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ALSO IN THIS ISSUE

The Cost-Effectiveness of Using Rebates to Incentivize Groundwater Recharge

Molly Bruce, Luke Sherman, Ellen Bruno, Andrew Fisher, and Michael Kiparsky

Managed aquifer recharge has emerged as a popular supply-side management tool for basins facing groundwater overdraft. We studied the effectiveness of an incentive structure similar to net energy metering that subsidizes private parties who conduct recharge on their land. A pilot program in the Pajaro Valley demonstrates that the strategy is more cost effective than many other groundwater management options.

Correcting our groundwater issues will likely require some combination of supply augmentation and demand management. When wet winters come around, common questions arise: How can we capture that water and store it for later use? And, how can we incentivize farmers, water managers, and other private individuals to help? In part because of the lack of clear answers to these questions, groundwater is in crisis throughout the world—new tools and approaches are sorely needed.

Managed aquifer recharge can enhance aquifer conditions and increase locally available groundwater supply. Managed aquifer recharge diverts available water (e.g., stormwater, excess flood water, recycled water) to either engineered (e.g., injection wells) or natural infrastructure (e.g., flood plains) to increase infiltration. But often, locations with hydrogeologic conditions amenable to managed aquifer recharge are located on private land. Individual landowners have little incentive to use their land to undertake recharge for the benefit of the basin at large if they must bear all the cost.

In this article, we explore the potential for incentives to encourage the development of distributed managed aquifer recharge—catchment systems spread throughout a groundwater basin, rather than centralized in a single location. As we detailed in a recently published article in *Nature Water*, we used a case study of recharge net metering (ReNeM), a novel rebate program deployed in the Pajaro Valley of California, to demonstrate the cost-effectiveness of these incentives relative to other groundwater management alternatives. We also used this case study to demonstrate the potential for use of ReNeM rebates elsewhere.

Akin to net energy metering, which compensates program participants with at-home solar power systems for the energy they feed to the electric grid, ReNeM incentivizes the construction and operation of managed aquifer recharge projects on private property by compensating participants based on the measured quantity of water each project infiltrates. The program engages three parties: 1) the water agency that runs the program, 2) the operators that facilitate recharge on their properties, and 3) a third-party certifier that helps identify viable sites, assists in project design and monitoring, and, importantly, measures the infiltration quantity that informs rebate payments.

Groundwater 101

Groundwater can be a replenishable resource in the sense that groundwater pumping can deplete it, but precipitation can recover it; when rain, snow, or other surface water sources collect in an area with appropriate conditions, that water percolates through the soil into the aquifer and groundwater levels recover. However, much more groundwater is removed in a given

year than gets replenished, leading to declining groundwater supplies.

Groundwater overdraft is a major concern in California and in many other groundwater-dependent agricultural regions. In California, groundwater extraction is largely unmetered; landowners have historically faced few pumping restrictions. This has led to the chronic lowering of groundwater levels, which in turn has led to higher pumping costs, land subsidence, deteriorated water quality, and other negative outcomes.

In response to these concerns, at the end of 2014, California passed groundwater legislation that is changing the way groundwater is being used and managed throughout the state. The Sustainable Groundwater Management Act requires local water agencies to manage their basin's groundwater for long-run sustainability. To meet this mandate, these agencies are deploying a range of supply- and demand-side management strategies, finding additional surface water supplies to offset groundwater pumping when possible, and limiting groundwater use where necessary.

California's climate features an oscillating pattern of wet and dry years. Groundwater serves as a critical buffer to surface water shortages during those drought years but needs to be replenished during wet years. Managed aquifer recharge could be an important part of the solution, and strategies for incentivizing landowners to participate in groundwater recharge will likely be necessary.

The Pajaro Valley Case Study

The Pajaro Valley is an agricultural region on California's central coast that relies almost exclusively on groundwater to irrigate a variety of high-value crops like berries and vegetables. Agriculture accounts for about 90% of the region's water demand.

The Pajaro Valley's basin-wide pumping exceeds recharge, contributing to chronic groundwater overdraft at a rate of roughly 12,000 acre-feet per year. A key impact of this overdraft is seawater intrusion, which can increase the salinity of the water used to irrigate crops. The local water agency, the Pajaro Valley Water Management Agency (PV Water), has been striving to resolve this problem for many years because of its threat to the viability of the local agricultural industry. Groundwater-dependent agricultural regions throughout California and the world face analogous water-management challenges because supplies are inadequate to meet current and projected demand.

Table 1. Pajaro Valley Water Management Agency's Priority Projects

Water Management Project and Description	Cost Per Acre-Foot (2021 U.S. Dollars)	Yield Estimate (Acre-Feet Per Year)
(D-6) Increased Recycled Water Deliveries	0	1,250
(D-7) Conservation	229	5,000
Recharge Net Metering (ReNeM)*	570	375
(S-22) Harkins Slough Recharge Facility Upgrades	572	1,000
(R-6) Increased Recycled Water Storage at Treatment Facility	801	750
(S-2) Watsonville Slough With Recharge Basins	1,145	1,200
(S-3) College Lake With Inland Pipeline to CDS	1,259	2,400
(S-1) Murphy Crossing With Recharge Basins	1,602	500
(R-11) Aquifer Storage and Recovery	1,717	3,200
(S-11) River Conveyance of Water for Recharge at Murphy Crossing	1,717	2,000
(G-3) San Benito County Groundwater Demineralization at Watsonville Wastewater Treatment Plant	2,862	3,000
(S-4) Expanded College Lake With Pinto Lake, Corralitos Creek, Watsonville Slough, and Aquifer Storage and Recovery	3,319	2,000
(SEA-1) Seawater Desalination	3,892	7,500
(S-5) Bolsa de San Cayetano With Pajaro River Diversion	4,006	3,500

Source: Bruce et al. 2023. Available at: https://www.nature.com/articles/s44221-023-00141-1.
Note: *ReNeM estimates are based on two pilot sites for comparison with other PV Water projects.

How Does ReNeM Work?

