nearly 50%. She has also made infrastructure improvements, installing soil moisture probes, solar panels on well pumps, gray-water washing systems and landscaping fabric, with assistance from the State Water Efficiency and Enhancement Program (SWEEP).

Torbert is a leader in Yolo County's Farmer's Guild, the local branch of a statewide organization that brings small growers together to share sustainable best management practices and pool efforts to address shared challenges. She represents an early-career, small, organic grower, and reiterated many of Cameron and Lester's comments on the high economic and opportunity costs of participating directly in SGMA processes. She shared that she cannot afford to dedicate time away from her farm to participate in local GSA-planning discussions. She is hopeful that groups like the Farmer's Guild or California Certified Organic Farmers (CCOF) will coordinate small growers across the state to efficiently share the costs of participation and advocate for adequate representation of their groundwater needs throughout SGMA planning phases.

Emma Torbert, The Cloverleaf Farm

Challenges

Cameron, Lester and Torbert represent just a few of the many perspectives within the agricultural community, but they highlight important differences that will be felt across the state as operations of different sizes move forward with SGMA compliance. We focus here on concerns related to information dissemination, new expenses and political representation.

Producing and accessing information. Cameron, Lester and Torbert all emphasized the need for improved information.

One common desire is for a better understanding of how local surface and groundwater resources interact. Despite extensive monitoring efforts by the California Department of Water Resources throughout the state's 515 groundwater basins, groundwater flux and reserve information is not readily available to growers, particularly in basins that have been given a low priority designation. SGMA requires understanding these basins' withdrawals and reserves, and thus will likely require the development of a new fine-scale monitoring system, which may include well monitors on all public and private pumps.

Torbert expressed wanting specific instruction on when and how to participate in local SGMA decision-making processes. We hypothesize this is a common feeling shared among many small to mid-sized or politically unseasoned growers who have little to no experience participating in governance processes or defining resource management rules.

Bridging organizations that work in spaces between research, policy and implementation sectors often play an essential role in coordinating and sharing this type of information (Cash 2011). We suggest that UC Cooperative Extension, the Natural Resources Conservation Service, and resource conservation districts, and active agricultural and environmental nongovernmental organizations, fill this role, and by doing so, could assist in equalizing knowledge among growers, so that those less politically active are sufficiently informed to be able to participate if they choose. In fact, SGMA may provide a kick-start to improved communication both between individual growers and across institutions working within the agricultural sector to share knowledge and collaborate across scales around adapting to changing climate conditions.

New expenses. Farms of all scales will be required to meet similar groundwater sustainability goals. Compliance may result in increased pumping operational and capital costs (e.g., new or updated pumping infrastructure, monitoring and reporting, compliance fees, training and education). In addition, caps on pumping may drive the emergence of markets for trading pumping allowances among farms. While such trading should result in more efficient use of groundwater overall, it will increase costs for growers that need to buy pumping allowances.

These increased costs are expected to have greater relative impact on smaller growers. To mitigate these burdens, Cameron advocates for the state to assist in funding the systemic infrastructure and monitoring adaptations that are likely to be mandated by SGMA. Torbert pointed to opportunities to crowd-source funds through community engagement with local customers who like to support small-scale growers. Cost-sharing programs will be particularly important for small and mid-sized growers with less budget flexibility and limited ability to participate in state-funded conservation programs. These growers, particularly early-career farmers, face high entrance barriers to access land and equipment and are vulnerable to acquisition by larger operations, conditions that could be exacerbated by new economic challenges. In actuality, accessing funds to assist in SGMA compliance efforts is a palpable challenge that will generate debates amongst growers and is mostly likely to be addressed uniquely within each GSA (rather than by the state).

Representing varied resource needs. Small and mid-sized farms tend to face steeper barriers in terms of opportunity costs for staff to participate in policy planning forums. Thus, we can anticipate that farms with greater stocks of human, social and financial resources will be better prepared to play a prominent role in building new institutions and crafting collective rules of management practice within each GSA (Lubell 2002).

It is also important to note that participation in the GSA formation process does not necessarily translate into representation *per se*; attending a meeting does not guarantee voting rights or that one's priorities are discussed. Furthermore, differing access and control over resources influence stakeholders' positions in multi-stakeholder meetings and their capacity to actively engage in the decision-making process and influence group decisions (Bachrach et al. 1962; Lubell 2002; Swyngedouw 2015). As a result, power asymmetries among diverse stakeholders play an important role in the emergence of institutions like GSAs. The design of governance structures and the forms they take (e.g., allocation of pumping rights, rules of management practice) in turn shape institutional outcomes — including whose interests are considered and prioritized during GSP development and the nature and extent of groundwater management regulations on farms. Certain parts of the state with higher farm diversity (fig. 2) will need to accommodate wider ranges of needs in their GSPs, which we hypothesize will challenge balancing equitable participation, representation and distribution of resources. This suggests a strong need for small farmer communities to formally collaborate to have their voices heard at SGMA institutional processes.

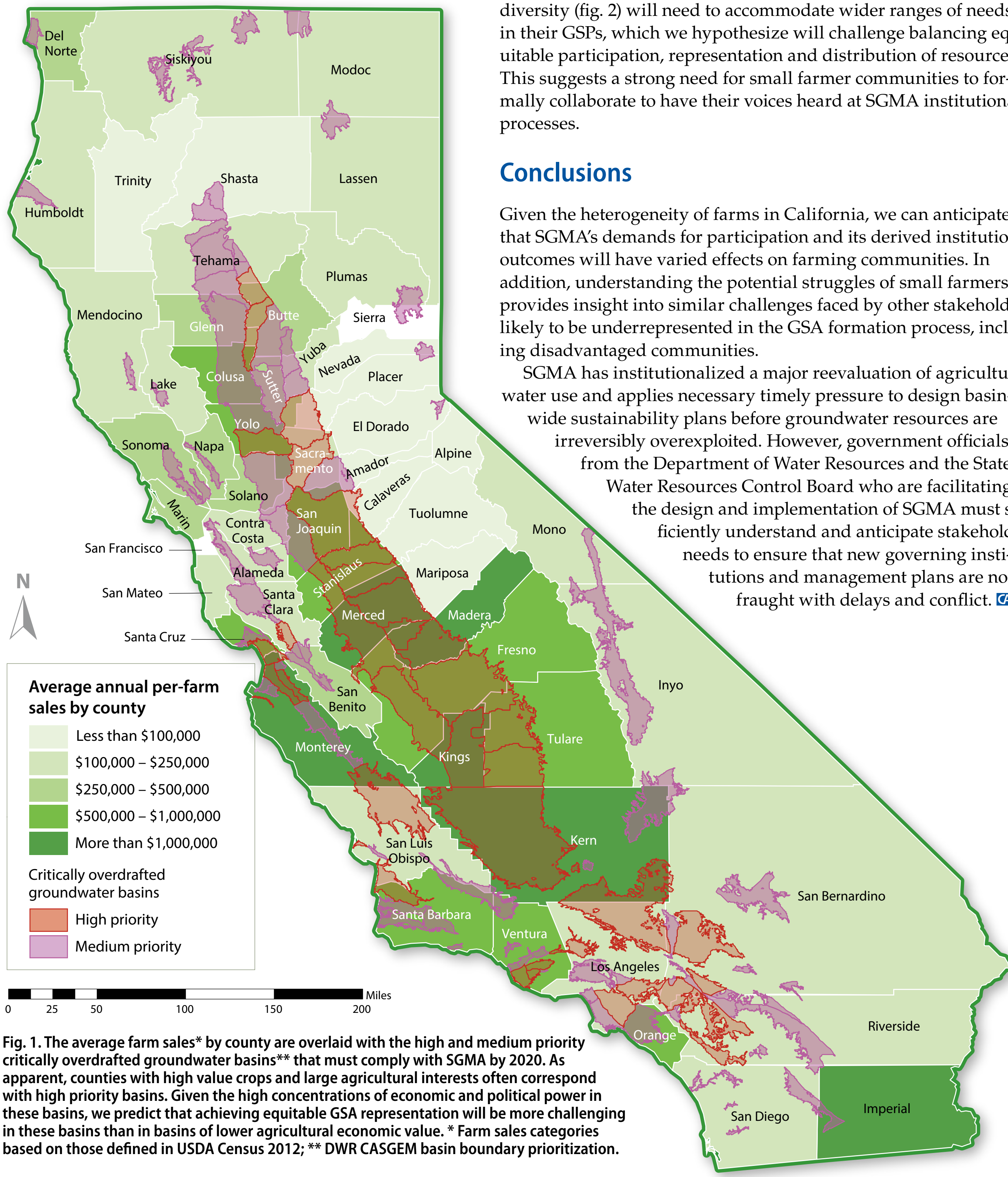


Fig. 1. The average farm sales* by county are overlaid with the high and medium priority critically overdrafted groundwater basins that must comply with SGMA by 2020. As apparent, counties with high value crops and large agricultural interests often correspond with high priority basins. Given the high concentrations of economic and political power in these basins, we predict that achieving equitable GSA representation will be more challenging in these basins than in basins of lower agricultural economic value. * Farm sales categories based on those defined in USDA Census 2012; ** DWR CASGEM basin boundary prioritization.**

Conclusions

Given the heterogeneity of farms in California, we can anticipate that SGMA's demands for participation and its derived institutional outcomes will have varied effects on farming communities. In addition, understanding the potential struggles of small farmers provides insight into similar challenges faced by other stakeholders likely to be underrepresented in the GSA formation process, including disadvantaged communities.

SGMA has institutionalized a major reevaluation of agricultural water use and applies necessary timely pressure to design basin-wide sustainability plans before groundwater resources are irreversibly overexploited. However, government officials from the Department of Water Resources and the State Water Resources Control Board who are facilitating the design and implementation of SGMA must sufficiently understand and anticipate stakeholder needs to ensure that new governing institutions and management plans are not fraught with delays and conflict. CA

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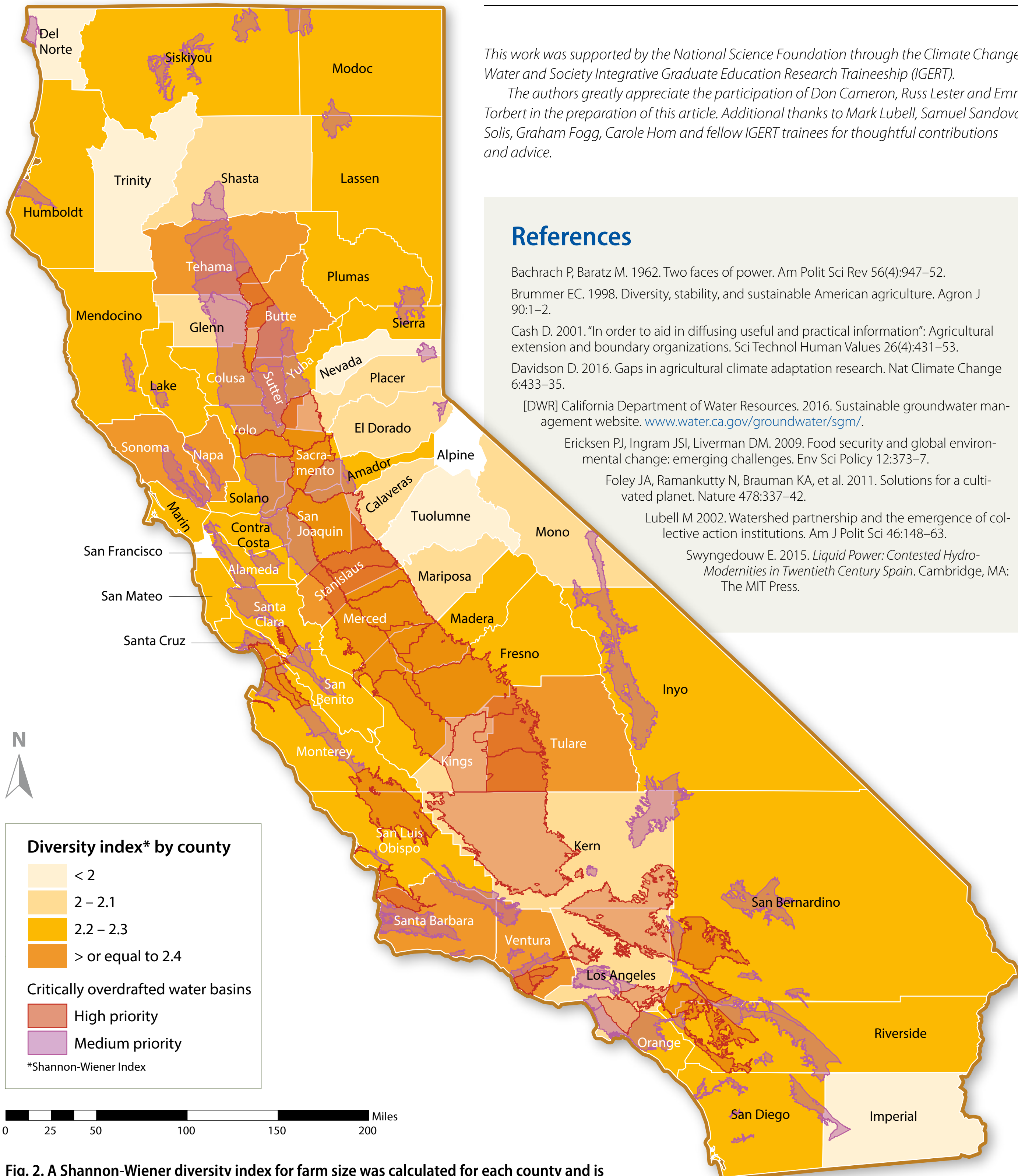

Fig. 2. A Shannon-Wiener diversity index for farm size was calculated for each county and is overlaid with high and medium priority critically overdrafted groundwater basins*. The diversity index is calculated based on the number of farm size categories present in each county and the distribution of individual farms within each size category, where greater diversity scores correspond to more even distributions of farms of different sizes. We predict that equitable representation of agricultural interests in GSAs will be even more difficult in basins with greater farm diversity. Pre-existing agencies could aid in this process by providing established leaders, management plans, or monitoring systems, but the legacy of organized water management controlled by these agencies may further challenge representation of new and diverse agricultural water users. * DWR CASGEM basin boundary prioritization; **Farm size categories based on those defined in USDA Census 2012.**

Sierra Foothill REC: Quantifying IPM benefits in rangeland systems

There's a strong scientific case that integrated pest management strategies for rangeland weeds are effective — yet adoption of these practices on rangeland is extremely low. How come?

One likely reason, says Jeremy James, director of Sierra Foothill Research and Extension Center (SFREC), is that it's unclear whether investing in reducing weed populations makes financial sense.


Elena Zhukova

Medusahead (in green, above) is an aggressive invasive annual grass that is unpalatable to livestock for most of its life cycle.

"We have a good idea that invasive plants have negative ecological impacts — but what we surprisingly do not know is if there is actually any economic cost of having weeds on rangelands," James said.

A national assessment of rangeland integrated pest management strategies like targeted grazing, seeding of desirable plants, prescribed fire and the use of selective herbicides found abundant evidence that these practices work (Sheley et al. 2011). However, the same study also found that that these practices are little-used — in part because of the difficulty of assessing their economic benefit.

The 13 test paddocks (nine of which are shown here) enclose 5 acres each and are infested with medusahead to varying degrees — from 11% to 50% coverage.

To better understand the economic case for weed management, James and a team of researchers — including Tehama County livestock, range and natural resources advisor Josh Davy, Stanislaus County range and natural resources advisor Theresa Becchetti, Shasta County livestock, range and natural resources advisor Larry Forero and UC Davis Plant Science professor Emilio Laca — are running a series of experiments at SFREC.

Beginning in 2013, the team manipulated pastures to have different degrees of weediness, measured by the percentage of land infested with medusahead, a common rangeland weed. After 3 years, they had developed a series of 13 experimental 5-acre paddocks, with medusahead coverage ranging from 11% to 50%.

This spring, the researchers stocked the pastures with steers from March through May and evaluated how weight gain varied with weed coverage.

Results from this first season of tests indicate that weight gain does indeed suffer as weediness increases: for every 10% increase in weed cover, total weight gain was reduced by roughly 30 pounds per acre — a reduction in market value of $30 to $50 per acre at current prices.

"For beef cattle production, those numbers are right in the middle of being something that might pencil out to treat," said James. "They're not going to cause ranchers to go out of business, but at the same time they're not negligible."

The study is scheduled to continue for at least another 2 years. The team will replicate the spring grazing study and also assess the effects of weeds at other times of year, James said.

The project is part of a collection of studies funded by the U.S. Department of Agriculture that aims to quantify the value of the many ecosystem services that rangelands can provide. Some of these, like the effect of weeds on cattle weight gain, can be directly quantified in economic terms. Others — such as the provision of habitat to support biodiversity or the benefits that healthy soil can provide for groundwater infiltration — may be more difficult to value but may still be desirable for ranchers to support. The overall goal of the project, James said, is to document the full suite of benefits that investments in rangeland management can deliver. CA

— *Jim Downing*

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Laura Snell: Studying the wild horses of northeastern California

This September, the U.S. Forest Service (USFS), in partnership with Modoc County and the U.S. Bureau of Land Management (BLM), conducted the first major roundup of wild horses on Devil's Garden Plateau since 2006. The state's largest population of wild horses is found here, on a high-desert expanse of Modoc National Forest surrounded by private ranchland and tribal lands. A survey in February estimated 2,246 horses here, far above the target of 206 to 402 adult wild horses established by the 2013 management plan for the 230,000 acres of designated wild horse territory on the plateau.

Through 2006, the Devil's Garden horse population had long been stabilized at a few hundred adults through regular roundups, called gathers, which removed horses from the range every year or two. Since then, a combination of legal challenges to federal wild horse management plans and difficulty securing funding stopped large gathers. That allowed the population to balloon, with horses stressing grazing allotments on USFS land and straying onto private and tribal lands.

As the horse herds and their impacts on rangelands have grown, it has ratcheted up tensions among ranchers, wild horse advocates, hunters, recreational users and local officials — and the federal land managers charged with adjudicating the use of the Devil's Garden rangelands.

"This is the most controversial research I've ever been involved in," said livestock and natural resources advisor Laura Snell, who joined UC Cooperative Extension (UCCE) in 2015. "I had Modoc County ranchers coming up to me on my second day of work asking me how to solve the wild horse issue."

In partnership with USFS range management specialists, UCCE Lassen County director David Lile and UC Davis–based UCCE specialist Roger Baldwin, Snell is collecting new photographic data on a key area of dispute in the wild horses debate: the impact horses have on rangeland vegetation and soils, especially around water sources, and on other wildlife.

"We can't just take vegetation data, we need the visuals to show people what's going on," she said.

The study, begun in 2015 and scheduled to continue at least through 2017, uses wildlife cameras placed for two-week periods at 24 remote water

UCCE Modoc County advisor Laura Snell and USFS rangeland management specialist Jenny Jayo mount a wildlife monitoring camera at Bottle Springs, a water source in Modoc National Forest.

Will Suckow

Wild horse impacts near Bottle Springs, Modoc National Forest.

Laura Snell and her dog Zuri.

sources in wild horse territory in Modoc and Lassen counties. At each site, the camera takes a burst of three pictures automatically every 15 minutes; motion detectors on the cameras also trigger a shot whenever an animal enters the field of view.

On a monitoring trip this summer, Snell and her dog Zuri hiked with USFS range management specialist Jenny Jayo over the rocky terrain to a site called Bottle Springs. They strapped a camera to a makeshift tripod of fallen juniper branches and made notes on the vegetation in the area around the spring, which was deeply rutted with hoofprints.

Bottle Springs is in a part of the plateau used particularly heavily by the horses. The grazing allotment in this part of Devil's Garden previously supported cow-calf pairs, but in recent years cattle have not been allowed at all due to the horses' impacts on the land, especially in riparian areas. A key difference between cattle and wild horses, Snell noted, is that the location and timing of cattle grazing in a given area is controlled by ranchers and USFS range managers, while horses are on the land year-round with no controls.

Collectively, the field cameras generate more than 100,000 images in each sampling period. These are processed by UC ANR staffer Stacy Schneider at the Lassen-Shasta-Modoc UCCE office in the town of MacArthur. Preliminary data from 2015 shows some striking findings. At one spring site, for instance, more than 71% of all animals detected over the sampling period were horses. Cattle accounted for 19% of the detections; the remainder were pronghorn, deer and hawks. Those figures, and the images that go along with them, provide strong evidence that deteriorating range conditions in the area are due to horses rather than cattle or other species.

One lesson of the years-long planning process that led to the September gather, said Sean Curtis, a Modoc County natural resources manager who helped coordinate it, is that strong scientific support for an ecological need to remove horses from the range is critical to making a case for a gather than can stand up to appeals. That's one important way in which data from Snell's study could be used.

"I think if enough people saw what was going on out here they would understand that unmanaged grazing is bad for rangelands," she said.

A native of Iowa, Snell joined UC ANR in 2015, from a research position at the University of Nebraska, where she also attended college and graduate

Cameras placed in the field capture images every 15 minutes during daylight hours, as well as when a motion detector senses an animal nearby. Data from the hundreds of thousands of photographs can then be fed into what are known as occupancy models, which provide robust estimates of the true number of animals of each species that visit the site.

A wild stallion on Devil's Garden Plateau.

Laura Snell near another monitoring site.

school. For her master's thesis, she studied multi-use grazing in Namibia.

One thing that attracted her to UCCE, Snell said, was the chance to have an academic job based in a rural community, with the prospect of remaining in the same county for her entire career.

The wild horse issue certainly appears to be one that will demand attention for years to come in Modoc County and other communities across the West.

A 1971 federal law mandates that wild horses and burros be "protected, managed and controlled" on public lands by the BLM to allow for coexistence with wildlife and livestock. But with few natural predators, unmanaged wild horse populations can grow 20% per year — leading quickly to conflicts with the other uses of the land that the government is obliged to protect. Today, the combined number of wild horses and burros — about 55,000 and 12,000, respectively — is two and a half times the "appropriate management level" established by the federal government. Wild horses in the West are not native — genetic studies indicate that they are descended from released or abandoned domestic horses (NRC 2013).

Many horse advocacy groups push for a hands-off approach, arguing that the populations should be allowed to expand until limited by factors like predation and food supply — though a number of groups also support measures to reduce fertility. Ranchers, hunting groups and some wildlife advocates, on the other hand, argue that the horses need to be physically removed through gathers to protect the rangeland for other uses.

A gather like the one conducted in September, which removed 200 horses from private and tribal land adjacent to Modoc National Forest land, costs about $800,000. The work is done by a specialty contractor that uses helicopters to herd the animals into temporary corrals and also manages, in partnership with the USFS and BLM, an array of other logistics, including providing viewing platforms for horse advocates. Wild horse groups generally oppose gathers, arguing that they overstress the animals and break up family structures in the herds.

While gathers are expensive to conduct, even more costly is taking care of the horses once they are taken off the range. The captured horses are made available for adoption, but the great majority — now a total of 46,000 horses and burros — are not claimed and end up in BLM-funded care on private ranches, generally in the Plains states. Supporting these animals consumes two-thirds of the BLM's $75 million federal budget for wild horse management, and it puts the agency in a bind: Spending more to remove additional horses from the range will increase the cost to care for the off-range horses.

Wild horses have a powerful emotional appeal, and that greatly complicates their management (NRC 2013). In September, a citizens panel that advises the BLM recommended that the agency kill significant numbers of its off-range horses to save money so that it could better manage horses in the wild. But public outcry was instant, and as the committee's recommendation grew quickly into a national news story, the BLM hurried to issue statements that it would not be killing any horses.

Fertility control for horses on the range may eventually be a useful management tool. But the current method, a vaccine called PZP that can be injected by a rifle dart and temporarily renders mares infertile, is effective for only a year — meaning that many thousands of horses would have to be darted annually to shrink the herds.

There is official recognition that the current situation is unsustainable. In late October, a report from the inspector general of the Department of the Interior found that BLM lacks a strategic plan to satisfactorily address either the expanding on-range populations or the growing expense of holding the animals off-range. CA

—Jim Downing

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Tina Saitone:

Understanding the beef market, and whether sheepdogs are earning their keep

A visit to the supermarket meat case makes clear that special types of beef command special prices. From certified Angus to antibiotic-free to pasture-raised — along with designations such as certifications of traceability or specific vaccination protocols that consumers don't see — beef cattle are now marketed with long lists of "value-added" attributes.

For a rancher, each attribute represents both an added production cost and an opportunity to earn more when cattle are sold.

But cattle are sold at auction for a single price per pound — there's no itemization for what the buyer is paying for each attribute — so it can be difficult for ranchers to tell which practices are profitable and which aren't worth the trouble.

"Producers know their costs better than anyone, but the marginal value of each value-added attribute is really hard for ranchers assess," said Tina Saitone, who joined UC Cooperative Extension (UCCE) in June as a specialist in livestock and rangeland economics based at UC Davis.

Tina Saitone is a UC Cooperative Extension specialist based in the Department of Agricultural and Resource Economics at UC Davis.

In a research paper in this issue of *California Agriculture* (page 179), Saitone and her co-authors report findings from a study designed to tease out the value of each of these attributes, as well as the price effects of forward contracting (fixing a price a month or more before the cattle are delivered) and the distance a lot of cattle is from the major cattle feeding and meat processing hubs in the central United States.

Broadly, Saitone's research program aims to help cattle and sheep producers better understand the economics that influence their business decisions.

A native of Sonoma County, where until recently her family ran a small, century-old vineyard started with rootstock brought from Italy by her great-grandparents, Saitone grew up around farming and horses and gravitated to economics as an undergraduate at Sonoma State University. She completed her Ph.D. in agricultural and resource economics at UC Davis in 2008 and worked for an economic consulting firm before returning to UC Davis.

An ongoing challenge is developing good sources of data on livestock markets in California.

The study described above drew on sales data involving more than 2 million head of cattle over 17 years, provided by Western Video Market, a Chico-based video auction operator that has partnered with UCCE Shasta County director Larry Forero on market studies for several years. In a video auction, buyers bid on groups of cattle based on video footage of the animals as well as verification documentation collected by the auction operator. Because the transactions are conducted online, video auctions generate large, well-organized data sets.

But Western Video Market represents only a portion of the total cattle sales in the state — most of the rest are sold through in-person auctions, with no systems for data reporting.

One long-term plan for Saitone and ANR collaborators — Forero, as well as Tehama County Livestock, Range and Natural Resources Advisor Josh Davy — calls for developing a monthly market report for cattle producers based on data from all of live auctions. The group is working with auction operators to standardize data collection and reporting.

Saitone is also working to better understand the role of predation in livestock production in California and the cost-benefit associated with a wide variety of non-lethal depredation strategies. One study looks at the guard dogs — typically Great Pyrenees or Anatolian Pyrenees — that many sheep producers now use to protect flocks from coyotes and other predators. By gathering data on lamb losses to predation, the effectiveness of guard dogs at preventing those losses, and the costs of maintaining a guard dog, Saitone said she hopes to help sheep producers with a basic calculation:

"Does the dog make sense? Does it save you enough to be worth it?"

— *Jim Downing*

Calf and yearling prices in California and the western United States

by Tina L. Saitone, Larry C. Forero, Glenn A. Nader *and* Leslie E. Forero

This paper investigates spatial, quality and temporal factors impacting the pricing of calves and yearlings in the western United States using data from a satellite video auction and a hedonic regression framework. Results suggest that spatial price discounts received by western ranchers closely match reported shipping costs and, thus, are consistent with free-on-board pricing and competitive procurement. This study also identifies the presence of temporal price premiums, on average, for seller-offered forward contracts at video auctions. With respect to quality attributes, this study provides estimates of the marginal value associated with various quality attributes and management practices, including vaccination protocols, weaning, certified Angus beef candidates, and age and source verification. Finally, we show that the considerable year-to-year variability in estimated valuations for value-added attributes in hedonic regression models of cattle pricing can be linked to the stage of the cattle cycle, with premiums paid by buyers being attenuated when cattle inventories are high.

Cattle-feeding and meat-processing sectors have become increasingly consolidated and concentrated geographically in the central portion of the country. Yet, beef cattle production remains an important industry in many states across the country. Figure 1 is a dot density plot of calf inventories in the United States in 2015. As it shows, calf inventories are geographically diffuse with no one state having more than 14% of the total inventory. In contrast, figure 2, a dot density plot of cattle on feed, shows that by a considerable margin, the greatest intensity of cattle on feed occurs in the Great Plains. Ultimately five states (Texas, Nebraska, Kansas, Colorado and Iowa) market 76% of all fed cattle for slaughter in the United States (USDA 2012).

Online: https://doi.org/10.3733/ca.2016a0019

Geographic location may place cattle ranchers in California and other western states at a disadvantage, relative to their counterparts in the Midwest, due to costs of transporting cattle to feeding and processing facilities and, potentially, less competition among buyers to procure western cattle. Indeed, prior work suggests that western ranchers receive lower prices, relative to their midwestern counterparts (Blank et al. 2009). However, no prior research has quantified the magnitude of such discounts as a function of distance from the midwestern hub of feeding and processing, or determined whether lower prices are due solely to spatial factors or also involve buyer market power.

Temporal considerations may also play a role in the prices paid for cattle. Video auctions allow for buyers to procure cattle in advance of taking possession of those animals (i.e., forward contracting). This may be advantageous to buyers who need a steady supply of animals to sell to processors and, as a consequence, they may be willing to pay a premium to secure those animals in advance.

Ranchers can also add value to their cattle by engaging in a wide variety of value-added management practices. In this article, we consider those practices commonly employed by ranchers selling their cattle through Western Video Market Auction (WVM). These include vaccinations, weaning, age and source verification, natural (no implants or antibiotics), and certified Angus beef candidates.

In this paper we investigate spatial, quality and temporal factors impacting the pricing of calves and yearlings in California and the western United States using data from a satellite video auction and a hedonic regression framework.

Research suggests that western ranchers receive lower prices relative to their midwestern counterparts due to costs of transporting cattle to feeding and processing facilities, which are concentrated in the central United States.

Larry Forero

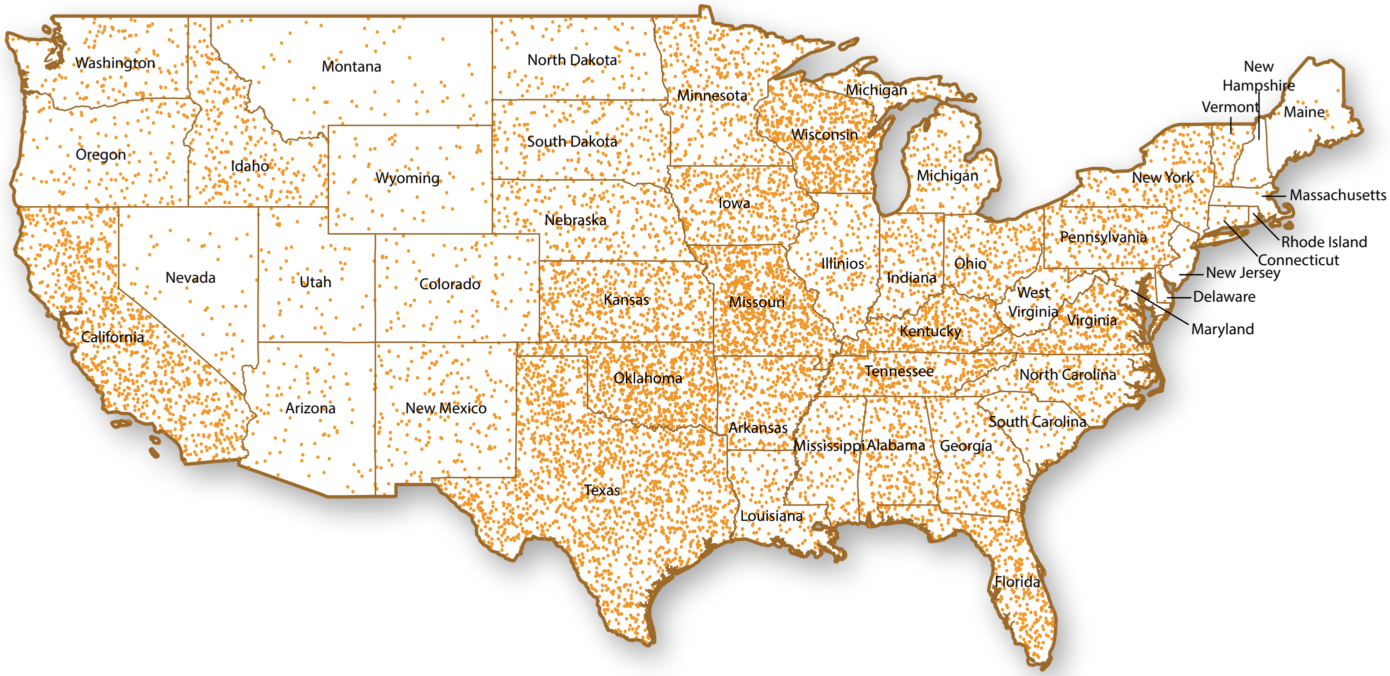

Fig. 1. Dot density plot of calf inventory, January 1, 2015. Map shows state-level inventory totals with each dot representing 1,500 calves. Calf inventories are not breed or industry specific and thus include both beef and dairy "type" animals. Source: Calf Inventory, January 1, 2015. U.S. Department of Agriculture, National Agricultural Statistics Service.

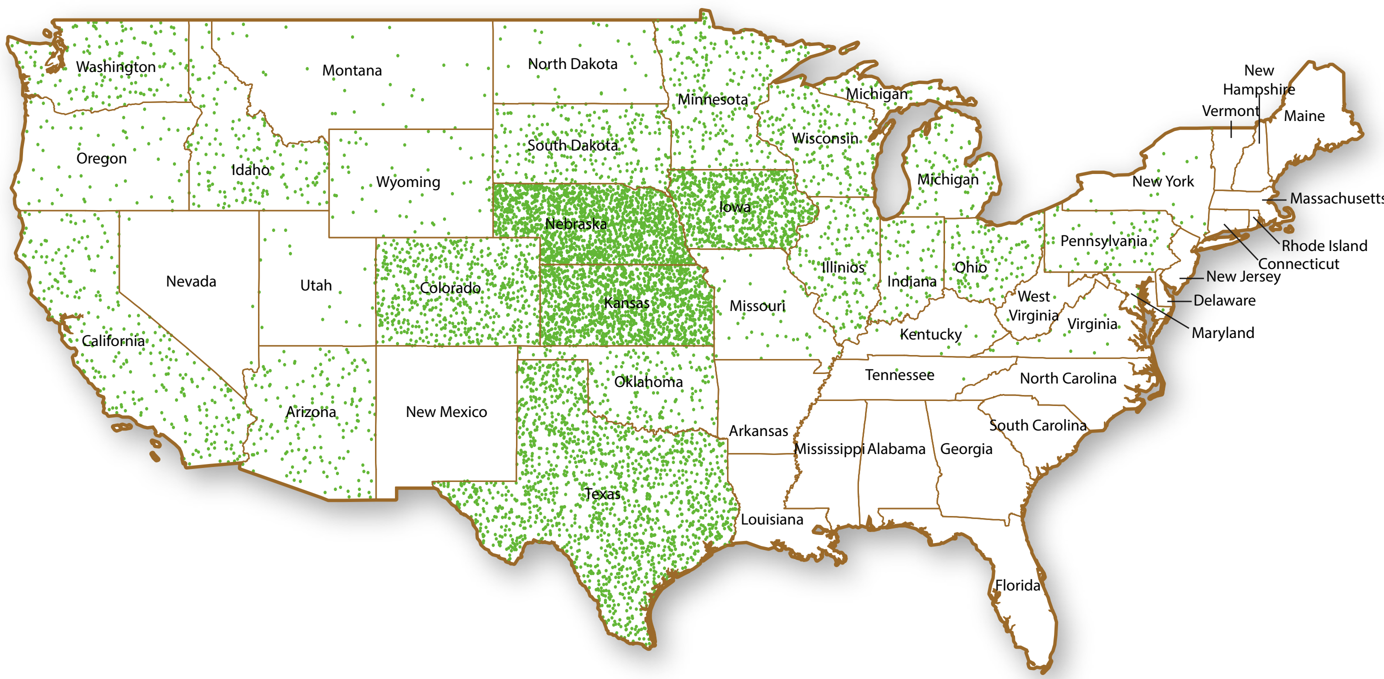

Fig. 2. Dot density plot of cattle on feed, January 1, 2015. Map shows state-level inventory totals with each dot representing 1,500 head. Cattle on feed are defined as those animals being fed a ration of grain, silage, hay or protein supplements and expected to produce a carcass that will grade Select or better. States with few cattle on feed are aggregated into an "other states" category, which accounts for a total of 56,000 head (0.4%). Source: Cattle on Feed Inventory, January 1, 2015. U.S. Department of Agriculture, National Agricultural Statistics Service.