Unlike most irrigators in California, irrigators in the Pajaro Valley already pay volumetric water-extraction fees, so ReNeM acts as a rebate on these charges. Annual payments to rechargers in the Pajaro Valley are currently based on a simple formula:

$$\text{Payment} = \lambda Q_t C_t$$

where Q_t is a project's net infiltration in acre-feet in a given year t, and C_t is a per-unit groundwater pumping fee in year t. Payments are scaled by a factor, λ, which 1) accounts for uncertainty, and 2) could in principle be adjusted to alter the incentives for participation, the distribution of benefits, or other elements of program performance and outcomes. The scaling factor (λ) is currently set to 0.5.

Because the rebate payment corresponds to infiltration volume (Q_t), factors such as site selection, system design, and project management decisions can each influence a project's performance and therefore the size of the rebate payment. Additionally,

infiltration volume depends on hydrologic conditions, which vary both within and across years.

How Does ReNeM Compare to Other Projects?

In our evaluation of two pilot sites in the Pajaro Valley, we found that ReNeM has the potential to reduce overdraft at a lower unit cost than most alternative water management methods under consideration in the region.

The local water agency has identified numerous possible water management methods as part of its long-term basin management planning, has modeled these methods' annualized costs, and has prioritized these options, largely based on fiscal and political feasibility. Table 1 lists these various projects, their estimated costs, and their projected yields. Project codes included in parenthesis correspond with those used in PV Water's 2014 Basin Management Plan—see PV Water's Basin Management Plan for full descriptions of each project. We similarly calculated ReNeM's annualized costs and compared it to the annualized costs of alternative methods.

Our calculation of ReNeM's costs included 1) operation and maintenance costs such as equipment, labor, permitting, and third-party certifier services, 2) capital costs such as design and construction, and 3) opportunity costs of land used for recharge. Though ReNeM's costs also included transaction costs associated with finding a third-party certifier, landowner outreach, and overall program management, these costs were unable to be quantified and therefore were not included in our analysis. Importantly, the cost of water supply to PV Water's ReNeM program was zero because rechargers used hillslope runoff.

ReNeM's total annualized cost from the two pilot sites was $570 per acre-foot, which falls well below that of seawater desalination ($3,892 per acre-foot) and nine other projects the agency has prioritized that range in cost from $801 to $4,006 per acre-foot.

Figure 1 compares costs across projects by ordering them from lowest to highest unit cost. Each block in this figure represents a project that the local water agency has under consideration, its estimated cost per acre-foot, and its volumetric contribution to addressing chronic groundwater overdraft. The red vertical line shows the Pajaro Valley's overdraft volume–the amount by which groundwater extraction in the basin outstrips replenishment. To correct overdraft, the agency plans to undertake all projects to the left of this red line (displayed in yellow). ReNeM, outlined in black, may yield a relatively small contribution to the water balance, but does so at relatively low cost.

Positive Net Benefits

We next calculated ReNeM's net present value (NPV) over a 25-year project lifespan, discounted to the present at a 6% discount rate:

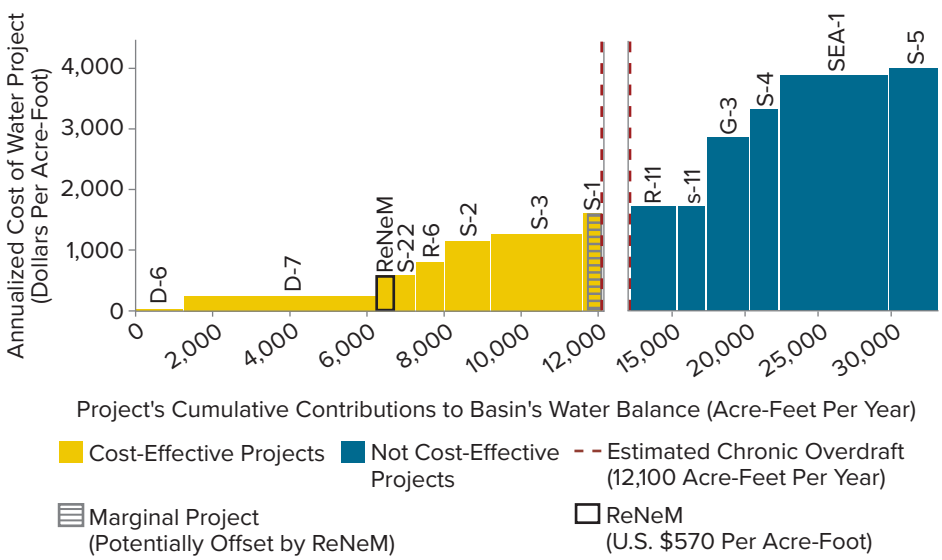
$$\text{NPV}=\sum_{t=1}^{25}\frac{\text{benefits}_t-\text{costs}_t}{(1.06)^t}$$

where benefits and costs are estimated in each year, t.

ReNeM's primary monetized benefit was its relative cost savings—the money saved by avoiding other, more costly groundwater management projects that would otherwise be necessary to correct overdraft in ReNeM's absence. This benefit was calculated by multiplying the amount of water ReNeM infiltrated by the value of that water, which was estimated to be $650 per acre-foot by the third-party certifier using the average of a group of low-cost projects described in PV Water's Basin Management Plan. Plugging in the estimated costs and benefits using values shown in Table 2 (on page 4), we estimated that the project would generate net benefits equivalent to $1.9 million over the project's lifespan. Benefits would be even greater if we used the marginal water-replacement value of $1,602 (project S1—see Table 1) to quantify the value of avoiding other, more costly groundwater management projects.

After calculating the program's overall NPV, our analysis then considered how ReNeM's benefits and costs were distributed separately between rechargers and the agency. ReNeM's

Figure 1. Comparison of Annualized Costs Across PV Water Projects



Source: Bruce et al. 2023. Available at: https://www.nature.com/articles/s44221-023-00141-1.

NPV of $1.9 million was distributed between rechargers and PV Water, acting on behalf of the groundwater basin, to the tune of $270,000 and $1.63 million, respectively, as shown in Figure 2. Error bars show 95% confidence intervals based on a Monte Carlo simulation that modeled the impact of hydrologic variability on infiltration and, as a consequence, on the NPV. The amount that accrues to landowners is driven by the rebate payment formula and the magnitude of λ, which can be adjusted.