Video auctions

Video auctions operate much like a traditional auction, but have the potential to generate a much larger pool of buyers from across the country. Cattle sold in video auctions are located at ranches across multiple states, thus providing an opportunity to analyze sales by producers at different locations, examine spatial pricing patterns and test hypotheses pertaining to regional price differences.

Video auctions provide rich data on the characteristics of cattle offered in lots for sale, making them ideally suited to analyze the marginal valuation of animal characteristics and attributes following the hedonic framework. A possible downside to analysis based on video auction data is a sample selection problem if cattle sold at video auctions are not representative of the cattle inventories in California. For example, Bailey et al. (1991) found evidence that cattle sold on video auctions tended to be higher quality than cattle sold elsewhere.

Relative to prior studies of cattle pricing using a hedonic framework, this study makes a number of contributions: (i) it provides a detailed analysis of the spatial and competitive dimensions of calf and yearling prices that are a central concern to western ranchers; (ii) it isolates the price impacts of forward contracting sales of cattle, finding in most cases that forward contracting earns a seller premium; and (iii) it links a persistent year-to-year variation in the premiums earned for value-added practices to the stage of the cattle cycle.

Empirical model

WVM, headquartered in Northern California, serves as a marketing outlet for cattle ranchers in 16 western states selling approximately 250,000 head of cattle each year. WVM holds live-cattle auctions broadcast via satellite each month except February. WVM provided data on 6,500 lots of steer calves and 8,016 lots of yearling steers sold in all of their auctions held from 1997 through 2013. Steer calves are castrated males that are around 6 months of age and roughly 450 to 600 pounds, while yearling steers are castrated males that are about one year old and usually 800 to 950 pounds. The number of lots sold per year ranged from 154 in 1998 to 530 in 2007 for calves and from 234 in 1997 to 620 in 2005 for yearlings. In total, 888,438 calves and 1,300,440 yearlings were included in the data. Most of our analysis focuses on the most recent 10-year period, 2004–2013. However, the entire 17 years of data were utilized in an analysis of premium variability for value-added practices.

Prices for calves and yearlings were analyzed separately. In both cases, only steers were considered. All calf lots had a flesh score of medium, a frame score of medium or medium-large and average weights in the 500- to 625-pound range. This weight range was chosen to focus on the price effects of management of calves at weaning. Yearling lots had average weights in the 750- to 925-pound range. Lots with animals weighing between 625 and 750 pounds were excluded from the study, as were lots of cattle that included steers and heifers. Lots of Brahman influence, Mexican origin and Holsteins were not included in the analysis given that WVM is not a common sales outlet for these types of cattle.

We utilize a traditional hedonic regression framework to analyze the price per hundredweight (cwt.) received for each lot of cattle. Each lot of cattle, Y_i, is defined by its characteristic bundle, $X_i = \{X^1,\ldots,X^n\}$ where $X^1,\ldots,X^n$ are characteristics/attributes that collectively define the lot Y. Price, P_i, of product i is specified as a function of its characteristics vector: $P_i = f(X_i)$, or in linear form as

$$P_i = \beta_0 + \beta_1 X_i^1 + \beta_2 X_i^2 + \cdots + \beta_n X_i^n + \upsilon_i,$$

where v_i represents a random error term, and the terms represent the marginal effect or value of characteristic j in determining the price of lot Y. The lot-level characteristics/attributes that are controlled for in the model include: (a) the physical characteristics of the lot, including breed, number of cattle in the lot and average per-animal weight, (b) geographic distance from the midwestern sales/processing hub, (c) value-added characteristics and (d) variables to account for temporal effects, including delivery month and whether the lot was sold as a forward contract.

Summary statistics for 2004–2013 are contained in table 1. The distance variable (*miles to Omaha, NE*) is the driving distance in hundreds of miles from Omaha to the location of the ranch selling the lot of cattle. Based on lot-level auction data, each lot is geocoded and the driving distance from that location to Omaha, Nebraska, is computed using Google Maps. The spatial dispersion of lots sold through the video auction allows us to estimate the degree to which prices for cattle sold in the West are discounted based on their distance from the concentration of feeding and processing capacity. Use of Omaha is consistent with its central

TABLE 1. Summary statistics for calves and yearlings, 2004–2013*

	Calves (*n* = *4,444 lots*)		Yearlings (*n* = *5,175 lots*)	
Variables	**Mean**	**SD**	**Mean**	**SD**
Price ($/cwt)	130.90	21.97	109.50	15.31
Weight (cwt)	5.676	0.366	8.490	0.486
Natural	0.332	0.471	0.258	0.437
Certified Angus beef (candidates)	0.223	0.416	0.184	0.388
Age and source verified	0.316	0.465	0.226	0.418
Number of head in lot	134.2	92.78	153.8	157.2
Miles to Omaha, NE (100s)	10.67	4.774	13.97	4.367
Vaccinated	0.720	0.449		
Weaned	0.450	0.498		
Fed on hay			0.453	0.498
Fed on pasture			0.371	0.483
Angus	0.758	0.429	0.765	0.424
Charolais	0.048	0.215	0.029	0.166
Hereford	0.098	0.298	0.101	0.301
Continental	0.001	0.033	0.000	0.020
Mixed breed cattle	0.094	0.292	0.105	0.306
Purchased 1 month before delivery	0.159	0.366	0.405	0.491
Purchased 2 months before delivery	0.223	0.416	0.151	0.358
Purchased 3 months before delivery	0.202	0.402	0.043	0.202
Purchased 4 or more months before delivery	0.261	0.439	0.038	0.191
Lots with some variability	0.292	0.455	0.306	0.461
Lots with high variability	0.569	0.495	0.613	0.487

* Unless otherwise indicated, figures represent the fraction of all lots with a given characteristic.

Premiums for value-added characteristics such as vaccinations, weaning, and age and source verification were factors that influenced bids made by buyers.

location in terms of processing capacity and results of prior research, which has found Nebraska, and Omaha in particular, to be the key hub in price setting for the cattle market (Schroeder 1997; Tomek 1980).

Estimation of separate models for calves and yearlings enables us to specify variables to represent characteristics of lots that are potentially important to determining the value of each type of animal (Anderson and Trapp 2000). However, several indicator variables were common to both the calf and yearling models. The *Certified Angus beef* indicator variable indicates a steer that is a certified Angus beef candidate. This designation requires that cattle qualify for U.S. Department of Agriculture (USDA) specifications for the Angus Influence by meeting either the genotype (positive identification and traceability to Angus parentage) requirements or the phenotype (appearance of predominantly solid black) requirements.

On average, seller-offered forward-contracted cattle sell at a premium, relative to lots sold spot.

The *Natural* variable signifies that the seller certifies the steer has been raised without implants or antibiotics. *Age and source verified* denotes that the seller is participating in one of two USDA programs (the Process Verified Program or Quality System Assessment Program) intended to provide certification of production practices for buyers primarily targeting export markets.

Weight and *weight squared* are the average lot weight per head and its square. These variables test for premiums or discounts related to the size of the steers in a lot. For calves, *Weaned* is an indicator variable that denotes a steer that has been weaned 30 or more days prior to sale, compared to the baseline of a calf that has not been weaned. *Vaccinated* is an indicator variable that denotes the lot has received a respiratory vaccine (either two kill vaccines or one modified live vaccine for IBR/BVD/PI_3/BRSV).

The model uses fixed effects to control for time invariant price differences across breeds of cattle. Breed fixed effects are included for (i) Angus and other black-hided breeds, (ii) Charolais, (iii) Hereford, (v) Continental and (v) mixed cattle. The share of Angus and black-hided cattle sold via WVM has increased over time while the shares of Herefords and mixed breed cattle have commensurately decreased over the sample period.

For yearlings, the lot characteristics examined also included indicator variables to depict the feeding regimen for the animals in the lot. The variable *Fed on pasture* denotes steers that had been fed on pasture only, and *Fed on hay* denotes steers fed on hay only. Each is compared to the baseline of steers fed on both pasture and hay. Steers fed hay may adapt better to feedlot conditions, making such animals more valuable to some buyers.

By comparing the sale and delivery dates, we derived a series of indicator variables to identify forward contracting for 1 month, 2 months, 3 months and 4 or more months, with the baseline being cash sales (lots delivered the same month as the sale). These variables enable us to conduct tests for premiums or discounts associated with forward contracting sale for immediate delivery.

In addition to the full 10-year period from 2004 to 2013, results are reported for each 2-year interval within that time span. Regression results for calves and yearlings are provided in tables 2 and 3, respectively.

Impact of distance

The variable *Miles to Omaha* was statistically significant at the 0.01 level in each of the calves and yearlings regressions. In the calf price equation, the coefficient on *Miles* is −0.807 over the full 10-year period, indicating that the price received by ranchers over the sample period was discounted by about 81 cents per cwt. for each 100 miles the calves were located from Omaha, Nebraska, other factors constant. The estimated effect of distance was somewhat smaller for yearlings — a coefficient of −0.652 or a discount of 65 cents per cwt. per 100 miles from Omaha. With one exception, the 2010–2011 calves regression, the coefficient on *Miles* was relatively stable across the biennial regressions. These estimates confirm that ranchers that are selling cattle farther away from the concentration of processing capacity in the midwestern United

These estimates confirm that ranchers that are selling cattle farther away from the concentration of processing capacity in the midwestern United States are receiving discounted prices.

States are receiving discounted prices. Even if western cattle are not shipped directly to the Midwest and instead go to stocker operations or feedlots located elsewhere, most of these cattle must eventually travel to the Midwest for processing, and thus buyers at these intermediate market stages pay less for western cattle, recognizing that the prices they receive subsequently for sales to processors will be discounted by transportation costs, shrink and mortality associated with shipments to the Midwest.

A clearer sense of the impact of spatial discounts is obtained by examining the impacts of *Miles* in major ranching areas located at different distances from Omaha. To make this comparison, we use coefficient estimates from the most recent biennial model (2012–2013) to compare to shipping costs quoted in 2015. For example, Redding, California, is located 1,642 miles from Omaha. Our results suggest that a lot of calves based in Redding sold for $12.76 less per cwt. in 2012–2013 than a comparable lot located near Omaha. The discount for yearlings was $14.71 per cwt. Based on information from industry sources, actual transportation costs from Redding to Omaha during this time were about $11.97 per cwt., based on a load cost of $3.50 per mile.

A key consideration is how tightly linked our estimates of spatial discounts are to actual shipping costs. The tighter this relationship, the stronger the evidence that western ranchers are experiencing discounts in the prices they receive that are consistent with free-on-board (FOB) pricing. FOB pricing, where the seller is responsible for shipping costs, either explicitly or implicitly in the form of a price discount, is the only pricing structure that is consistent with competitive

TABLE 2. Ten-year and biennial calf regression coefficient estimates

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	**2004–2013**	**2004–2005**	**2006–2007**	**2008–2009**	**2010–2011**	**2012–2013**
Miles to Omaha, NE (100s)	−0.807***	−0.807***	−1.120***	−0.749***	−0.372***	−0.777***
	(0.0275)	(0.0525)	(0.0480)	(0.0471)	(0.0653)	(0.101)
Vaccinated	0.932***	0.431	1.247***	0.154	1.448***	4.146***
	(0.231)	(0.374)	(0.387)	(0.349)	(0.553)	(1.092)
Age and source verified	1.623***		2.663***	1.669***	2.231***	1.901**
	(0.254)		(0.551)	(0.351)	(0.436)	(0.740)
Certified Angus beef (candidates)	1.495***	1.246***	1.497***	0.935**	1.262**	2.445***
	(0.258)	(0.478)	(0.458)	(0.438)	(0.505)	(0.908)
Natural	1.462***	1.174***	0.768**	1.264***	1.234***	1.383*
	(0.232)	(0.437)	(0.380)	(0.418)	(0.458)	(0.749)
Weaned	3.655***	3.366***	2.736***	3.342***	4.195***	4.457***
	(0.277)	(0.526)	(0.473)	(0.492)	(0.562)	(0.806)
Lots with some variability	−1.475***	−0.130	−1.167**	−1.407***	−2.400***	−4.407***
	(0.306)	(0.542)	(0.526)	(0.452)	(0.613)	(1.289)
Lots with high variability	−1.688***	−0.938*	−1.807***	−2.015***	−1.347***	−3.452***
	(0.287)	(0.536)	(0.483)	(0.447)	(0.506)	(1.177)
Weight (100s of lbs.)	−67.56***	−79.41***	−59.86***	−42.12***	−85.15***	−65.14**
	(9.048)	(17.07)	(15.07)	(13.85)	(18.96)	(27.42)
Weight squared (100s of lbs.)	4.909***	5.890***	4.317***	2.942**	6.378***	4.478*
	(0.799)	(1.506)	(1.326)	(1.221)	(1.671)	(2.429)
Constant	354.6***	388.7***	327.3***	256.3***	425.1***	395.1***
	(25.50)	(48.09)	(42.62)	(39.15)	(53.57)	(77.04)
Observations	4,444	1,048	974	947	766	709
R-squared	0.905	0.573	0.690	0.650	0.901	0.556
Forward contracting fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Breed fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Delivery month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

procurement. Alternative pricing schemes (e.g., those that include "freight absorption," where the buyer assumes some or all of the shipping costs) discriminate against those sellers that are closer to the buyer in favor of those who are further away. Spatial price discrimination cannot survive under competitive procurement because sellers disfavored under one buyer's discriminatory pricing plan would receive better offers from competing buyers. The estimated actual shipping cost lies within the 95% confidence interval of the price discount for both calves and yearlings and is thus supportive of an FOB pricing structure for feeder cattle in the West and is consistent with, but not conclusive of, a competitive procurement market. Thus, these results suggest that the discounts that we observe are due to transportation costs and are unlikely to be the result of downstream buyers (e.g., feeding operations) exercising buyer power to depress prices.

Absent the establishment of new processing facilities in the West, these results suggest that western ranchers face a chronic disadvantage in price relative to their counterparts in the Midwest.

Impacts of forward contracting

The coefficients on the variables estimating the impact of forward contracting were positive and statistically significant at the 0.01 level in each instance in the 2004–2013 models for both calves and yearlings. Most coefficients in the biennial models are also positive and significant.

The coefficients themselves, however, do not provide estimates of the premiums or discounts associated with forward contracts versus spot sales. Forward-contracted cattle are sold based upon their anticipated weight at delivery. We thus needed to compare the forward-contracted auction price to an estimate of the price the forward-contracted lot would have received if it had been sold at video auction in its delivery month.

TABLE 3. Ten-year and biennial yearling regression coefficient estimates

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	2004–2013	2004–2005	2006–2007	2008–2009	2010–2011	2012–2013
Miles to Omaha, NE (100s)	−0.652***	−0.565***	−0.762***	−0.583***	−0.636***	−0.896***
	(0.0173)	(0.0361)	(0.0307)	(0.0254)	(0.0347)	(0.0644)
Age and source verified	0.792***		0.00736	0.985***	0.928**	0.641
	(0.216)		(0.384)	(0.286)	(0.436)	(0.876)
Certified Angus beef (candidates)	1.463***	1.671***	2.312***	1.383***	0.564	0.170
	(0.214)	(0.560)	(0.354)	(0.249)	(0.435)	(1.128)
Natural	2.958***	4.549***	2.822***	1.502***	2.976***	3.991***
	(0.214)	(0.495)	(0.319)	(0.275)	(0.427)	(0.937)
Fed on hay	2.677***	1.504***	1.541***	3.723***	1.349*	0.223
	(0.269)	(0.484)	(0.404)	(0.569)	(0.783)	(1.504)
Fed on pasture	0.861**	0.963	1.565*	1.328	0.364	1.015
	(0.405)	(0.700)	(0.858)	(1.043)	(0.675)	(1.243)
Lots with some variability	−1.087***	−1.553***	−0.664	−0.340	−1.019*	0.451
	(0.297)	(0.505)	(0.572)	(0.477)	(0.603)	(1.338)
Lots with high variability	−1.131***	−1.266**	−0.711	−0.485	−0.728	−0.951
	(0.285)	(0.494)	(0.571)	(0.459)	(0.532)	(1.220)
Constant	111.1***	107.1***	109.8***	91.36***	130.3***	155.4***
	(0.648)	(1.072)	(1.025)	(1.084)	(2.038)	(2.613)
Observations	5,175	1,174	1,158	1,097	1,004	742
R-squared	0.869	0.498	0.594	0.773	0.865	0.358
Forward contracting fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Breed fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Delivery month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

To make this comparison, we first computed the predicted price for each forward-contracted lot in the data set using the pooled 2004–2013 model and then computed the predicted price for the same lot if it had been sold as a "spot" transaction in its delivery month. This approach allows the analysis to incorporate month and, in some cases, year fixed effects that account for seasonal and other inter-temporal effects in the market. For example, August is a comparatively high-price month for calves, and October is a low-price month, so figuratively "reselling" a lot of calves in October that were in reality sold in August for delivery in October (that is, a 2-month forward contract) enables us to control for these temporal effects, thereby focusing solely on the price impact due to forward contracting. The difference between the actual predicted price for a lot and its predicted price for a spot sale in the delivery month represents the estimated premium or discount received from forward contracting the lot.

The results from this analysis of forward contracting are presented in table 4. Forward-contracted calves and yearlings each earned a price premium on average for each of the four possible contract lengths. For calves the average premium ranged from $1.57 per cwt. for a 1-month forward contract to $2.90 for 4 or more months. For yearlings the range was $0.72 for a 1-month forward contract to $2.31 for 4 or more months. There is, however, considerable variation in the estimated premiums, as reflected in the standard deviations reported in table 4. Such variability in the premiums is likely due to unanticipated changes in market conditions and price expectations between the sale and delivery month.

On balance, these results provide rather strong evidence that a premium existed on average for seller-offered forward-contracted calves and yearlings over this time period. The ability to lock in a sale or purchase at a fixed price is beneficial to both buyers and sellers, depending upon each party's aversion to risk. Beyond simple risk aversion, however, downstream buyers also benefit from guaranteeing in advance a supply of cattle to their facilities, which is a crucial factor in determining their operating efficiency and unit cost. Given downstream buyers' clear incentive to lock in supplies of cattle, it should not be surprising to find that, on average, they pay a price premium on forward-contracted cattle, thereby providing an opportunity for sellers to gain a price premium relative to spot sales.