Generalizing Beyond the Pajaro Valley

ReNeM is particularly well-suited for use in regions that levy extraction fees on groundwater users: payments can be pegged to extraction fees, which can, in turn, make the program revenue-neutral, or even revenue-positive for the agency. But fees are not necessary—an incentive scheme can still work in the absence of extraction fees.

Though the cost of water supply to PV Water's ReNeM program was zero because rechargers used hillslope runoff, other locations that explore ReNeM may face permitting costs to use hillslope runoff or incur other costs associated with alternative water supplies for recharge. In either case, these locations will want to incorporate the cost of water into an economic analysis of the program.

Concluding Thoughts

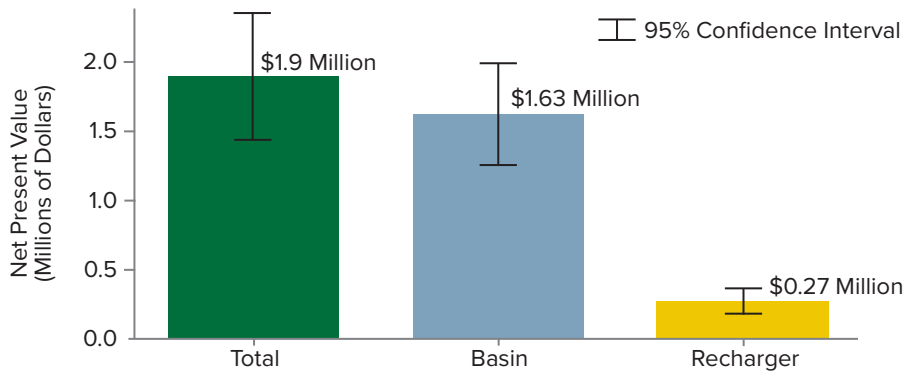
Subsidies for groundwater recharge are one additional tool that can be added to the groundwater management toolkit. ReNeM presents a unique policy tool whereby landowners are financially incentivized to conduct recharge on their land. By studying pilot projects in the Pajaro Valley, we found that ReNeM's incentive structure can be a promising approach to cost effectively promote groundwater recharge. Our analysis suggests that aggregate net benefits remain positive over a range of scenarios beyond that which exists in the Pajaro Valley, suggesting that this type of incentive structure may be beneficial in other regions.

Table 2. ReNeM Parameter Values for Cost-Benefit Analysis

Variable	Value
Project Lifespan	25 years
Quantity of Infiltration	375 acre-feet per year average (varies)
Water Replacement Value	$650 per acre-foot
Discount Rate	6%
Site Management, Operation, and Maintenance	$1,000 per acre per year
Site Supplies, Operation, and Maintenance	$500 per project per year
Opportunity Costs to Land	$1,780 per acre per year
Fixed Project Design Costs	$847,000
Annual Third-Party Certifier Expenses	$13,400 per project
One-Time Third-Party Certifier Expenses	$3,700 per project

Source: Bruce et al. 2023. Available at: https://www.nature.com/articles/s44221-023-00141-1.

Figure 2. Distribution of ReNeM's Net Benefits Among Parties



Source: Bruce et al. 2023. Available at: https://www.nature.com/articles/s44221-023-00141-1.

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Economics of Navel Orangeworm Management in Almond and Pistachio Orchards

Scott Somerville and Brittney K. Goodrich

Navel Orangeworm (NOW) infestations damage tree nuts, reduce grower revenue, require costly management practices to control, and threaten food safety and trade. We estimate that from 2018 through 2021, almond and pistachio growers spent an average of $393 and $262 per bearing acre, respectively, on winter sanitation and pesticide sprays targeting NOW. These costs are equivalent to 7.8% of almond and 3.7% of pistachio revenues.

Navel Orangeworm (NOW) is the top pest of California almonds and pistachios and affects other crops like walnuts, pomegranates, and figs. Female NOW moths lay their eggs on the fruiting bodies of tree nuts, and the resulting larvae burrow through the shell and eat the kernel. NOW damage is linked to aflatoxin contamination—a carcinogen—threatening food safety and exports to highly regulated key markets, such as the European Union.

To ensure product quality and food safety, nut processors—known as handlers—remove inedible nuts primarily caused by NOW damage. The share of inedible nuts delivered to handlers provides the best statewide estimate of NOW damage, which, for almonds, averaged 1.5% over the past two decades, as shown in Figure 1. However, a 2023 report from a major almond handler notes "excessive reject levels attributable to NOW… with levels running well into double-digit percentages for many loads."

Handlers incur costs to remove damaged nuts and pay growers premiums based on the reject percentage. This means that NOW damage influences grower revenues from two angles: first, the quantity of edible nuts they are paid for, and second, the resulting price per pound of edible nuts.

This article provides an analysis of NOW management practices and associated costs and benefits in almond and pistachio orchards. Our study focuses on years 2018 through 2021, including the most recent available pesticide use and cost data, and where appropriate, averages over four years to avoid bias caused by alternate bearing crop yields.

NOW Management Practices and Costs

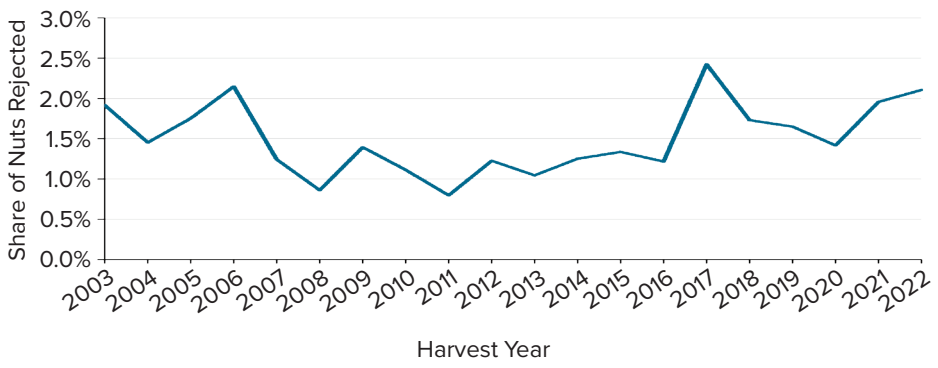
NOW larvae overwinter in the residual nuts in trees and on orchard floors from the previous harvest. These nuts are also known as mummy nuts. Moths emerge from mummy nuts around April, with subsequent generations emerging in late June/early July, August, and September. A new crop of tree nuts is safe from NOW infestation until the fleshy nut hull splits open, allowing moths access to the developing shell and kernel. Almonds reach the hull split stage in June/July, while pistachios split in August/September.

The primary tools available to growers to combat NOW damage include winter sanitation, mating disruption, pesticide sprays, monitoring pest populations, and early harvest. When growers combine these and other practices to form an Integrated Pest Management (IPM) protocol, they can reduce the share of harvested meats rejected by the handler, leading to an increased yield of edible nuts and price premiums for quality, while minimizing negative environmental impacts from pesticides.

Winter Sanitation

Beginning as early as November, winter sanitation involves removing mummy nuts from trees and then gathering and destroying them before March. Using almond Cost and Return Studies published by the Department of Agricultural and Resource Economics at the University of California, Davis, we calculate that almond winter sanitation costs were approximately $268 per acre. Assuming growers sanitize all bearing acreage, the annual average winter sanitation cost per almond-bearing acre is equivalent to 5.3% of the 2018–2021 average yearly revenues of about $5,080 per acre in 2021 dollars. This cost includes labor, fuel, lube, repairs, and custom services associated with mechanically

Figure 1. Rejected Share of Almonds Delivered to Handlers



Source: Almond Board of California, 2022; Almond Almanac; USDA NASS, 2023; Noncitrus Fruits and Nuts 2022 Summary.

shaking and hand poling mummy nuts from the trees, sweeping nuts into windrows, and shredding them with a mower.

In pistachio orchards, once the mummy nuts have been shaken to the ground and windrowed, growers destroy them alongside tree prunings, resulting in a winter sanitation cost of roughly $138 per acre, equivalent to 2% of 2018–2021 average yearly revenues of $7,000 per acre in 2021 dollars.

Despite being a foundational component of an effective NOW IPM program, winter sanitation is still challenged by weather and economic considerations. In a 2020/21 survey, about 82% of almond and 80% of pistachio growers reported using winter sanitation every year. Respondents reported that precipitation, which prevents growers from accessing fields with heavy equipment, is the top impediment to winter sanitation.

Using weather data and San Joaquin Valley (SJV) almond orchard locations, we calculate that precipitation in December 2022 through January 2023 was more than three times the average for the same months over the preceding twenty years. High winter rainfall in winter 2022–2023 may have hindered winter sanitation. Beginning winter sanitation in November is one strategy to mitigate the risk of high rainfall, but that coincides with other orchard activities like pruning and weed control.

Furthermore, labor is a large share of winter sanitation costs, and recent changes to California labor laws have increased minimum wage rates and decreased the overtime pay threshold, resulting in higher labor costs for some growers. Using UC Davis Cost and Return Studies, we estimate that labor accounts for 25% of almond winter sanitation costs in the Sacramento Valley and northern SJV. This estimate includes the cost of equipment operator labor, manual labor, and labor provided by custom services. In the southern SJV, labor accounts for 75% of winter sanitation costs. This is due to the high reliance on hand poling to remove mummy nuts from trees to achieve the UC IPM recommendation for the region of less than one mummy nut for every five almond trees, compared to less than two per tree in the Sacramento Valley and southern SJV. From the 2020 South SJV Pistachio Cost and Return Study, we estimate that labor accounts for 54% of winter sanitation costs. Thus, increasing labor costs can have a substantial impact on NOW management costs.

Pesticide Applications

Pesticides play a vital role in NOW management in most tree nut orchards, but applications require careful timing to coincide with moth emergence and hull split to be effective.

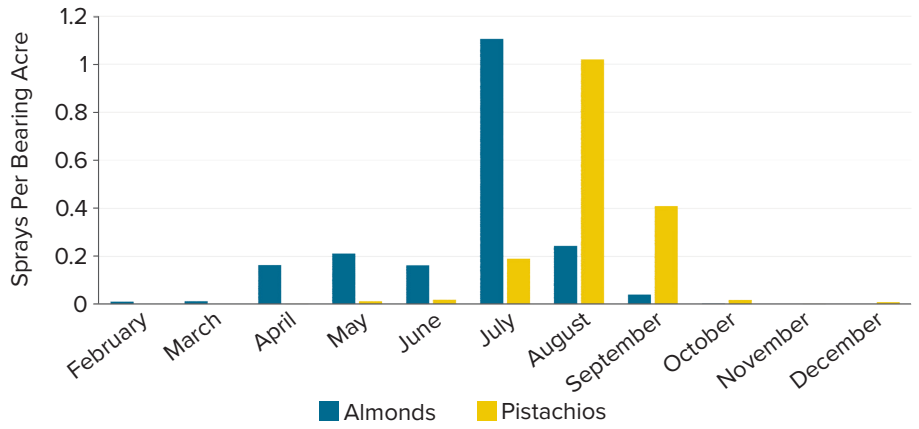
According to the UC IPM guidelines, almond orchards may require up to two pesticide sprays during hull split and a spring spray in orchards with a history of NOW damage. In pistachios, the UC IPM guidelines suggest spraying once during hull split and again when pest populations are high or when harvest is delayed. The number of pesticide applications has important operating cost implications, especially around peak application periods.

We use 2018 through 2021 data from the California Department of Pesticide Regulation (CDPR) to analyze the quantity and timing of products used to target NOW, distributor prices, and application costs from UC Davis Cost and Return Studies.

We find that, on average, growers apply 1.9 and 1.7 pesticide sprays targeting NOW per bearing acre per year in almond and pistachio orchards, respectively. Peak spraying activity occurs around hull split, as shown in Figure 2, when each almond and pistachio acre receives, on average, roughly one pesticide spray. Timing spray applications to coincide with hull split and moth emergence is critical to spray efficacy and requires daily monitoring of hull split progression and pest populations. Growers also use spring sprays to target NOW emerging from mummy nuts.