TABLE 4. Premiums for forward contracting

	Calves		Yearlings	
	Avg. price difference	SD price difference	Avg. price difference	SD price difference
1 Month	$1.57	$3.58	$0.72	$2.43
2 Months	$2.20	$1.10	$1.38	$1.90
3 Months	$1.83	$0.75	$1.85	$2.88
4+ Months	$2.90	$2.24	$2.31	$5.39

Premiums for value-added characteristics

Table 2 contains results on quality and management variables that attract price premiums for calves. For calves, weaning is a very important practice that generated an estimated premium of $3.66/cwt. over the 10-year period; the premium was relatively stable across each of the five biennial regressions. Our estimates are smaller than those of Schumacher et al. (2012) ($5.35/cwt.) and Williams et al. (2014) ($5.23/cwt.) but consistent with Zimmerman et al. (2012) ($3.47/cwt. in 2010). *Certified Angus beef* candidates earned an average premium of $1.50/cwt. over and above the premium afforded black-hided cattle that were not part of the program. Operator certification of *Natural* beef earned a consistent premium over the 10-year period, with a coefficient of $1.46/cwt. in the pooled model. *Age and source verified* resulted in an average premium of $1.62/cwt., and was quite consistent across the biennial regressions. *Vaccinated* earned a smaller average premium of $0.93/cwt., but this premium was highly variable across the biennial regressions.

Variability of flesh and frame of cattle in a given lot earned a consistent discount, with little difference in the discounts across moderate- and high-variability lots at $1.48/cwt. for lots with some variability versus $1.69/cwt. for lots with high variability. This is consistent with the findings of Zimmerman et al. (2012) that lots classified as very uneven were discounted $1.67/cwt. These discounts were relatively stable for the first four biennial models, but were dramatically higher for the 2012–2013 model.

Throughout the weight range specified in the data for calves, 500–625 pounds, larger animals received a lower price ceteris paribus throughout the weight range in the data. Smaller calves generally have a greater opportunity for weight gain and, thus, profit potential, ceteris paribus.

The results for yearlings in table 3 reveal a slightly smaller average premium for *Certified Angus beef* as for calves of $1.46/cwt., but the premium is much more variable in the biennial regressions for yearlings and is not statistically significant in the 2010–2011 and 2012–2013 models. Ranchers who certified that their yearlings were raised *Natural* earned a substantial premium on average of $2.96/cwt., although the premium varied considerably in the biennial models. *Age and source verified* earned a smaller average premium, $0.79/cwt., compared to the premium afforded calves, and the premium failed to attain statistical significance in two of the biennial regressions.

Feeding practices for yearlings yielded somewhat ambiguous results. *Fed on hay* earned a statistically significant premium of $2.68/cwt. compared to the baseline of a yearling fed on both hay and pasture, but this premium was highly variable in the biennial models. Yearlings fed solely on pasture also, and somewhat paradoxically, earned a small premium (even though this is likely a less expensive way to add weight), although this premium was not statistically significant in four of the five biennial models.

Variability in lots of yearlings was penalized by price discounts that were very similar in magnitude to those for calves. The discounts tended to be similar in magnitude for moderate and high variability.

Assessing variability in premiums

As noted, coefficients for many of the value-added attributes of calves and yearlings exhibit considerable variability across the biennial regression models in tables 2 and 3. Given that cattle prices have changed considerably over the time period of our sample, we also considered these premiums as a percentage of the average price for cattle sold during that time period as a robustness check. Use of percent premiums essentially deflates the dollar-value premium by the average sales price in each of the biennial models. The percent premiums, however, still display considerable inter-temporal variation. Similar variability in coefficients has been found in other studies (e.g., Zimmerman et al. 2012). In order to confirm that the variation in the marginal valuations of the value-added attributes are statistically significant, we estimated a "restricted" version of our standard regression specification wherein the coefficient estimate is the average premium for that characteristic over the sample period (2004–2013). We then estimated an "unrestricted" model wherein we allow the estimate of the value-added attribute to change in each year of the sample and then used an *F*-test to compare the coefficient estimates across the restricted and unrestricted models. This procedure confirms that the annual coefficient estimates are significantly different from the coefficient estimate in the restricted model (i.e., the average premium for the entire sample period). Thus, we went on to test the hypothesis that at least some portion of this variability is due to stages of the cattle cycle and in particular the hypothesis that during periods when cattle inventories are high, buyers will be less motivated to bid up to their valuations for particular lots.

In order to test this hypothesis, we used the estimated regression coefficients for *Age source verified*, *Certified Angus beef*, *Natural* and *Vaccinated* from a set of annual models (1997–2013) as the dependent variable of the model. The key explanatory variable in this analysis was the USDA's January estimate of U.S. cattle inventory. Also included in the model are year fixed effects to control for demand-side factors that may be influencing some of the variation in value-added premiums. In the peak stages of the cattle cycle, cattle inventory numbers are large. Accordingly, price is lower due to the supply effect. Our research question was whether premiums for value-added practices were also reduced during the peak of the cycle.

We found that the level of *Cattle inventory* was negatively associated with the price premiums earned for value-added practices and statistically significant (at the 0.10 level). Thus, an additional million head of cattle in inventory is estimated to reduce value-added premiums paid by \$0.08 to \$0.09/cwt., on average. When bidders perceive cattle to be plentiful (i.e., inventories are high), they are less likely to bid their full valuations for any given lot of cattle. Alternatively, when bidders perceive cattle inventories to be low, they are more likely to bid up lots of cattle in order to secure animals with the necessary characteristics to fulfill the demand of downstream buyers.

Implications for western ranchers

The importance and potential usefulness of hedonic pricing models for live cattle to industry participants and advisors is enhanced by the growing set of variables that may add to or detract from an animal's value and by the presence of satellite video auctions that acquire and maintain detailed records on characteristics of the lots of cattle sold under their auspices.

To our knowledge, this study is the first to isolate the presence of price premiums for seller-offered forward contracts at video auctions. Although the premiums exhibited considerable variability, they were positive on balance and the coefficients supporting the premiums were statistically significant for most of the forward contracts considered. This result is consistent with the well-known desire of downstream buyers to lock up commitments of cattle to ensure operation of their facilities at efficient capacity. Further, this is also the first study we are aware of that has linked variability in the premiums paid by buyers for value-added management attributes to stages of the cattle cycle.

In summary, our results suggest a chronic locational disadvantage for western ranchers relative to counterparts in the central part of the country due to the paucity of feeding and processing capacity in the West, with little hope for gaining new capacity in the near term. This disadvantage heightens the imperative for western ranchers to be on the forefront of adopting practices that can add value to their cattle. In that regard, we hope this study, through identifying and quantifying premiums associated with forward contracting and value-added production and management practices, can help western ranchers and their advisors obtain maximum value and return from their operations. CA

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Efficacy of selenium supplementation methods in California yearling beef cattle and resulting effect on weight gain

by Josh Davy, Larry Forero, Thomas Tucker, Christie Mayo, Daniel Drake, John Maas *and* James Oltjen

Selenium (Se) deficiency occurs commonly in California grazing cattle and has been associated with reduced immune function and, in some studies, reduced weight gain. Multiple methods of supplementing Se are available, but little research has compared the effects of these methods on whole blood Se levels and weight gain. In two trials, we evaluated four methods of Se supplementation — an intraruminal bolus, two injectable preparations and a loose salt containing 120 ppm Se — over an 85- to 90-day period in Se-deficient yearling cattle in Tehama County. The bolus treatment raised whole blood Se levels to an adequate level (0.08 ppm) for the entire study period. Whole blood Se concentrations in injected cattle initially reached adequate levels but then declined to deficient levels. The loose salt treatment acted slowly, with average whole blood Se concentration reaching adequate levels at the end of the study period. None of the treatments significantly affected weight gain and Se blood concentration was not correlated with weight gain. In growing cattle, it appears that Se supplementation may be viewed not as a direct driver of weight gain, but rather as similar to vaccination, in that it can prevent health problems that might otherwise lead to reduced weight gain.

Selenium (Se) deficiency in California livestock species is widespread and is estimated to exist in excess of 60% of herds in the state (Dunbar et al. 1988; Williams 1980). Se is an essential nutrient for all animals, including cattle (NRC 1996). The importance of correcting Se deficiencies is well documented. Adequate Se levels have been found to boost immunity, thereby reducing mortality, diarrhea and increasing disease resistance in cattle (Arthur et al. 2003; Gerloff 1992; Maas 1983; Salles et al. 2014; Spears et al. 1986).

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Soils with low concentrations of Se are the primary cause of plants providing limited Se levels to cattle in forage (NRC 1996). Methods of increasing forage Se concentrations through the use of soil amendments have been successful in providing adequate Se in forage to cattle (Ajwa et al. 1998). Currently, the use of fertilizers containing Se is not legal in California, leaving direct supplementation of livestock the only method to alleviate Se deficiency. The difficulty facing California livestock producers is determining the most appropriate supplementation strategy that fits their particular operation.

Se injections are a common method of supplementing deficient cattle. Research has found this can be an effective supplementation method, though its effective adequacy period has not been found to last for more than 45 days (Genther and Hansen 2014; Maas et al. 1993). The use of an intraruminal time release bolus has been demonstrated as a safe, long-term Se supplementation strategy (Hemingway et al. 2003; Maas et al. 1994; Sprinkle et al. 2006).

Results from two trials suggest that a selenium rumen bolus can maintain adequate levels of whole blood selenium throughout the study period, whereas the benefits of selenium injections do not last as long.

Larry Forero

The U.S. Food and Drug Administration allows a maximum dietary supplement of 3 milligrams per head (mg/head) per day in cattle diets. This is the equivalent of 120 parts per million (ppm) of Se added to a salt supplement mixture that is formulated for consumption of one ounce per head per day. The use of free-choice salt-mineral mixes as a method of Se supplementation has limited research, but in some cases has been found to bring Se to adequate levels (Patterson et al. 2013). Results can be variable due to individual animal intake, varying pasture conditions and climatic conditions such as temperature, precipitation and season. Research quantifying Se status from herds that are provided salt-based supplements is necessary, especially in California conditions, as this is one of the most common methods of supplementation used by California livestock managers.

Unlike immune responses, weight gain and feed efficiency differences between Se-supplemented and -deficient cattle have been variable, with some studies finding significant improvement in supplemented cattle (Del Claro et al. 2013; Johnson et al. 1979; Nelson and Miller 1987; Perry et al. 1976; Spears et al. 1986), while others have not observed significant differences (Albaugh et al. 1967; Cozzi et al. 2011; Jenkins and Hidiroglou 1986; Nicholson et al. 1993; Salles et al. 2014; Swecker et al. 2008). In light of these varying results, current information specific to California conditions is needed to help quantify weight gain differences between Se-deficient and -adequate cattle.

We evaluated both the efficacy of Se supplementation methods and yearling cattle weight gain associated with whole blood Se levels. To our knowledge, these two trials are one of the only evaluations of both different supplement methods and their effect on increasing whole blood Se levels and the subsequent influence on yearling cattle weight gains. Specifically, trial 1 included treatments of a 15-mg/head Se injection (MU-SE), a 25-mg/head Se injection (Multimin) and an intrarumenal bolus against a control group. Trial 2 monitored the effectiveness of a loose salt-based supplement compared to an intrarumenal bolus positive control and true negative control groups.

Study site

The study site for the two trials was a commercial cattle ranch in Cottonwood (Tehama County), California. Herd whole blood and forage sampling prior to the trial showed the site to be a Se-deficient irrigated pasture. Cottonwood has a typical Mediterranean climate with cool wet winters and warm dry summers. The perennial irrigated pastures are grazed from early spring to late fall and rested in the winter rainy season when cattle are hauled to winter annual rangeland. The soil is an Arbuckle gravelly loam formed in alluvial materials from mainly conglomerate and metasedimentary rocks (USDA 2014). Vegetation consisted of dallisgrass (*Paspalum dilatatum*), tall fescue (*Schedonorus arundinaceus*), ryegrass (*Lolium* spp.), bermudagrass (*Cynodon dactylon*) and white clover (*Trifolium repens*), with a minor weed component including smartweed (*Polygonum lapathifolium*), sedge (*Cyperus difformis*) and mint (*Mentha pulegium*). The trials were conducted using the same pastures in both 2011 and 2013. Since the pastures are perennial, the composition did not vary largely between years.

Cattle

Trials 1 and 2 consisted of preconditioned weaned steers with an average starting weight of 643 pounds (range 488–824 pounds) in 2011, and an average of 551 pounds (range 325–760 pounds) in 2013. Though not a purebred herd, the ranch has used strictly Angus genetics for many years, categorizing the research steers as Black Angus cattle.

Whole blood sampling

Although liver biopsy is the most preferred sampling method, whole blood sampling for Se has been found to be an accurate and less invasive tool for the assessment of Se status of cattle (Kirk et al. 1995; Pavlata et al. 2001). Unlike other trace minerals, serum has not proven reliable compared to whole blood testing of Se (Maas et al. 1992).

In both trials, collection of whole blood for Se testing was completed using EDTA tubes. Samples were submitted to the California Animal Health and Food Safety laboratory at UC Davis for testing. Samples of the cattle were tested prior to trial initiation to confirm deficiency,

Farm Advisor Josh Davy sorting and processing blood samples to send to the lab for analysis.

conduct stratification, and to make certain there was not a large variance in the herd level.

For sample interpretive purposes, whole blood sample results were placed into four groups that described the mineral level status. The groups were classified as severely deficient at levels of 0–0.050 ppm, marginally deficient at 0.051–0.080 ppm, adequate at 0.081–0.160 ppm and highly adequate at 0.161 ppm or more (Dargatz and Ross 1996).

Trial 1 methods (2011)

In the 2011 trial, 80 individually identified steers were stratified into four groups of 20 head each. Stratification was completed by creating four weight groups starting with the lightest 20 cattle in group one and continuing in ascending order to group four. Equal numbers of each stratification group were randomly assigned to each treatment. Analysis of variance confirmed that no difference in weight existed between treatments prior to treatment initiation.

The trial began on July 25, 2011. Treatments included 3 cc of a 5-mg/ml injection of sodium selenite (MU-SE, Merck Animal Health, Madison, New Jersey) (15 mg Se/head), a 5-cc injection of a 5-mg/ml sodium selenite in a mixture of zinc oxide, manganese carbonate and copper carbonate (Multimin 90, Multimin, Fort Collins, Colorado) (25 mg Se/head), a Se oral bolus (Se365 Se bolus, Pacific Trace Minerals, Sacramento, California) designed to release not more than 3 mg/head/day, and an untreated control group. Both injections of Se were performed subcutaneously. The two rates were based off of label recommendations of competing Se injection products commonly used for supplementing cattle.

Body weight for each animal was recorded at 30-day intervals for 90 days following treatment initiation. Whole blood Se samples were collected on day 30 and again on day 90 after treatment initiation. All treatment groups were combined in the same pasture throughout the trial.

Trial 2 methods (2013)

The second trial, which began May 28, 2013, built on the previous trial by focusing on loose salt as a supplement source. This trial evaluated the ability of a loose salt mixture to raise deficient cattle to a status of adequate. As in trial 1, we sought to determine whether differences in Se status would affect yearling steer weight gains. Forty-eight steers were placed in a salt-supplemented treatment group with free access to a sodium selenite–based Se supplement at a concentration of 120 ppm. Six positive control steers were given a Se bolus and six negative control steers were given no treatment. The positive control cattle were given a bolus because the 2011 trial had shown it to be a treatment that had the ability to raise and maintain whole blood Se throughout the trial period.

Both the positive and negative control steers were placed in an adjacent pasture to the loose salt–supplemented steers to prevent access to the supplement. Stratification was completed in the same manner as for trial 1 except that two weight groups and three Se groups within weight groups were used. Weight gain and whole blood sampling of all cattle occurred on day zero and four subsequent 21-day intervals.

The control and treated pastures were also sampled on the same dates as the cattle. In cross-pasture transects that reached from one corner of each pasture to the other, six equally spaced individual points were sampled in order to obtain a representation of the grazing area. Each sampling point recorded pasture composition, standing biomass, forage quality, mineral content and plant height. Pasture composition was recorded as basal cover of plant species present in a one-square-foot frame.

Once composition and average plant height was recorded, the samples were clipped to ground level, dried to 100% drymatter, weighed and then split in half for submission of forage quality and mineral content analysis. Forage quality analysis was conducted by Dairy One forage laboratory in Ithaca, New York, and the forage mineral content was analyzed by the California Animal Health and Food Safety laboratory at UC Davis. The process was repeated in each field at the same sampling date.

Statistical analysis

To analyze weight gain, both trials were run separately using multiple analyses of variance for average daily gain and whole blood Se level. Categorical variables


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Farm Advisor Larry Forero processing cattle in the squeeze chute.

included treatment, date, their interactions and a covariate of the individual animal identification (when applicable) using Statgraphics Centurion (StatPoint 2009). Covariates including initial weight and Se level were run, but were omitted because they were not significant in the model ($P > 0.05$). Mean separation was completed using least square means at the 0.05 level. Pearson product moment correlations were run for both forage species to Se forage content, and Se whole blood level to weight gain. Se level graphing used 95% least significant difference bars to present true treatment differences. To depict weight gain, both trials were graphed expressing cumulative average daily gain with 95% confidence intervals in Minitab (Minitab Inc. 2013). Likewise, whole blood Se levels are depicted graphically using Minitab.

Trial 1 results

Cattle that received some type of Se treatment generally reached the adequate level of 0.08 ppm whole blood Se at 31 days post treatment (fig. 1). Although the lower dose Se injection (MU-SE) crossed the 0.08-ppm level, it also did not differ from the control ($P > 0.05$). The higher dose Se injection (Multimin) and Se bolus were significantly higher in whole blood Se than both the lower dose Se injection and the control ($P < 0.05$, respectively), though they were not different from each other at 30 days posttreatment ($P > 0.05$).

At 90 days posttreatment, the only Se supplement that remained at an adequate whole blood level was the Se bolus treatment. The control Se blood levels dropped between 30 and 90 days posttreatment, indicating that the grazed pasture was deficient in Se, though forage samples were not completed in this trial. The control treatment at day 90 was severely deficient in whole blood Se. Both Se injection treatments were significantly lower than they were on day 90 compared to day 30 ($P < 0.05$, respectively), and fell between marginally and severely deficient.