We estimate that the annual average pesticide materials plus equipment, fuel, and labor used to spray orchards equaled $125 and $124 per bearing acre of almonds and pistachios, respectively—equivalent to 2.5% of almond and 1.8% of pistachio revenues. Table 1 provides a breakdown of pesticide material and application costs.

Figure 2. Average Number of Pesticide Applications Targeting Navel Orangeworm Per Bearing Acre in 2018–2021



Source: Authors' calculations using CDPR Pesticide Use Reporting data.

Total spraying costs exhibit large variations across the state. Focusing on almonds, for which we have reliable county bearing-acreage data, we calculate the average spray costs by county and present the results in Figure 3. We find that growers in Fresno County use an average of 2.6 pesticide sprays targeting NOW per bearing acre per year and have the highest average expenditure on spray materials plus application costs, spending on average $171 per bearing acre in 2018 through 2021. Fresno is the largest almond-producing county, with approximately 250,000 bearing acres out of the 1.3 million bearing acres in California in 2021.

Almond growers in the southern SJV spend more on NOW pesticides than their counterparts in the northern SJV and the Sacramento Valley. Glenn County is one exception, where growers use two pesticide sprays per acre at an annual average cost of $127 per bearing acre, approximately double the average spray costs across other Sacramento Valley counties. Glenn County contained about 4% of the almond bearing acres in 2021.

Mating Disruption

NOW mating disruption is a relatively new pest management technology in tree nut production, with the first products appearing on the market around 2008. Mating disruption uses sex pheromones to confuse adult moths, interrupt mating patterns, and reduce the number of larvae that can go on to damage nuts. Growers hang mating disruption dispensers in the orchard canopy in March/April, and the devices emit pheromones throughout the growing season.

Mating disruption materials plus installation costs total about $120 per acre. In a survey of growers, 25% of almond and 58% of pistachio growers report using mating disruption every year. Results from field experiments in Central Valley almond orchards show about a 50% reduction in nut damage when mating disruption is used in combination with insecticides and winter sanitation compared to insecticides and sanitation only.

Cost of NOW Damage

NOW damage leads to a lower yield of edible nuts, with damaged nuts rejected and receiving no payment. In addition, the edible nuts receive a price premium or deduction based on the share of nuts rejected. Figure 4 (on page 8) presents examples of an almond and pistachio price schedule with respect to the percentage of inedible nuts rejected by the handler and shows a steep decrease in price per pound of edible nuts as the share of rejected nuts increases.

To quantify the total cost of NOW damage in almonds, we use the price schedule in Figure 4 and incorporate the almond industry rule of thumb that for every pound of damaged almonds delivered to the handler, an additional pound of damaged kernels is lost during harvest, hulling, and shelling.

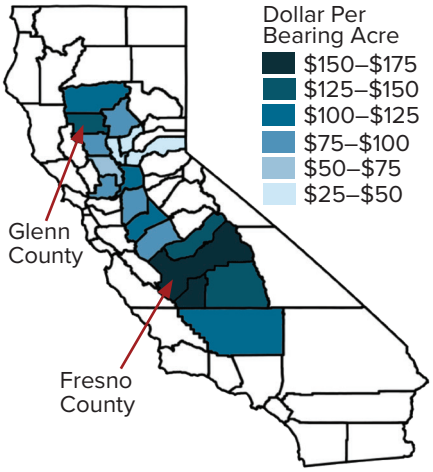
Our analysis reveals that a reduction in the share of nuts delivered to the handler with NOW damage can significantly impact per-acre revenues. For instance, assuming an almond price before premiums and deductions of $1.86 per pound, as in Figure 4, the handler rejects 3% of the nuts, and the yield of edible nuts is 2,150 pounds per acre. From these initial conditions, we estimate that reducing the share of nuts damaged to 2% increases almond revenues by $225 per acre, about a 5.6% increase in average 2018–2021 revenues. Reducing damaged nuts to 1.5% increases revenues by $335 per acre, about 8.4%.

In the case of pistachios, we assume a base price of $2.16 per pound, and that the handler rejects 3% of nuts and the yield of edible nuts is 2,800 pounds per acre. Reducing the share of nuts rejected to 2% in this situation could increase revenues by $347 per acre, about 5.6%.

Comparing Farm Costs and Benefits of NOW Management

We estimate that in 2018 through 2021, almond growers spent $393, and pistachio growers spent $262, per bearing

Figure 3. Average 2018–2021 Spray Material Plus Application Costs Per Almond Bearing Acre Targeting NOW



Source: Authors' calculations.

Note: We exclude counties with less than 1,000 bearing acres of almonds. Prices in 2021 dollars.

Table 1. Average Annual Pesticide Sprays Targeting NOW Per Bearing Acre and Associated Costs in 2018–2021

	Almond	Pistachio
Number of Pesticide Sprays	1.9	1.7
Pesticide Material Costs	$95.19	$92.54
Pesticide Application Costs	$29.94	$31.50

Source: Authors' calculations using CDPR Pesticide Use Reporting data, University of California, Davis Cost and Return Studies, and pesticide prices from distributors.

Note: We calculate that average pesticide application costs per spray per acre equal $15.36 in almonds and $18.83 in pistachios. This includes the cost of fuel, lube, repairs, custom services, and labor. Annual average costs converted into 2021 dollars before averaging over years.

acre per year on average on winter sanitation and pesticide sprays targeting NOW. This represents a meaningful portion of annual operating costs for tree nut growers, especially in areas with high pest pressure.

Studies have shown that in some areas leaving two or more mummy nuts per almond tree regularly results in damage rates of 8% or higher. Thus, implementing a NOW IPM program that brings reject rates from 8% down to 2% would result in an increase in revenues of $792 per acre in almonds (using the price schedule in Figure 4 and an initial edible nut yield of 2,150 pounds per acre). The increase in revenue can be broken down into two parts. First, an increase of $524 per acre due to a higher edible nut yield of 2,440 pounds per acre sold at the original price (inclusive of deductions) of $1.81 per pound. Second, an increase of $268 per acre due to a higher price (inclusive of premiums) of $1.92 per pound, paid for the higher yield of edible almonds.