Trial 2 results

All of the steers in trial 2 began the trial deficient in Se, and most would be considered severely deficient (fig. 2, 6/17/13). As seen in trial 1, the positive control steers that were treated with a Se bolus were adequate in whole blood Se at the first sampling posttreatment (7/8/13) and remained adequate for the duration of the trial. The negative control steers that were not supplemented remained below adequate levels throughout the trial. The loose salt treatment group significantly had higher whole blood Se levels in the first sampling after treatment initiation ($P < 0.05$). Se levels remained constant between first and second samplings after treatment initiation ($P > 0.05$). In the third sampling after treatment (8/20/13), whole blood Se levels decreased, but then actually significantly rebounded, reaching adequate levels in the fourth and final posttreatment sampling of the project ($P < 0.05$).

The pasture forage Se level was substantially low (fig. 3). A level of 0.1 ppm with a maximum intake of 2 ppm is considered necessary for cattle (NRC 2000). Both pastures in 2013, with the exception of one outlier sampling in July, were generally below this guideline, which again

TABLE 1. Se correlations with pasture forage species in trial 2, 2013

Forage species	Se level
Dallisgrass	−0.0474, P=0.7237
Tall fescue	0.0934, P=0.4854
Ryegrass	−0.1664, P=0.2119
Bermudagrass	0.2737, P=0.0376
White clover	−0.0493, P=0.7135
Smartweed	0.0372, P=0.7817
Sedge	−0.0773, P=0.5643
Mint	−0.1301, P=0.3304

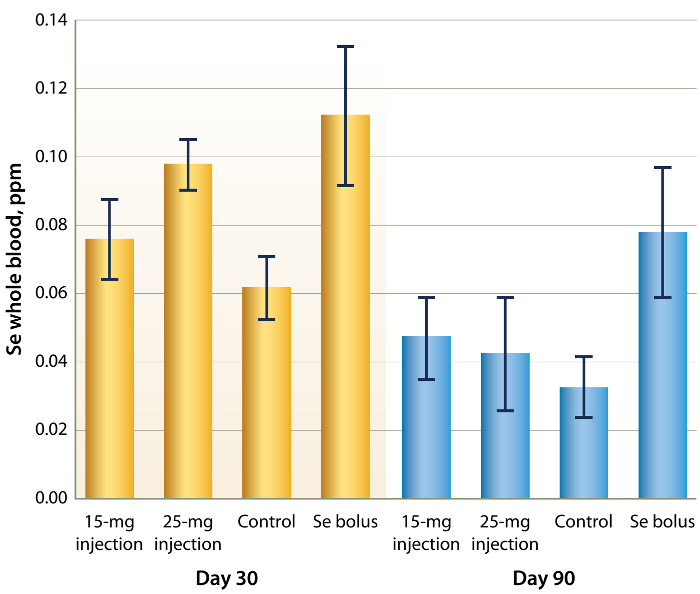

Fig. 1. Se whole blood levels (ppm) with 95% confidence intervals based on treatment and sample date for trial 1, 2011.

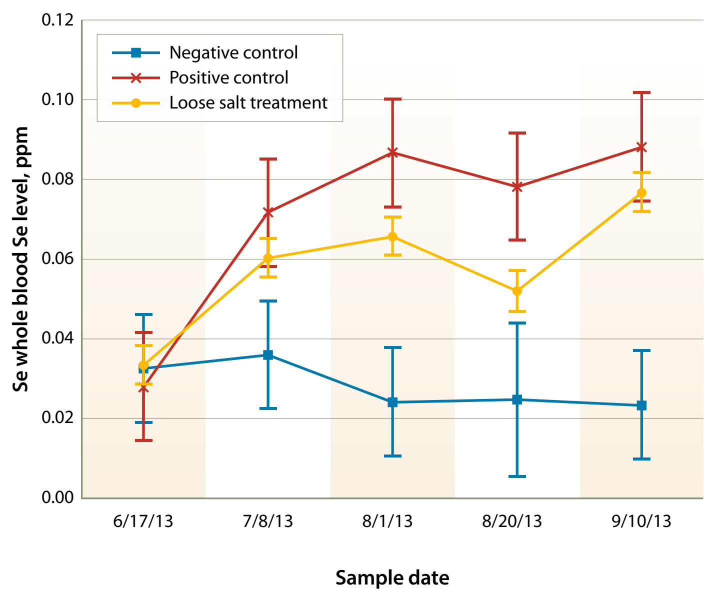

Fig. 2. Whole blood Se response with least significant differences by treatment and date in trial 2, 2013.

was evident with the consistent decline of Se levels in control cattle. Most likely due to the outlier sampling date, there was a significant date and date–pasture interaction ($P < 0.01$, $P = 0.04$, respectively), though pasture itself was not significant ($P = 0.07$). Only one significant correlation between forage species and Se level existed, which was bermudagrass, but the correlation was low ($P = 0.04$, $r = 0.27$, table 1).

TABLE 2. Average consumption of loose salt mineral supplement and associated Se uptake of the whole herd in trial 2, 2013

Sampling date	Loose salt consumed *oz/head/day*	Actual Se consumed *mg/head/day*	Herd average Se blood level *ppm*
7/8/2013	5.63	19	0.06
8/1/2013	2.76	9	0.07
8/20/2013	2.26	8	0.05
9/10/2013	4.43	15	0.08

Weight gain

Treatment did not significantly affect average daily gain in either trial ($P = 0.20$ and 0.12, respectively; fig. 4). Likewise, no correlation existed between Se whole blood level and cumulative average daily gain ($r = 0.15$) or weight at each sampling ($r = 0.16$) in the 2013 trial.

Comparison of treatment methods

Similar to the findings of Renquist et al. (2007), our data show that sustained herd average of adequate levels of whole blood Se are possible through the use of a Se rumen bolus. In both trial 1 and trial 2, Se levels elevated quickly, with most steers reaching adequate levels soon after treatment. This group consistently stayed at an adequate level throughout both trials. The rumen bolus method of supplementation appears to be a very dependable method of supplementation, particularly if Se is the only deficient mineral.

Injection forms of Se are easier to administer in terms of cattle restraint, applicator skill, and, usually, time. The injections do elevate Se levels. In our trials, the higher injection dose at 25 (Multimin) versus 15 (MU-SE) mg/head provided significantly higher whole blood Se levels than the lower dose at 30 days posttreatment. In this time frame, the Se whole blood level in cattle treated with the higher dose was equal to that in the Se bolus–treated cattle, but the benefits didn't last as long. Our results agree with others that at 90 days, an injection of Se should not be expected to provide any supplemental benefit regardless of dose (Genther and Hansen 2014; Maas et al. 1983). However, this method may be a practical consideration when combined with the loose salt–based supplemental method.

The greatest benefit of a salt-based supplement is that it allows multiple minerals to be supplemented at the same time. Our 2013 trial found that it was possible for the herd to reach an adequate level of Se with this supplemental method. The difference between this method and the others is that it takes a longer time period to bring deficient cattle to adequate levels. This treatment did increase whole blood Se levels soon after the supplement was placed into the treatment pasture, but remained at a marginally deficient level until the final sampling.

Since forage Se differences were not significantly impacted by plant species or pasture, we attribute differences in whole blood Se levels to the supplement consumed, and in fact, whole blood Se levels corresponded to consumption of

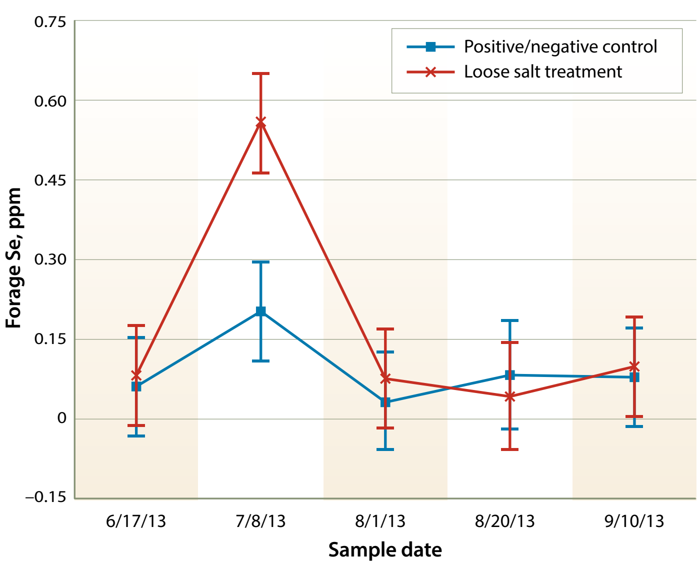

Fig. 3. Forage Se levels by pasture and sample date in trial 2, 2013.

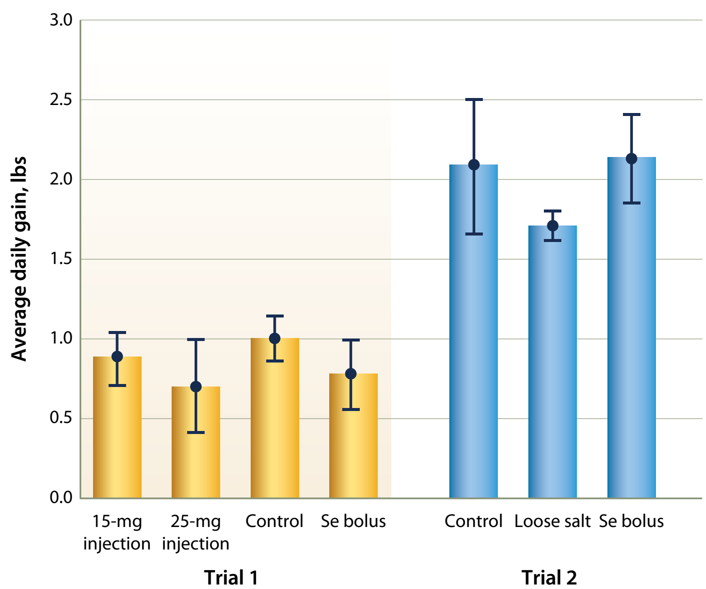

Fig. 4. Cumulative average daily gain and associated 95% confidence intervals by treatment in each trial.

TABLE 3. Average herd whole blood level and corresponding percentage of cattle below adequate and severely deficient in the salt-supplemented group of trial 2, 2013

Sampling date	Average herd Se blood level *ppm*	Salt-supplemented group below 0.08 ppm *%*	Salt-supplemented group below 0.05 ppm *%*
6/17/2013	0.03	100	88
7/8/2013	0.06	73	33
8/1/2013	0.07	69	29
8/20/2013	0.05	88	58
9/10/2013	0.08	54	21

the loose mineral supplement. Intake levels were high when the supplement was first placed in the pasture (6/17/13). At a consumption rate of 5.6 oz/head/day, the corresponding Se intake was 19 mg/head/day, which is similar to levels administered through Se injection. On the first posttreatment sampling date (7/8/2013, table 2), Se intake was 19 mg/head/day. By the next sampling date (8/1/2013), Se intake had declined to 9 mg/head/day, and then to 8 mg/head/day on the third sampling (8/20/13). Yet, on the last sampling date (9/10/13), the herd average intake had increased to 15 mg/head/day, and corresponding Se whole blood levels had again increased significantly. This data indicates the importance of continued consumption of the supplement in known deficient areas. Seasonal supplementation, such as only during the breeding season, does not appear to be a method to adequately maintain Se levels.

Though they did very well at a herd average, no supplemental method, including the bolus, brought all animals to adequate levels. Table 3 depicts the percentage of the loose salt treatment cattle that were still deficient or severely deficient as compared to the herd average Se level at each sampling. Surprisingly, all treatments were similar in this effect. Though the salt treatment reduced the percentage of cattle that were severely deficient by four times, there were still 21% of cattle that were severely deficient when the herd average was adequate. Even the bolus, which was considered a reliable long-term treatment, left 23% and 17% of animals severely deficient in trials 1 and 2, respectively. Combining supplementation methods may decrease the overall number of deficient cattle. This may include practices such as administering Se injections at the beginning of the supplementation period and then providing salt supplement as a means to maintain Se levels.

The rumen bolus method of supplementation appears to be a very dependable long-term method of supplementation, particularly if Se is the only deficient mineral.

Surprisingly, weight gain was not a function of Se whole blood level. Both trials had significant variance in animal Se levels and neither proved significantly attributed nor correlated with gain differences based on Se. Pasture appeared to be a greater influence on weight gain in 2013 than Se treatment. The pasture with the positive and negative control cattle had better gains, though not different from each other, than the separated loose salt treatment group. Correspondingly, the positive/negative control pasture was also higher in energy (total digestible nutrients, TDN) ($P < 0.01$) and protein ($P < 0.01$). We suspect this was due to a 10% higher basal cover composition of white clover in the control pasture ($P < 0.01$). This was surprising, as the pastures were separated only by a single fence line and both were originally planted on the same date.

This does not imply that correction of low Se levels is not important. Salles

Cattle grazed free-choice on irrigated pasture during both trials.

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et al. (2014) found significant immune response with elevated Se levels in calves. Nicholson et al. (1993) found slight antibody increases in yearling cattle that were supplemented with Se. Similarly, Makimura et al. (1993) found greater vaccine antibody response in Se-supplemented cattle. It appears that Se may not directly influence weight gain as do factors such as TDN in a ration; rather, it may have an indirect affect on an animal's overall health. Reductions in weight gain may only be noticed in Se-deficient cattle that experience some sort of immune challenge, which secondarily reduces weight gain. The possibilities for this type of challenge could be numerous, including parasite and disease infections, which are commonly faced by beef cattle producers. It is likely in our two controlled trials that these challenges were minimal due to many factors, such as contained herds with little exposure to outside cattle or off-ranch forage sources. However, one could speculate that at some time an immune challenge would occur, resulting in any number of animal health problems in a Se-deficient group of cattle. CA

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Larry Forero

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Practitioner perspectives on using nonnative plants for revegetation

by Elise Gornish, Elizabeth Brusati *and* Douglas W. Johnson

Restoration practitioners use both native and nonnative plant species for revegetation projects. Typically, when rehabilitating damaged working lands, more practitioners consider nonnative plants; while those working to restore habitat have focused on native plants. But this may be shifting. Novel ecosystems (non-analog communities) are commonly being discussed in academic circles, while practical factors such as affordability and availability of natives and the need for more drought tolerant species to accommodate climate change may be making nonnative species attractive to land managers. To better understand the current use of nonnatives for revegetation, we surveyed 192 California restoration stakeholders who worked in a variety of habitats. A large portion (42%) of them considered nonnatives for their projects, and of survey respondents who did not use nonnatives in vegetation rehabilitation, almost half indicated that they would consider them in the future. Across habitats, the dominant value of nonnatives for vegetation rehabilitation was found to be erosion control, and many respondents noted the high cost and unavailability of natives as important drivers of nonnative use in revegetation projects. Moreover, 37% of respondents noted they had changed their opinion or use of nonnatives in response to climate change.

Revegetation is a key restoration technique to address environmental damage and increase the ecological value of degraded habitat. It involves the active re-establishment of plant communities through seeding and planting, and is undertaken usually in response to a natural disturbance, such as wildfire, or another restoration activity such as the removal of invasive plants.

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The design and deployment of effective revegetation requires a practitioner to set project goals, choose plant species and determine methods to reach the desired final state for a site. Species selection is important because plants can modify the physical attributes of a site, land use, community composition and invasive plant species dominance (e.g., Meli et al. 2014).

Often, a fundamental requirement of a candidate plant species for revegetation is its classification as a native species. Native plants facilitate plant community trajectories toward a reference site condition, augment nutrient cycling, enhance wildlife habitat and reverse biodiversity loss (e.g., Bullock et al. 2011). In addition to the clear value of using native species to re-establish plant communities, however, there are several limitations of a natives-only requirement for revegetation projects. For example, native plant materials can be financially prohibitive (sometimes costing more than $1,000 per acre; Gornish 2015) and difficult to acquire.

The high cost of plant materials is one of the leading obstacles to effective revegetation nationwide (Brodt et al. 2009; Clewell and Rieger 1997; Stanturf et al. 2001). The exclusive use of native plants

A recent survey sheds light on how California's land management community views the use of nonnative species for revegetation projects. Here, author Elise Gornish surveys restoration plots in Yolo County.

Carissa Koopman-Rivers

can also restrict revegetation success because natives may not compete well with extant invasive species (Davies et al. 2010; Herget et al. 2015) and they may not establish as readily as nonnative species (Monsen 2004).

For the goals of some revegetation projects, nonnative plants provide greater management value than natives (e.g., D'Antonio and Meyerson 2002; SER 2004). For example, nonnative species might be competitively dominant to local weeds and, once seeded, prevent the establishment and spread of, and damage caused by, aggressive invasive plant species (Davies et al. 2010; Davies et al. 2015).

The rapid establishment rate of nonnatives is useful for erosion control in high-stress environments where soil destabilization is typical or revegetating landscapes exposed to intense wildfire (Pyke et al. 2013). The presence and persistence of nonnatives might also be facilitated more by changing environmental conditions than natives through, for example, altered introduction mechanisms (Hellmann et al. 2008). This would allow practitioners to accommodate the continuing effects of climate change on degraded habitat (Stromberg and Griffin 1996; Vasey and Holl 2007).

As expected, there is heated debate as to the overall environmental benefit and ecological ethics associated with using nonnatives for revegetation projects (Davison and Smith 1996; Pyke et al. 2013). Researchers acknowledge that many ecological habitats cannot return to the traditional native reference states that often form the basis of restoration project designs (e.g., Egan and Howell 2001). These habitats, termed "novel ecosystems" (Hobbs et al. 2006; Hobbs et al. 2009), contain novel species assemblages, interactions and functions (often as a result of climate change) and may require atypical approaches to revegetation. As a result, many practitioners now appear to be willing to consider nonnative species in revegetation projects (Carroll 2011; Eviner et al. 2012; Ewel and Putz 2004; Rodriguez 2006).