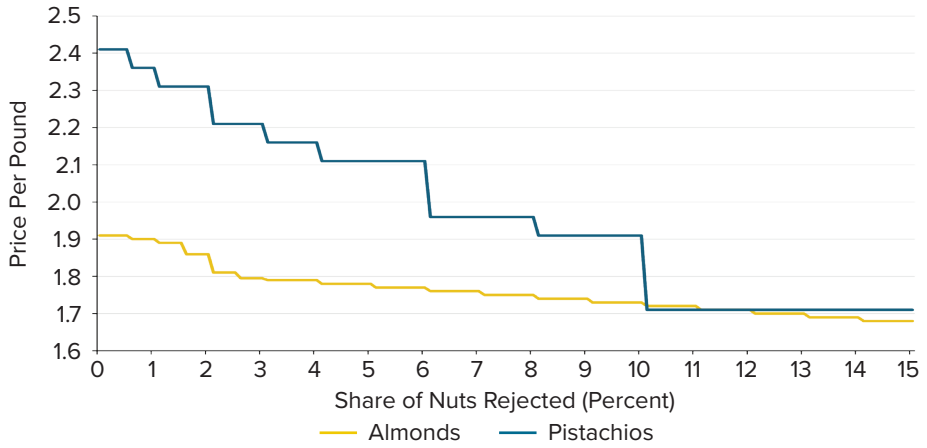
We conducted a similar calculation for pistachios using a reduction in rejects from 8% to 2%, the price schedule in Figure 4, and an initial edible nut yield of 2,800 pounds per acre. In this scenario, pistachio growers earn $1,402 per acre in additional revenues, comprised of $358 per acre from a higher edible nut yield of 2,980 pounds sold at the initial price of $1.96 per pound, and $1,044 per acre from the higher price of $2.31 per pound.

Even in years with low tree nut prices, it is easy to see that the estimated returns from NOW IPM programs will likely outweigh the costs.

Almond NOW IPM Cost-Benefit Calculator

Effective NOW IPM protocols are critical to the sustainability of California tree nut industries. To help almond growers explore the costs and benefits of alternative IPM programs and damage percentages, we produced an online calculator that can be accessed by scanning the QR code below with a mobile phone. We plan to develop similar tools for pistachio and walnut growers in the future.

Figure 4. Price Schedules With Respect to Share of Nuts Rejected



Source: Authors' calculations based on a premium schedule from a Central Valley pistachio handler (not publicly available) and almond premium schedules published in the Blue Diamond Growers 2021 Crop Delivery Information brochure. Available at: https://bit.ly/3Rt3ADG.

Note: In the almond price schedule, we assume deliveries to handlers contain 0.4% foreign material, and 3.6% chipped and broken nuts (informed by Blue Diamond Growers data from 2019–2022) and therefore achieve the second highest Nonpareil bonus, conditional on reject percentage. We use base prices of $1.86 per pound of almonds and $2.16 per pound of pistachios.

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For additional information, the authors recommend:

Gordon, Phoebe E., Brittney K. Goodrich, and Houston Wilson. 2023. "Adoption of *Amyelois transitella* (Navel Orangeworm) Monitoring and Management Practices Across California Tree Nut Crops." *Journal of Integrated Pest Management* 14(1): 1–14. Available at: https://bit.ly/3Gl60On.

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Cost & Return Studies

Trends in California Farmland Sales Prices and the Impacts of Drought

Siddharth Kishore, Mehdi Nemati, Ariel Dinar, Cory Struthers, Scott MacKenzie, and Matthew Shugart

This paper describes the trends in the California farmland market across counties and crop types over the past two decades. We explored the trends in farmland sales transactions and farmland values during drought events. The number of parcels sold and farmland value increased following the major drought periods in California between 2001 and 2021.

Land has many uses, with agriculture being one of the most important. Monitoring changes in the farmland market can improve our understanding of the performance of the agricultural sector and the financial well-being of agricultural producers. Farmland values across the United States are on the rise. The value of farmland can be explained by several factors, especially urban development pressures, and agricultural constraints, such as irrigation restrictions caused by water scarcity and deteriorated water quality, and concerns about the impact of climate change on agricultural productivity.

Publicly accessible data on farmland can be found via the U.S. Department of Agriculture's National Agricultural Statistics Service (NASS) and the NASS June Area Survey. However, the self-reported property values from both sources could have an inherent bias. Using a novel data set on farmland sales prices, this paper provides descriptive evidence of trends in the California farmland market over the past two decades (2001–2021), which encompasses multiple drought events.

Trends in California Farmland Sale Prices

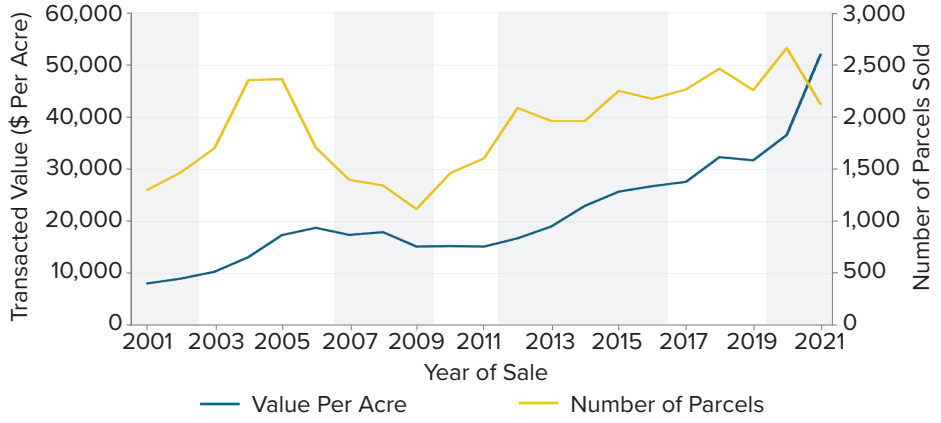
We began with farmland parcels in California that were associated with cultivated field crops, orchards, and vineyards and that were sold between 2001 and 2021. We analyzed a sample of 40,086 observations representing 28,239 farmland parcels in California obtained from ATTOM Data Solutions, a private data vendor that collects farmland-assessed values and sales prices. All values are adjusted for inflation (2021 dollars) using the annual Consumer Price Index.

Farmland markets are often characterized as thin markets, with a small number of transactions compared to other real estate markets. The number of farm parcels sold annually in California between 2001 and 2021 ranged from a minimum of 1,120 to a maximum of 2,664, with an average of 1,908. The average farmland sales price has increased by roughly 538% in the past 21 years, from $8,150 per acre in 2001 to $52,021 in 2021. The yearly total acreage of sold farmland has also undergone a significant change over these years. For example, in 2009, a total of 116,092 acres of agricultural land was sold, while in 2019, a total of 348,464 acres of agricultural land was sold—more than a three-fold increase in a decade.

We explored changes to the farmland market during four major drought periods, including 2001–2002, 2007–2009, 2012–2016, and 2020–2021. After major droughts, there was an increase in the number of parcels of farmland sold. For example, in 2004 and 2005, the number of parcels sold increased by 69% compared to 2002; in 2011, the increase was 49% compared to sales in 2009; and in 2020, the increase was 20% compared to sales in 2016. Figure 1 presents a summary of the recent trends in California farmland sales prices and the number of parcels sold.

In the past two decades, the number of parcels sold in the central and southern parts of the San Joaquin Valley has increased. In our sample of farms sold in California from 2001–2021, 34% were sold for between $16,000 and $17,000 per acre. The largest volume of sales occurred in Fresno County (with a total of 591,944 acres sold over

Figure 1. Recent Trends in Farmland Sale Prices and the Number of Parcels Sold, 2001–2021



Source: Authors' calculations based on data from ATTOM Data Solutions for the years 2001–2021.
Note: The figure shows the recent trends in farmland sale price (blue line) and the number of sales (yellow line). Transacted value is in 2021 U.S. dollars. In the background of the graphs, we highlight the major droughts in California: 2001–2002, 2007–2009, 2012–2016, and 2020–2021.

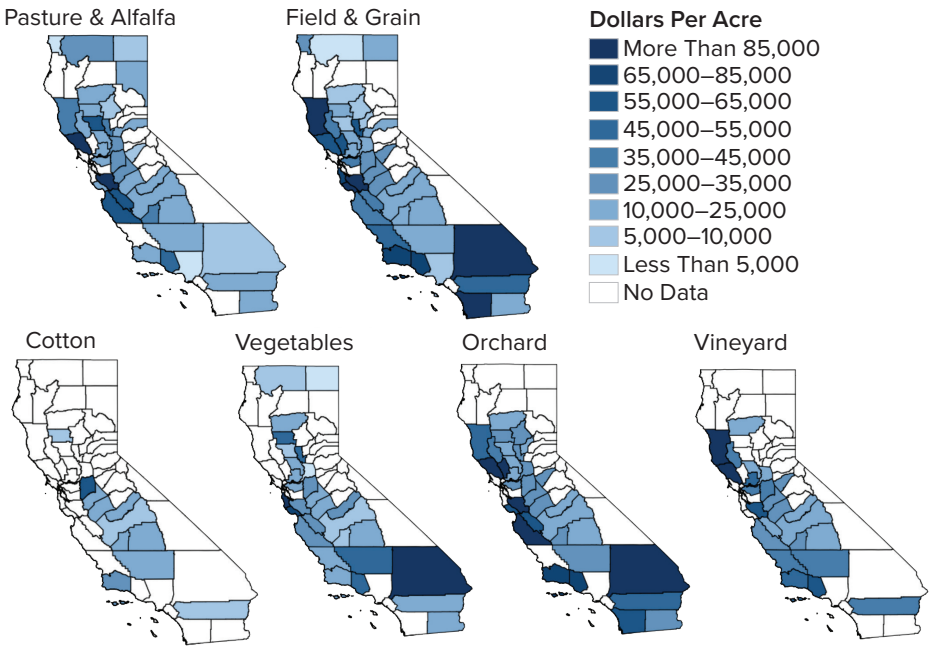
21 years), Tulare County (403,813 acres), Kern County (385,576 acres), Humboldt County (315,592 acres), Monterey County (262,159 acres), and Merced County (221,432 acres). Napa County had the highest average farmland value per acre of $120,204, with 13,613 acres sold. Santa Clara County had the second-highest average farmland value of $75,627 per acre, with 12,209 acres sold. Farmland in Santa Cruz, Sonoma, San Bernardino, Santa Barbara, and Ventura counties sold for a range of $50,000–$55,000 per acre. A total of 77,380 acres were sold in Sonoma County, followed by Santa Barbara County (65,700 acres), Ventura County (55,532 acres), San Bernardino County (8,179 acres), and Santa Cruz County (3,777 acres). Together, these five counties accounted for 6% of all farmland sold in California.

Table 1. Summary Statistics: California's Farmland Price Per Acre by Crop (2008–2021)

	Minimum	Maximum	Mean
	(2021 U.S. Dollars Per Acre)		
Pasture and Alfalfa	1,756	168,115	28,192
Field and Grain	3,183	190,483	46,149
Cotton	6,953	58,074	19,400
Vegetables	2,237	154,000	31,640
Orchard (and Other Tree Crops)	16,491	196,117	48,000
Vineyard	11,562	201,000	45,183

Source: Authors' calculations based on data from ATTOM Data Solutions and CDL data from USDA NASS for the years 2008–2021. CDL data is available at: https://bit.ly/3ux6LkN.
Note: Table 1 is obtained by aggregating mean farmland sales prices per acre across various crop types and then analyzing the summary statistics. Orchard includes almonds, pistachios, other nuts, citrus, other subtropical fruits, and other tree crops. Field crops and grains includes rice, dry beans, safflower, corn, and other field crops. Vegetables include melons, squash, cucumbers, onions, garlic, potatoes, tomatoes, berries, and other types of vegetables.