In California, where over 1,500 nonnative species have become naturalized or invasive in agricultural and natural areas (DiTomaso and Healy 2007), discussions concerning the potential role of nonnatives for revegetation are particularly intense due to the well-recognized ecological and economic impacts of weedy species. For example, major parts of the intermountain region within and adjacent to California are largely degraded from historic overgrazing and heavily infested by the aggressive annual grass *Bromus tectorum* (downy brome, or cheatgrass). Although revegetation attempts using native-only species have been longstanding, competitive pressure from downy brome, combined with low moisture availability in the region, has hindered rehabilitation efforts. In response, practitioners have employed nonnative species such as crested wheatgrass (*Agropyron cristatum* and *A. desertorum*), which have demonstrated great capacity to exclude downy brome and provide adequate ground cover (Asay and Johnson 1983).

These practices have elicited significant controversy. There are those who value the ecosystem services provided by crested wheatgrass and those who want to improve habitat using only native vegetation. The debate is ongoing, as are the different kinds of approaches: some practitioners in the intermountain region continue to use crested wheatgrass for revegetation, and others work to restore planted crested wheatgrass stands to native plant communities (Davies et al. 2013).

Given that approaches to revegetation may be shifting, we wanted to develop an understanding of how California's diverse land management community currently considers nonnative species for ecological revegetation efforts. This basic information will be helpful as a foundation for further discussing the potential role of nonnatives for revegetation (Kondolf et al. 2007).

Survey of land managers

We conducted a survey to assess California land managers' decision-making strategies involving the use of nonnative plants in revegetation projects. Our goal was to answer three general questions: (1) Across habitat types and organization types, what percentage of individuals implementing revegetation in California use nonnative species? (2) What are the motivations driving the use of nonnative species for revegetation? (3) How does climate change mediate considerations of nonnative species use in revegetation projects?

We had several expectations for survey outcomes. First, we predicted that at least half of the individuals surveyed would consider nonnative species for revegetation projects. We expected this because the well-known difficulties in successfully re-establishing native plant communities in California (e.g., Allen et al. 2005; Stylinski and Allen 1999) can motivate practitioners to try less conventional revegetation approaches. Second, since government agencies can sometimes be slower to adopt new approaches, we predicted that individuals from federal, state and county agencies would be less likely to use nonnatives for revegetation projects

An in-progress restoration experiment in Monterey County. The right half of the fenced plot was sprayed to reduce invasive Russian thistle (tumbleweed).

than individuals from nongovernmental organizations (NGOs). We expected erosion control to be the most common motivation for using nonnatives in revegetation projects. Maintaining ground cover to arrest topsoil loss and maintain belowground moisture is one of the most critical components of landscape revegetation — an imperative highlighted by the Society for Ecological Restoration, which advocates for the use of nonnatives, when necessary, to provide ground cover early in the revegetation effort. Finally, many of the underlying principles of ecological revegetation, including the availability of an intact native reference site, and the appropriateness of locally adapted native species, become more complicated to apply when operating within a climate change scenario (Harris et al. 2006). As a result, we expected that a majority of revegetation stakeholders would reconsider attitudes or practices related to the use of nonnative species for revegetation in light of climate change.

TABLE 1. Survey questions

#	Question
1	For which agency or organization do you work?
2	Choose the type of agency • Federal government • State government • Local government • University • Resource Conservation District • Land trust • Nongovernmental organization • Other
3	Which ecological systems do you primarily work in (choose all that apply)? • Agriculture • Coastal scrub • Desert • Forest • Grassland • Riparian • Sage-steppe • Wetland • Urban • Other
4	Have you ever used nonnative plant species in restoration projects? • Yes • No
5	If no, why not? Choose all that apply. • Do not believe nonnatives should be planted • Have not needed to use nonnative species
6	If yes, what nonnative species have you used (specific species or types of plants)?
7	What were the goals for using nonnative species? Choose all that apply. • Erosion control • Forage for livestock or wildlife • Short-term fix • Availability/cost • Weed control
8	Have any of your attitudes or practices related to nonnative plants changed in response to climate change? • Yes • No
9	How have your practices related to revegetation changed in response to climate change? • Use nonlocal native species • Use nonnatives that are better adapted to drought • Willing to try more nonnatives for weed control
10	Name and contact information (optional)

Survey development

We conducted an electronic survey of land managers, restoration consultants and others involved in revegetation in California. Results from an informal pre-survey and interviews with land managers in 2012 were used to refine survey questions. The online survey (created using SurveyMonkey) consisted of 10, mostly multiple-choice questions with space for respondents to include additional comments (table 1). The survey was deliberately short, in an attempt to increase participation.

Questions investigated the habitat types in which respondents worked, whether they had used nonnative species, the purpose for which the species were used and whether practices were changing in response to climate change. Questions were posed with reference to restoration, with respondents using their own interpretation of that term.

The survey link was distributed by email in August 2015 to 321 contacts identified by the authors as active in the field of vegetation management. These contacts were composed of land managers drawn from the membership list of the nonprofit California Invasive Plant Council. The survey was also posted to the LinkedIn groups of the California Society for Ecological Restoration (SERCAL, 745 LinkedIn members) and the Society of Wetland Scientists Western Chapter (55 LinkedIn members). We distributed to these groups because they are some of the largest and most longstanding regional societies in California with a cultivated membership characteristic of our target audience. Membership in these groups is disproportionately composed of organizations involved in land management and government agencies, and, as a result, these organizations and agencies are represented disproportionately in the survey data.

Previous surveys deployed by the California Invasive Plant Council using the same approach elicited high response rates from a targeted population (Cal-IPC 2015). In the directions accompanying the survey, we requested that individuals fill out the survey only once, but we had no method to ensure that they did so. We closed the survey on Sept. 4, 2015. We received 192 responses, for an approximate response rate of 17% (there is overlap among members in the contact groups).

Analysis of survey data

To address sampling bias, all data were weighted proportionally to a globally derived group of affiliations based on our sampling lists (Maletta 2007). To simplify data for analysis, we organized organizational affiliations into more general groups. Survey responses from federal agencies (e.g., Bureau of Land Management [BLM], U.S. Fish and Wildlife Service, and U.S. National Park Service) were grouped into a federal category, state agencies (e.g., California Department of Water Resources, California Department of Food and Agriculture, and California State Parks) were grouped into a state category and local agencies (e.g., resource conservation districts, county agricultural commissioners' offices, and county departments of parks and recreation) were grouped into a local category. Private firms (e.g., for-profit restoration companies and for-profit consultants) were grouped into a private category, nonprofit organizations (e.g., land trusts, the Nature Conservancy, Audubon) were grouped into an NGO category and academic affiliations (e.g., colleges and universities, university-affiliated research reserves and UC Cooperative Extension) were grouped into a university category.

We also grouped habitat types to address unbalanced representation across systems. Where appropriate, habitat types that were represented by a very small number of (< 10) respondents were grouped with habitat types that shared major abiotic characteristics. For example, vernal pools were grouped with wetlands, sage-steppe and chaparral were grouped together, coastal dune and coastal scrub were grouped together, and oak woodlands were grouped with grasslands.

Using R version 3.2.0, we employed Pearson's chi-square tests to identify significant differences in (1) the use of nonnative species for revegetation among organizational types and (2) the role of climate change in modifying perspectives on using nonnative species in revegetation. Formal statistical analyses were not used on questions related to the use of nonnative species for revegetation in different habitat types or on questions about the goals for using nonnative species for revegetation because respondents were able to choose more than one habitat type and goal, violating chi-square assumptions of random independent trials.

Survey responses

Survey responses were dominated by individuals associated with government (but not necessarily regulatory) agencies at the federal (31%, 61 respondents), state (10%, 19) and local (11%, 22) levels (fig. 1). Of the remaining respondents, 3% (5) were from land trusts, 19% (37) from other NGOs, 17% (32) from university affiliations and UC Cooperative Extension, and 9% (17) from private firms.

We did not ask respondents for their geographic location, but the organizations listed cover at least 25 of the 58 counties in California. We asked respondents to categorize the ecological system in which they worked (fig. 2). The most common habitat types given were grassland (71%) and riparian (68%), followed by wetland (45%), forest (35%), coastal scrub (32%) and desert (19%). Other habitat types listed included sage-steppe (5%), oak woodland (4%), chaparral (4%), agriculture (3%), dunes/estuarine (2%), vernal pool (1%), open aquatic system (1%) and urban (1%). Most respondents (76%) noted that they worked in multiple habitat types.

Of the total respondents, 42% (80) said that they currently used or in the past had used nonnative species for revegetation. There were significant differences across affiliations (fig. 1; $\chi^2 = 33.90$, $p < 0.001$): While a majority of federal agency respondents (67%) used nonnative species for revegetation, only 39% of respondents from state agencies and 26% of respondents from local agencies used nonnative species for revegetation. Respondents from NGOs and private firms were less likely to use nonnatives (17% of NGO respondents and 19% of respondents in private firms). Half of respondents from university affiliations used nonnative species for revegetation.

There appeared to be differences in the use of nonnative species for revegetation across habitats (fig. 2), from a high of 55% in desert habitats to a low of 27% in coastal scrub. Of those who did not use nonnative species, 55% (62) stated that they were not comfortable with the use of nonnative species for planting and seeding projects; 52% (58) stated that they had not needed to use nonnative species and 5% (6) noted that they did not use nonnative species as a matter of formally mandated policy at their place of work (responders were able to identify more than one reason).

Across habitat types, there did not appear to be a difference in the factors that motivated the use of nonnative species for revegetation (fig. 3). For most of the habitats listed (agriculture, coastal scrub, forest, grassland, riparian, sage-steppe, urban and wetland), erosion control was the top or among the top goals cited for the use of nonnative species in revegetation. The exception was desert systems, in which forage was the top motivating factor (fig. 3).

Lastly, 37% (70) of all respondents noted that their attitudes or practices related to nonnative plants for revegetation had changed in response to climate

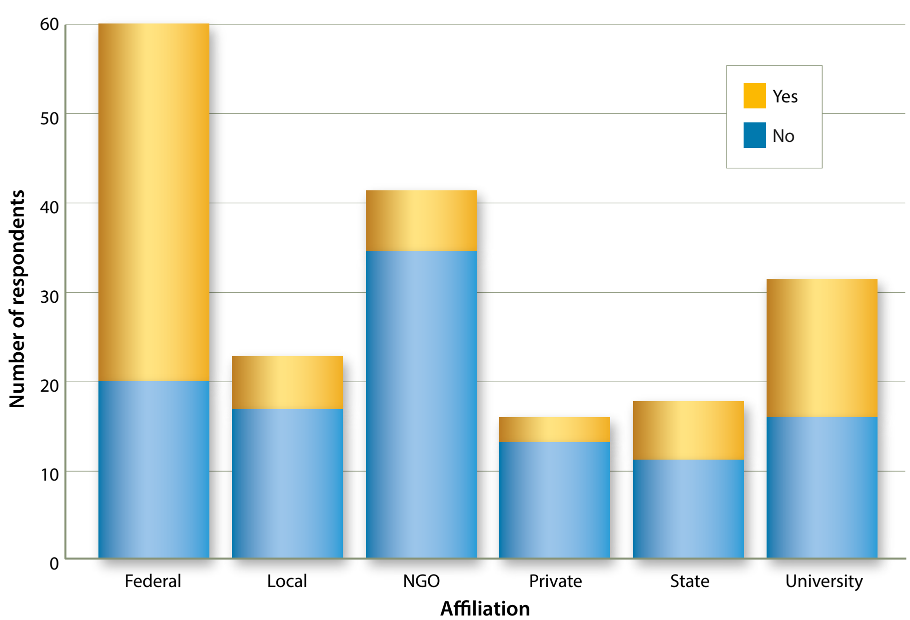

Fig. 1. Number of respondents, by agency, who used/did not use nonnative species for revegetation projects.

change (data not shown). These attitudes were unaffected by current use of nonnative plants in revegetation ($\chi^2 = 0.11$, $p = 0.742$) or affiliation ($\chi^2 = 8.58$, $p = 0.127$). Thirty of these individuals stated that they would consider using native plant materials from geographically nonlocal sources, while 24 noted that they would consider using nonnative species that are better adapted to climate change.

Nonnatives review

The majority of practitioners surveyed in this study did not consider using nonnative plant species for revegetation projects within California, an apprehension likely due in part to historical revegetation efforts that resulted in unintended ecological harm — for example, *Tamarix* spp. escaping U.S. Department of Agriculture bank stabilization projects to become noxious weeds in the West (Hultine et al. 2010). More than half of these respondents noted that they did not need to use nonnative species for revegetation. Their fill-in responses highlighted the utility of hybrids and varieties of natives to develop a high-diversity mix that proves beneficial for achieving revegetation goals.

Government agencies were more likely to use nonnative species for revegetation projects than other organizations (excluding university affiliates). This could be a result of a difference in revegetation goals. On lands managed for multiple use objectives, including grazing, revegetation goals may emphasize increasing forage production and palatability, and not necessarily include increasing native plant biodiversity. Revegetation goals on other lands may emphasize re-establishing functional plant communities that match an ecological reference site.

Despite a history of negative ecological consequences of using nonnative species for revegetation in the West (e.g., Cable 1971; Gray and Muir 2013), almost half of the practitioners surveyed indicated that they have used nonnative species for revegetation projects, suggesting that — from the perspective of a practitioner — the potential benefits of nonnative species can outweigh the ecological risks. Of the respondents who indicated that they did consider nonnative species for restoration, erosion control was the top motivator across habitat types. Erosion control, especially early in a restoration project, can enhance stability to subsequently resist invasive species spread and allow for the establishment and persistence of native species (Morris and Schupp 2009). Species highlighted in the fill-in section as commonly used for erosion control primarily included annual grasses, such as rye, barley, orchardgrass, and in some cases perennial grasses, such as wheatgrass (crested, intermediate and Siberian).

In some cases, nonnative species have proven utility for rehabilitation due to their adaptability, high establishment rates and low-cost availability (e.g., Richards et al. 1998). Indeed, respondents commonly mentioned the high cost of native plant material and the unavailability of many needed species, which has been discussed elsewhere (Török et al. 2011). However, the importance of maintaining and re-establishing native biodiversity is widely recognized.

One way to enhance widespread use of native species for revegetation projects is to expand the availability of native plant

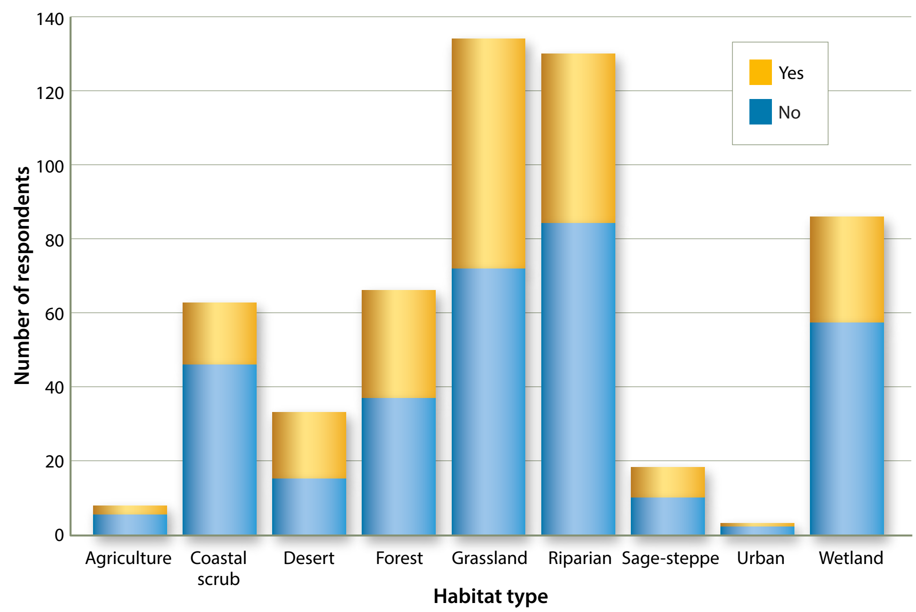

Fig. 2. Number of respondents, by habitat type, who used/did not use nonnative species for revegetation projects.

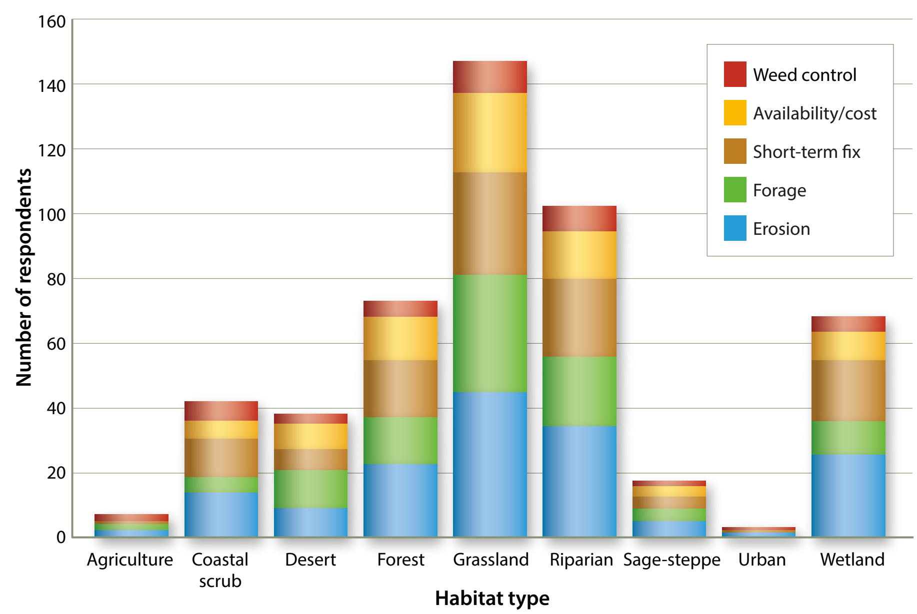

Fig 3. Goals, by system, for using nonnative species for revegetation. Respondents were able to indicate more than one motivation per system.

materials at a reasonable cost. Currently, many groups, such as the nursery industry, private organizations and government agencies, are making strides to expand the availability of natives (e.g., BLM's National Seed Strategy). Moreover, given that the top motivation for using nonnative species is erosion control, researchers might focus on identifying native plants with traits that enhance soil stability, such as rapid establishment and considerable root structure.

The relatively large portion (37%) of respondents who noted they had changed their perspective and practices related to nonnatives as a result of climate change highlights an important dynamic to be considered by both researchers and practitioners. As reliance on nonlocal and nonnative plant materials increases, continued research investigating the relationship between climate change and invasive plants (e.g., Hellmann et al. 2008) is imperative. It is needed to provide high-confidence predictions of the spread and impact of invasive species, which will help practitioners design effective revegetation strategies.

For their part, practitioners can request from native nurseries the seed collection and mass production of native species with traits that confer resilience to drought. Researchers in academia can take the lead on conducting greenhouse and field experiments that identify fruitful revegetation candidates. Cooperation among the entire network of stakeholders associated with restoration will result in more effective strategies for land managers designing and deploying revegetation projects that accommodate the effects of climate change.

Exploring the use of nonnative species in revegetation involves accepting, philosophically, the role of nonnative plants in ecosystems, and it involves practical considerations, such as project objectives and plant availability and cost. This survey illuminates current practices of those working in restoration in California, and these data will support further discussion about the role of nonnative plants in restoration. CA

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On-farm flood capture could reduce groundwater overdraft in Kings River Basin

by Philip A.M. Bachand, Sujoy B. Roy, Nicole Stern, Joseph Choperena, Don Cameron *and* William R. Horwath

Chronic groundwater overdraft threatens agricultural sustainability in California's Central Valley. Diverting flood flows onto farmland for groundwater recharge offers an opportunity to help address this challenge. We studied the infiltration rate of floodwater diverted from the Kings River at a turnout upstream of the James Weir onto adjoining cropland; and calculated how much land would be necessary to capture the available floodwater, how much recharge of groundwater might be achieved, and the costs. The 1,000-acre pilot study included fields growing tomatoes, wine grapes, alfalfa and pistachios. Flood flows diverted onto vineyards infiltrated at an average rate of 2.5 inches per day under sustained flooding. At that relatively high infiltration rate,10 acres are needed to capture one CFS of diverted flood flow. We considered these findings in the context of regional expansion. Based upon a 30-year record of Kings Basin surplus flood flows, we estimate 30,000 acres operated for on-farm flood recharge would have had the capacity to capture 80% of available flood flows and potentially offset overdraft rates in the Kings Basin. Costs of on-farm flood capture for this study were estimated at $36 per acre-foot, less than the cost for surface water storage and dedicated recharge basins.

California's Central Valley accounts for roughly 10% of U.S. agricultural production: $45 billion in 2014 (CDFA 2015; USDA 2016). The region faces two major hydrologic issues: severe and chronic groundwater overdraft, and flood risks from winter storms. Climate models suggest the Central Valley's droughts and floods will continue (Reclamation 2011, 2014), raising, for researchers, growers and other stakeholders, an interesting challenge: can groundwater overdraft be reduced and flood risks mitigated by diverting floodwaters onto agricultural lands for groundwater recharge?

Groundwater makes up 30%, 38% and 54% of total water demand in the Sacramento River, San Joaquin River and Tulare Lake hydrologic regions, respectively (DWR 2013). From 2005 to 2010, between 5.5 and 13 million acre-feet (MAF) of storage was lost in the Central Valley aquifer (DWR 2013), and San Joaquin Valley groundwater levels are more than 100 feet below previous historic lows (DWR 2014).

Most models predict more variation in average precipitation for California watersheds (Reclamation 2011, 2014), likely resulting in earlier snowmelt, more precipitation as rain, and increased frequency of extreme events, including droughts and floods. Earlier and more extreme runoff events are expected (DWR 2003; Hayhoe et al. 2004; Thorne et al. 2012), which will challenge the ability of California's water infrastructure to efficiently capture and convey sufficient water to meet municipal, agricultural and environmental water needs (DWR 2013). Diverting flood flows for groundwater recharge, a process known as on-farm flood capture, is considered an important

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Irrigation districts and water agencies are considering on-farm flood capture as a tool for increasing groundwater resources and managing increasingly variable precipitation due to climate change.

Philip Bachand

tool for coping with more-variable future precipitation (DWR 2013; Langridge et al. 2012; Tetra Tech 2011).

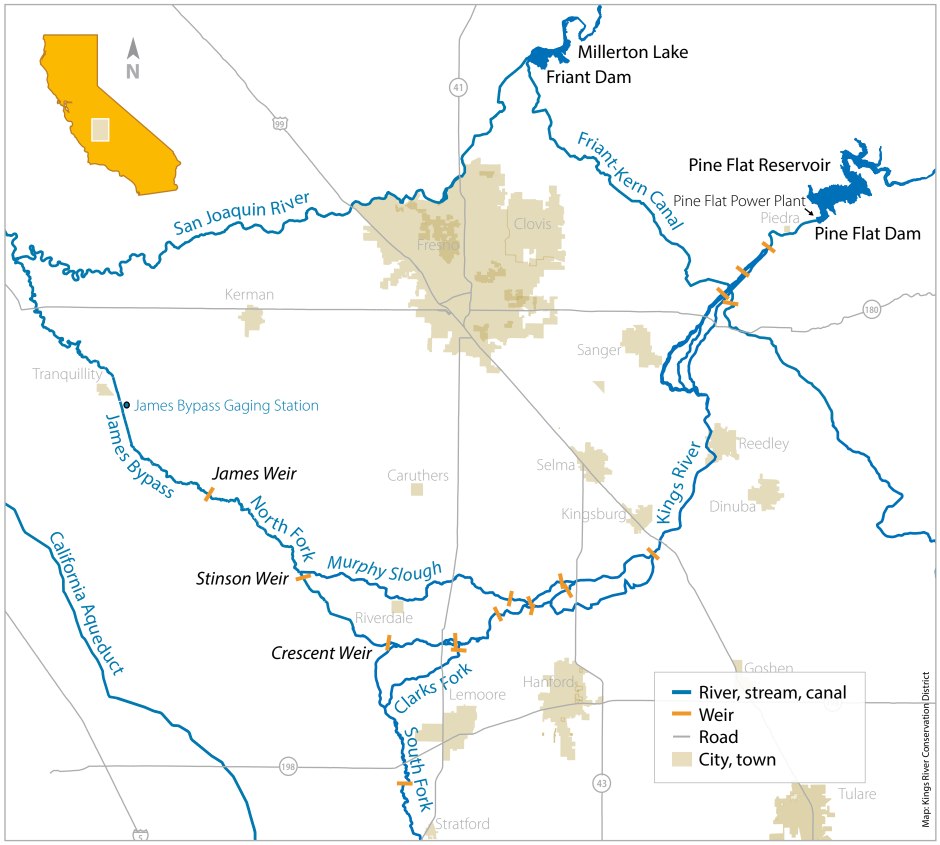
Kings River Basin

Our study looked at on-farm flood capture project in the Kings River Basin. Like the rest of the Central Valley, agricultural production in the area relies heavily on surface water supplies and groundwater to meet crop water needs. The Kings River Basin requires 2.7 MAF to meet irrigation demand. WRIME (2007) calculated a water budget for the Kings Basin from 1964 to 2004. Surface water deliveries to this area varied annually, ranging from about 0.3 to 1.5 MAF (WRIME 2007). Groundwater supplied 1 to 2.2 MAF, or about 60% of total water demand, resulting in an average 0.16 MAF annual overdraft (WRIME 2007). A more recent study found that, from 2003 to 2013, groundwater storage decreased 0.23 MAF annually (KRCD 2013).

Ironically, recurring floods along the Kings River corridor also impact the area. Over the 44-year U.S. Geological Survey (USGS) period of record (fig. 1; 1947–1954, 1973–1974, 1976–2009), 8.5 MAF of surplus flood flows have passed through the James Bypass, a man-made flood channel with a design capacity of 4,750 cubic feet per second (CFS) that is the continuation of the North Fork of the Kings River to the Mendota Pool and the San Joaquin River. These surplus flood flows are defined as unclaimed flood flows that are both hydrologically and legally available. Under normal operation the James Bypass is dry and hydrologically disconnected from the San Joaquin River (Reclamation 2005). Under high flow conditions, the U.S. Army Corps of Engineers diverts Kings River water into the North Fork-James Bypass channel at Crescent Weir (map).

Since 1983, flood damages in communities along the Kings River and the downstream San Joaquin River are $1.4 billion (2013 dollars) (Bachand et al. 2013; Reclamation 2005; USACE 1999). These floods have occurred despite joint management of upstream Pine Flat Reservoir and the river and drainage network by Kings River Water Association and the Army Corps of Engineers (i.e., diversions, bypasses, etc.) for flood control and water supply (KRCD and KRWA 2009; Reclamation 2005). That management protocol provides guidance for flow management, including when flows exceed the design capacity of system levees and channels, and requires under very high flow conditions that flows be sent down the James Bypass in excess of the channel design capacity (fig. 1; Reclamation 2005).

Irrigation districts are contemplating or have implemented recharge basins to capture available flood flows to increase groundwater resources (WRIME 2006a). Average surplus flood flows through the James Bypass during years in which (flood) flows occurred have been nearly 2,000 CFS, corresponding to a median



Under high flow conditions, Kings River water is diverted into the North Fork-James Bypass channel at Crescent Weir (bottom). Source: KRCD and KRWA 2009.

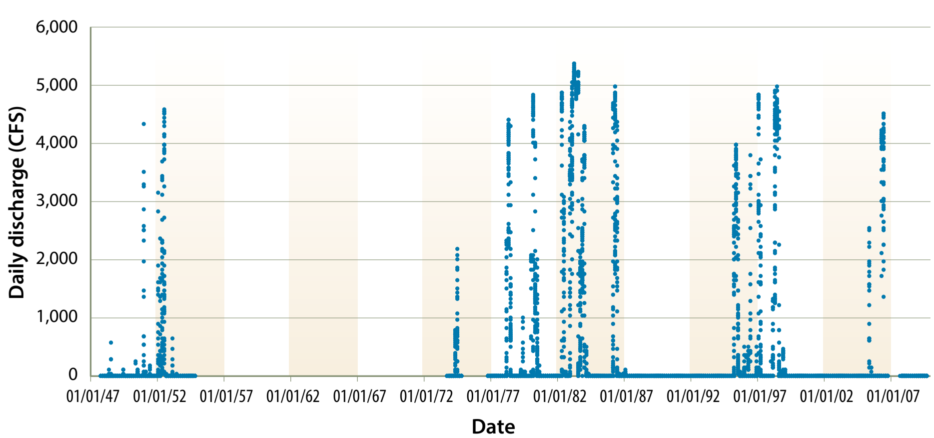


Fig. 1. Flows in excess of 100 CFS generally only occur in the James Bypass during flood flow conditions, and at those times they are managed to not exceed the channel design target of 4,750 CFS. Flood flows have a recurrence interval of 2 years and vary greatly in magnitude, at times exceeding the channel design capacity. Periods in which no data are shown do not have available or approved data. Source: USGS 2010.

capture of 0.18 MAF during those years. Those rates exceed annual groundwater overdraft rates for those specific years (WRIME 2007). However, these considered projects and other engineered solutions (e.g., recharge using irrigation canals) rely upon dedicated public or private lands (WRIME 2006a, 2006b), limiting flexibility and capacity.

Over the last two decades, Kings River Basin growers and landowners have worked with the Kings River Conservation District (KRCD), Kings River Water Association (KRWA) and other water agencies to explore and develop recharge strategies and facilities. Engineered recharge basins on 67 dedicated acres were proposed near the James Bypass that would be designed to capture up to 800 acre-feet of flood flows monthly, providing roughly 2,000 acre-feet annually of in-lieu recharge (groundwater conserved by surface water being used in lieu of pumping groundwater) and dormant flooding (flooding when crops are dormant) (KRCD 2000, 2006). Several public agencies began developing a regional conjunctive use program (combined management of surface water and groundwater) as part of the Kings Basin Integrated Regional Management Plan (IRWMP), completed in December 2006 with the publication of the Kings Basin Conjunctive Use Feasibility Analysis (WRIME 2006b). It recommended acquiring 2,600 recharge acres to capture flows of 660 CFS. Expanding into farmlands would significantly increase the recharge area available to help achieve the maximum potential recharge (RMC 2015).

Under this project, we studied the 2012 diversion of surplus flood flows onto agricultural lands at a turnout upstream of James Weir (fig. 2). Our goals were to (1) determine infiltration rates under a recharge condition on agricultural fields and assess likely groundwater quality impacts, (2) assess farm-scale implications for implementing on-farm flood capture, including the compatibility of land management for crop operations and for flood flow capture, and (3) estimate its costs. The study did not consider other considerations regarding resource management strategies as related to capturing flood flows (KBWA 2012; e.g., groundwater for drinking water; regional infrastructure, conveyance, coordination and integration; relationship to local water planning and regulation) or broader water rights issues regarding flood flows in the Central Valley.

Field tests

Field tests were conducted on an annual crop (tomatoes) and perennial crops (wine grapes, pistachios and alfalfa). Methods are presented in detail

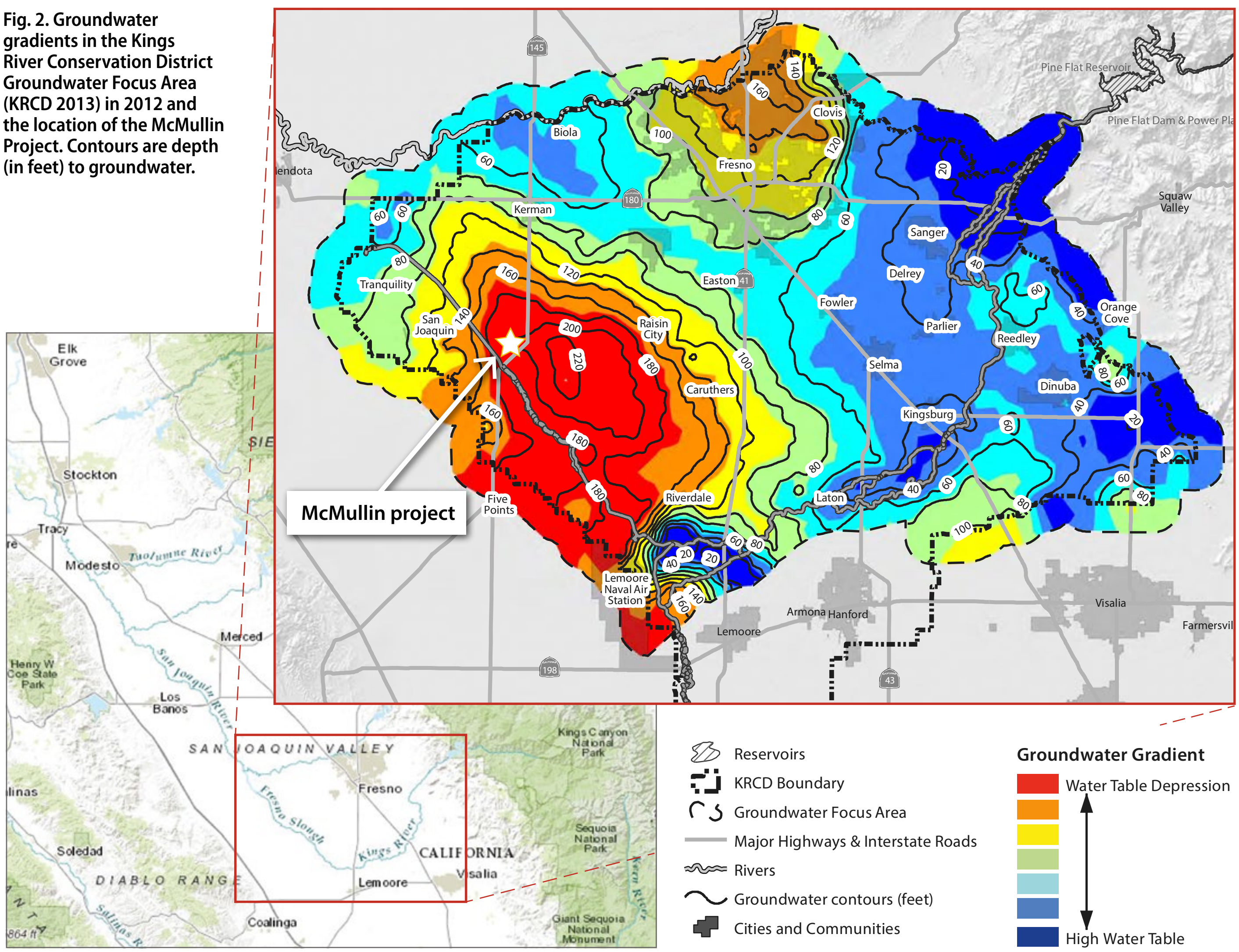


Fig. 2. Groundwater gradients in the Kings River Conservation District Groundwater Focus Area (KRCD 2013) in 2012 and the location of the McMullin Project. Contours are depth (in feet) to groundwater.

by Bachand et al. (2012, 2014). In brief, flows of 2 to 22 CFS were diverted via the turnout into a private irrigation canal in January and then from April to early July. Through a combination of permanent and temporary infrastructure, flows were distributed to experimental study checks and demonstration fields across 1,000 acres of Terranova Ranch, which is an approximately 6,000-acre farm. The flow diversions were for both direct (from the surface to groundwater) and in-lieu recharge. Flows in the James Bypass were in the 2,000 to 4,500 CFS range during this period (fig. 3).

Experimental study checks were used to determine potential infiltration rates under recharge conditions for agricultural fields and to assess water quality effects. Agricultural fields were divided into checks separated by small berms to allow uniform shallow flooding of 6 to 12 inches. Eleven checks were selected in wine grape and alfalfa fields to determine recharge infiltration rates and to assess water quality. These checks were on soils categorized as loamy sand or sandy loam (i.e., Fresno fine sandy loam, Fu; Cajon loamy coarse sand, Cb; Fresno-Traver complex, Fx; Pond fine sandy loam, Pt; Traver fine sandy loam, Tt). Except for Cajon loamy coarse sand, all of these soils are considered to have very limited infiltration rates (hydrologic soil groups C and D). Checks were in the range of 3 to 5 acres, representing a subset of the larger field test.

Pressure transducers calibrated to staff gauges recorded surface water elevation. Infiltration rates were corrected after accounting for evapotranspiration using crop coefficients derived from CIMIS (2011). River and canal water, surface water flooded onto fields, and pumped groundwater were analyzed for total and inorganic dissolved nitrogen and phosphorus, and electrical conductivity (EC) to assess water quality. In a subset of wine grape checks, soil moisture, EC and temperature probes were placed in the root zone, and soil cores were collected to depths of 15 to 25 feet, to assess soil pore water changes.

Agricultural fields located across 1,000 acres were studied to assess farm-scale considerations such as infrastructure, field management, logistics, crop effects and costs. Three rented pumps with capacities in the range of 3,600 to 5,000 gallons per minute (gpm) conveyed water from the diversion canal into the irrigation system and cycled floodwaters to the fields. Nutrient management was typical, with nutrients being added as necessary based on plant or soil analyses.