Figure 2. Spatial Variation in the Price of Farmland Sales by Crops Grown



Source: Authors' calculations based on data from ATTOM Data Solutions and CDL data from USDA NASS for the years 2008–2021. CDL data is available at: https://bit.ly/3ux6LkN.
Note: This figure displays the map of California farmland values per acre from 2008 through 2021 by crop type.

Spatial Variations in Farmland Prices by Crop

The farmland market is summarized in Table 1 by analyzing crops grown from 2008 through 2021. We merged the farmland sales data with the annual Cropland Data Layer (CDL) available at a 30-by-30-meter resolution for 2008 through 2021. We aggregated the farmland sales by county and crop type and excluded farmland sales associated with non-cultivated crops, such as fallowed land and natural vegetation (9,630 parcels). Orchards (and other tree crops) accounted for about 51% of all cultivated farmland sold, followed by field crops and grains (18%), vineyards (15%), pasture and alfalfa (10%), vegetables (4%), and cotton (2%).

Figure 2 shows the spatial variation in farmland sales prices based on crop types across counties in California. Napa County has the highest average farmland values ($201,000 per acre) associated with vineyards, followed by Sonoma County ($111,266 per acre), Mendocino County ($89,288 per acre), and Ventura and Santa Clara counties, ($62,000–$63,000 per acre).

Farmland associated with orchards (and other tree crops) sold for $196,117 per acre in Napa County, followed by Sonoma County ($145,893 per acre), and Santa Clara and San Bernardino counties, ($91,000–$95,000 per acre).

Farmland associated with field crops and grains sold for more than $100,000 per acre in San Bernardino, San Diego, Santa Cruz, Santa Clara, and Mendocino counties. Sonoma County had the highest farmland value for pasture and alfalfa at $168,115 per acre, followed by Santa Clara County ($89,786 per acre), San Benito and Monterey counties ($61,400 per acre), and Ventura and Colusa counties, with prices between $52,000–$55,000 per acre.

Vegetable-related farmland in San Mateo County sold for the highest

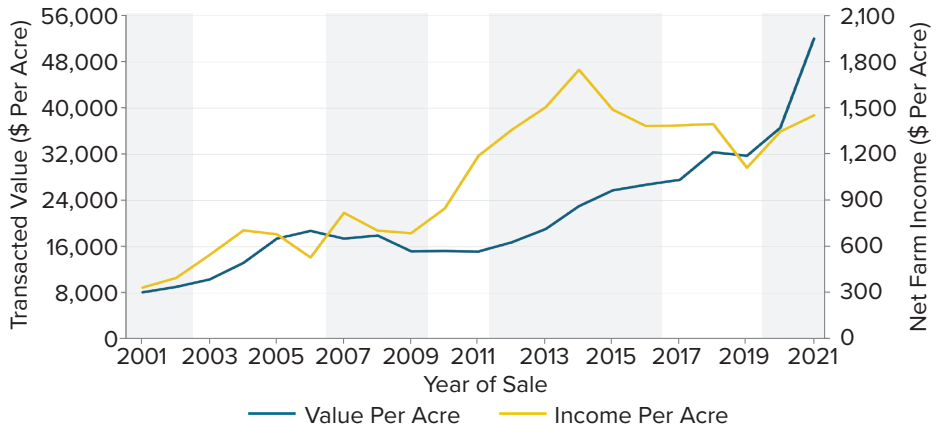
price at $154,000 per acre, followed by San Bernardino County ($94,000 per acre), Santa Cruz County ($69,000 per acre), and Sutter, Ventura, Glenn, and Kern counties ($45,000–$50,000 per acre). Finally, cotton farmland in San Joaquin County sold for the highest price ($58,074 per acre), followed by Santa Barbara County ($27,000 per acre).

Impacts of Climate Change on Net Farm Income and Farmland Sales Prices

The changing climate in California has a direct impact on farm incomes, which in turn is associated with changes in the sales price of farmland. In Figure 3, we show the trends in net farm income and farmland sales prices in California from 2001 to 2021. We constructed net farm income per acre (on the right y-axis) by dividing net farm income by total agricultural acreage. We obtained net farm income for California from the USDA Economic Research Service (ERS) farm income data and total agricultural acreage from the National Land Cover Database.

We calculated farmland sale prices per acre (Figure 3, left y-axis) by dividing farmland sales price by parcel size and then aggregating it to California by year of sale. Over the past two decades, the net farm income increased by 339% (annual increase of 16% over 21 years) compared to a 538% increase (annual increase of 26% over 21 years) in farmland values during the same time period; this demonstrates a significant gap between farm income and the value of farmland, particularly during the longer drought event of 2012–2016. The trend lines appear to diverge from 2009 to 2019, but then converge again. Surprisingly, it is farmland values that are lagging, not net farm income. The overall trend suggests that farm incomes are not aligned with farmland values, and agricultural productivity only partially contributes to farmland values.

Figure 3. Trends in Net Farm Income and Farmland Sales Prices in California, 2001–2021



Source: USDA ERS Farm Income data is available at: https://bit.ly/40ZxLpk. The National Land Cover Database was used to create county-level acreage and then utilized to compute net farm income per acre.
Note: The figure shows recent trends in farmland sale price (blue line) and the net farm income per acre (yellow line). In the background of the graphs, we highlight the major droughts in California.

High sales may be due to urban development pressure. We created an urban proximity variable for each parcel in our sample based on the nearest city center. The parcels in our sample are on average 4.1 miles away from the nearest city center, and the maximum distance was 28.3 miles. Unsurprisingly, the correlation between the distance from the city center and farmland value is negative.

Concluding Remarks

We examined trends in farmland sales transactions and assessed values in California. We showed that both have been steadily increasing over the past two decades, particularly after 2009. Farm earnings are weakly supporting farmland values, perhaps due to uncertainty arising from climate change and lower agricultural productivity. Drought was correlated with an increase in both the number of parcels and acreage sold in California. Importantly, we found that farm parcel sales are primarily associated with annual crops and that these sales are concentrated in the San Joaquin Valley. On average, parcels that sold for higher prices, particularly for annual crops, tended to be closer to the nearest city center.

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