Costs associated with project implementation, including field preparation,

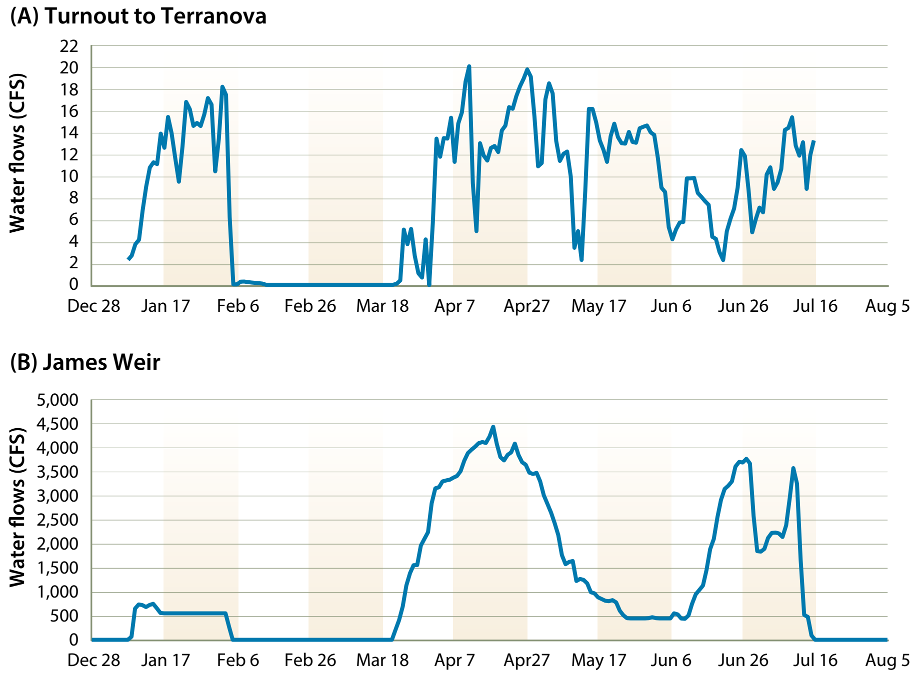


Fig. 3. Flows diverted into Terranova through the turnout (A) and past the James Weir into the James Bypass (B) (CDEC 2012). Diverted flows ranged up to 22 CFS. The total volume diverted to the ranch was 3,116 acre-feet.

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Pumps and engines were connected to piping to pull floodwater onto agricultural fields from the diversion canal on the James Bypass.

installation and rental of equipment and infrastructure, labor, energy and project support, were tracked by Terranova Ranch. From these costs we estimated costs for on-farm flood capture for a 25-year period, assuming an average flood recurrence interval of 2 years, based on historical records (fig. 1).

Infiltration rates

Initial infiltration rates on the studied wine grape and alfalfa checks averaged around 8 inches per day (up to 25 inches per day on one field with soil type Fx, considered to have very limited infiltration potential), decreasing to about 4 inches per day after 2 days, and then asymptotically approached 2 to 2.5 inches per day after sustained flooding of up to 20 days. These infiltration rates exceeded rates for the confining layers (the soil layers in the root zone that are documented as limiting the rate of infiltration) of these hydrologic group C and D soils (NRCS 1998). We attributed these higher infiltration rates to soil preparation, which included deep ripping, and associated crop establishment practices.

At the sustained infiltration rate of 2.5 inches per day, 10 acres are required to infiltrate 1 CFS (fig. 4; 62.5 acre-feet per month). For a field of approximately 70 acres, this relationship corresponds to pumping water onto the field at 3,500 gpm. These rates represent the potential infiltration achievable on Terranova Ranch where water conveyance and availability are not limiting.

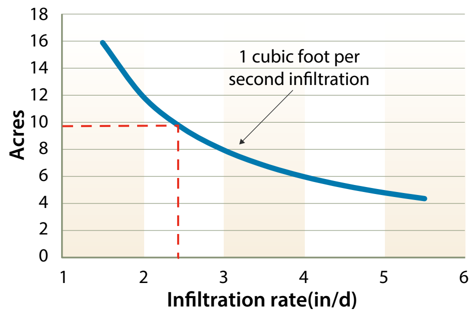

Fig. 4. At the infiltration rate of approximately 2.5 inches per day measured in this study, approximately 10 acres are required to capture 1 CFS. That relationship corresponds to pumping water at 3,500 gpm onto a 70-acre field.

Water quality

Kings River flood flows are derived from Sierra snowmelt, with salt and nitrate concentrations one or more orders of magnitude lower than in pumped groundwater at this study site. Soil probe and soil core data from the checks showed the applied water flushed salts and nitrate from the root zone. With implementation of this program, legacy salts and nitrate would be flushed from the root and vadose zone to groundwater.

For the Terranova site, a simple mass balance model was developed describing salinity and nitrate concentrations through the vadose zone using the collected soil core data and groundwater data. From that simple model, we calculated approximately 40 feet of water would be needed to displace the approximately 2.25 pounds per square foot (11 kilograms per square meter) of legacy salts and approximately 0.04 pounds N per square foot (0.2 kilograms N per square meter) of legacy nitrate into groundwater at this site (Bachand et al. 2014). We estimated an additional 40 feet of water would return groundwater to initial salt and nitrate levels through dilution (Bachand et al. 2012). Ariyama (2015), using a more sophisticated Hydrus model, estimated about 60 feet of water would be needed to return the groundwater to current salinity levels.

Further applied flood flows would improve groundwater salinity levels over time. This will benefit landowners throughout the flood corridor by improving soil quality and groundwater sustainability. The use of existing or modified water conveyance structures within irrigation districts could provide pristine floodwater to more landowners and magnify local benefits.

Wintertime modifications to tomato field to manage water were similar to rice checks to enable capture and infiltration of flood flows. Modifications included cutting small check berms to accommodate field gradients and installing low cost flashboard risers to manage water flow and elevations.

Farm-scale implementation

Flood flows were diverted throughout the 1,000 acres for about 2 weeks in January and then from April to early July. In all, over 3,000 acre-feet of water was diverted from the Kings River onto these fields. Wine grapes were flooded with sufficient water for direct recharge during April and May. One pistachio field and one alfalfa field also had sufficient floodwater in April for direct recharge of 13 and 7.5 inches, respectively. As the growing season progressed, evapotranspiration increased and more applied flood flows went to meeting consumptive demands as in-lieu recharge and less to direct recharge.

Conveyance constraints

Conveyance infrastructure (e.g., turnout, pump and pipe capacities) constrained flood flow applications. The distribution rate of water across the 1,000 acres (0.26 inches per day, or 0.65 feet per month), even during peak diversion periods in April and May, was an order of magnitude lower than the achievable long-term soil infiltration rates demonstrated in the experimental check studies (2.5 inches per day, or 6.3 feet per month).

Crop yield and quality

Flood flow diversion onto these fields was timed to not interfere with necessary land preparation practices for crop management. Wine grapes and alfalfa were expected to be able to tolerate flooding and saturated conditions. Vineyards showed no damage in either the 2010 or 2011 crops (Bachand et al. 2014). Pistachios were assumed to be able to tolerate flooding before leafing out. No significant yield penalties were found for either pistachios or alfalfa. Recharge on annual crops such as tomatoes was conducted during fallowed periods.

Costs support flood capture

Capturing and applying flood flows was calculated at $36 per acre-foot during this project (Bachand et al. 2013). These costs included labor costs, land preparation, fuel and farm-scale infrastructure improvements. Some applied water went to direct recharge for future benefits and some to in-lieu recharge for current benefits. In comparison, large-scale surface water storage can cost from $300 to $1,100 per acre-foot (DWR 2013), and dedicated recharge basins cost from $90 to $1,100 per acre-foot (Choy et al. 2014).

Groundwater is the only irrigation source in this region of the Kings Basin and groundwater is currently 220 to 230 feet below the surface in large areas of the Kings River Basin (KRCD 2013; fig. 2). In the study area, groundwater costs approximately $88 to $120 per acre-foot to extract (D. Cameron, personal communication; JID 2010; MWH 2004). For the study site, we calculated that if 25% or more of the captured flood flows can be used for in-lieu recharge, then the savings in groundwater pumping costs can support an active on-farm flood capture program by individual farmers (Bachand et al. 2012, 2014).

Considerations as a regional or statewide tool

Under a DWR Flood Corridor Grant being implemented by KRCD and with local matching funds by Terranova Ranch, the McMullin On-Farm Flood Capture and Recharge Project (McMullin Project) is expanding this technology to a more regional scale. Under Phase 1, the project will enroll approximately 5,000 acres (including the current project area) and have the capacity to divert 150 CFS of flood flows onto 1,500 acres actively managed for recharge during flood flow conditions. At full build-out, the project will increase the capacity to 500 CFS covering 16,000 acres of farmland with 5,000 acres managed for recharge at any given time (CNRA 2013). This diversion rate is equivalent to 30,000 acre-feet monthly.

The project will have implications in the Kings Basin as related to both (1) mitigating regional flood risks and (2) offsetting groundwater overdraft. A hydrologic and hydraulic (H&H) analysis was conducted using established modeling tools available for assessing California river flows and associated economic relationships: a one-dimensional unsteady network flow (UNET) model (DWR 2012; USACE 2002), and a HEC (Hydraulic Engineering Center) flood damage analysis (FDA) (DWR 2012). This analysis predicts a benefit-cost ratio for this project greater than 1.8, with benefits occurring downstream of the James Weir along the Kings and San Joaquin rivers, particularly from reducing damages associated with 10- to 100-year flood events (Bachand et al. 2013).

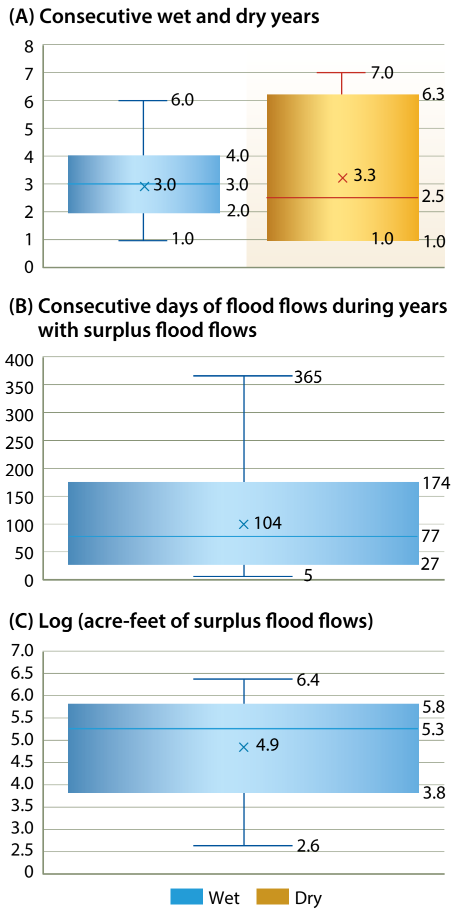

Fig. 5. Surplus flood flows past the James Weir on average have occurred every 2 years. However, wet and dry years are typically grouped with 2 to 4 consecutive wet years followed by 1 to 6 consecutive dry years. During wet years, flooding typically lasts from 1 to 6 months, with an average duration of 3.5 months and a median duration of 2.5 months. Large volumes of water flow through the James Bypass during those flood periods: the median annual volume is 0.18 MAF while the 75th percentile is 0.60 MAF. Graphs show min and max (whiskers), mean (x), 25th and 75th quartiles (box) and median (line). Source: USGS 2010.

Panoramic picture of the James Bypass from the Terranova Ranch in October 2010 (top) and early February 2011 (below) from the Highway 145 overpass to the James Weir. Flood flows occur approximately on a 2-year interval, but the James Bypass can be dry for years at a time or flooded for several months consecutively.

An integration of the WRIME (2007) and KRCD (2013) groundwater overdraft analyses finds groundwater overdraft rates in the Kings Basin similar in magnitude to surplus flood flow losses. For instance, from 1980 through 2009, surplus flood flows past the James Weir were 7.4 MAF, and groundwater overdraft was about 5.3 MAF. Current annual rates of groundwater overdraft of 0.23 MAF (KRCD 2013) are equivalent to the calculated annually averaged surplus flood flows from the USGS dataset (fig. 1).

The McMullin Project will provide capacity to offset Kings Basin groundwater overdraft. If operated over 3 months to capture flood flows, a period typical for flood flows past the James Weir (fig. 5), the McMullin Project would capture 90,000 acre-feet, about 40% of the annual King Basin overdraft of 230,000 acre-feet reported by KRCD (2013). When considering the historical record since 1980 (USGS 2010), at a fully operational capacity of 500 CFS, the McMullin Project would have enabled capture of nearly 20% of surplus flood flows (fig. 6). Additional systems would provide additional capacity. We estimate that four such projects (2,000 CFS diversion; 20,000 acres managed for recharge during flood flow conditions) would have been able to capture 60% of total flood flows over that period, while six such projects (3000 CFS diversion; 30,000 acres managed for recharge during flood flow conditions) would have been able to capture 80%. As the capacity increases, diminishing returns would be expected, given the decreasing frequency of flood flows great enough to fill the available recharge capacity.

Other factors come into play when considering regional and statewide scaling. Climate change will complicate surface water storage, altering the timing and magnitude of available surface water runoff from the Sierra (DWR 2013; Reclamation 2011, 2104). More recharge capacity than predicted by historical records is likely needed. Adjusting to these changes will require structural and operational adjustments to water management facilities. Flood capture through recharge is a relatively low cost and expandable approach that could address problems of both storage and timing. Changing the operation of the statewide reservoir system to release flows to optimize the integration of groundwater and surface water storage and to manage flood risks — rather than focusing only on optimizing surface water storage and managing flood risks — is a paradigm shift for statewide water management and could increase opportunities for groundwater recharge throughout the Central Valley.

Changing the operation of the statewide reservoir system to release flows to optimize the integration of groundwater and surface water storage and to manage flood risks . . . is a paradigm shift for statewide water management and could increase opportunities for groundwater recharge throughout the Central Valley.

Logistical, societal and legal issues also exist. Many areas in the Central Valley appear suitable for on-farm flood recharge (Bachand et al. 2015; O'Geen et al. 2015). But implementation challenges include providing sustainable funding mechanisms for system operation and maintenance, developing flexible flood capture strategies, working within water rights constraints and managing risks for growers (Bachand et al. 2015). For participating growers, challenges include integrating flood flow capture infrastructure and practices with farming operations, developing methods of funding such as selling easements and irrigation cost savings, working with water managers to rapidly mobilize when needed, and developing an appropriate cropping mix and nutrient management strategies to facilitate the flood flow program, promote dual-purpose use (i.e., flood capture and agriculture) and manage water quality risks. On-farm flood capture could be leveraged to address societal issues as well. Disadvantaged communities are disproportionately affected by poor groundwater quality in the Central Valley, and strategic implementation of on-farm flood capture could dilute common contaminants such as nitrate and salts (Ariyama 2015; Bachand et al. 2014) and improve groundwater quality. Finally, central to implementing on-farm flood capture broadly is the question of how it integrates into California's water rights, which provide the legal framework for distributing water in California. CA

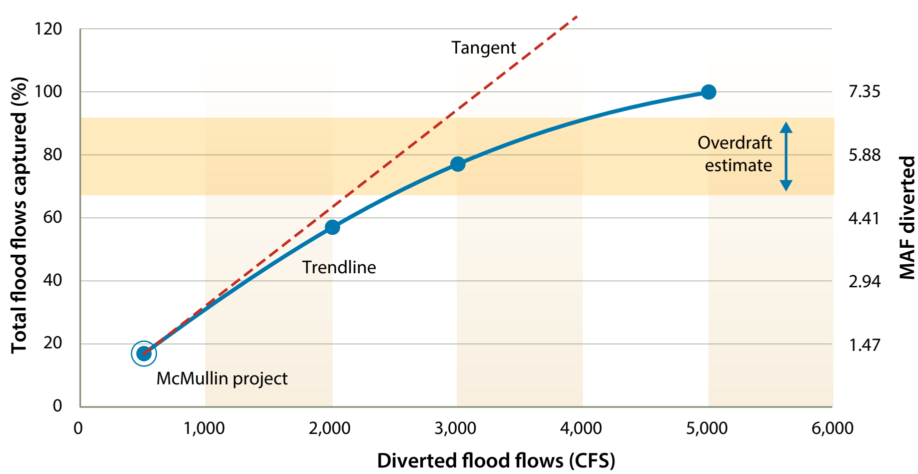

Fig. 6. The McMullin Project, if operational at build-out capacity (capable of diverting 500 CFS) since 1980, would have been able to capture nearly 20% (1.47 MAF) of the total available surplus flood flows (7.35 MAF) in the James Bypass from 1980 through 2009. We estimate that four equivalent projects (capable of diverting 2,000 CFS total), would have the capacity to capture 60% (4.41 MAF) of flood flows. As more capacity is added, diminishing returns occur because there are fewer flood events large enough to fill the recharge system to full capacity. Flow data source: USGS 2010. Overdraft estimate from WRIME (2006a) and KRCD (2013).

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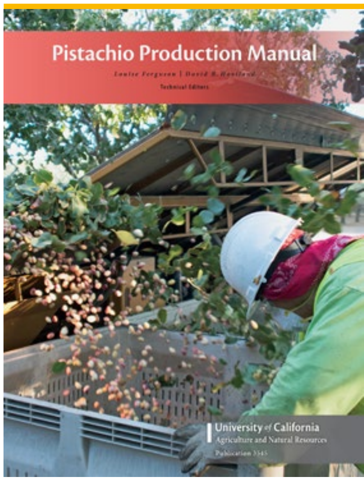

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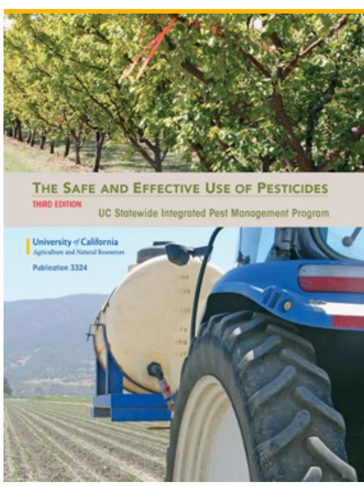

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