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Water and the Future of the San Joaquin Valley

Ellen Hanak,
Alvar Escriva-Bou,
Brian Gray,
Sarge Green,
Thomas Harter,
Jelena Jezdimirovic,
Jay Lund,
Josué Medellín-Azuara,
Peter Moyle,
Nathaniel Seavy

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SUMMARY

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Technical appendices to this report are available on the PPIC website.

The San Joaquin Valley—California's largest agricultural region and an important contributor to the nation's food supply—is in a time of great change. The valley is ground zero for many of California's most difficult water management problems—including groundwater overdraft, drinking water contamination, and declines in habitat and native species.

Local water supplies are limited, particularly in the southern half of the region. To irrigate their crops, many farmers use water imported from the Sacramento–San Joaquin Delta. But in many places farmers have also relied on groundwater overdraft—pumping groundwater in excess of the rate at which it is replenished. Worsening droughts, increasing regulations to protect endangered native fishes, and growing demand by Southern California for Delta imports have compounded surface water scarcity.

The state's Sustainable Groundwater Management Act (SGMA) requires local water users to bring groundwater use to sustainable levels by the early 2040s. This will have a broad impact on valley agriculture and the regional economy in coming years—likely including some permanent idling of farmland.

This report explores three key challenges facing the San Joaquin Valley and reviews the most promising approaches to address them:

- **Balancing water supplies and demands.** To close the groundwater deficit, groundwater sustainability agencies in the valley's overdrafted basins will have to augment supplies, reduce demands, or use some combination of these two approaches. A range of options are under consideration but they are not equally effective or practical.
- **Addressing groundwater quality challenges.** Poor groundwater quality impairs drinking water supplies in disadvantaged rural communities, reduces long-term agricultural prosperity, and degrades ecosystems. Providing safe drinking water is an urgent priority. Over the longer term, parties will also need to manage water quantity and quality together, to take advantage of synergies and avoid unintended consequences. The necessary coordination will be challenging because the various programs addressing valley water quality issues are carried out by numerous local and regional entities, whose lines of responsibility and geographic boundaries do not neatly align.
- **Fostering beneficial water and land use transitions.** Effectively addressing water scarcity and the resulting land use changes in the San Joaquin Valley offers opportunities to put lands coming out of production to good use—and gain "more pop per drop" from limited water resources. Multiple-benefit approaches to water and land

management can enhance groundwater recharge and improve air and water quality. They can also promote healthier soils, new recreational opportunities, additional flood protection, improved habitat, and new revenue streams for private landowners engaging in conservation-oriented management.

Addressing these complex and intertwined issues requires significant changes in water and land management and a major ramp-up in cooperation and coordination among a wide circle of stakeholders. Pursuing solutions that deliver multiple benefits will boost the chances of success overall. The entire region—and California as a whole—will benefit if solutions to these challenges are cost-effective and support the valley's economy while improving public health and the natural environment.

An overview of this report is available here.

ACRONYMS

af	acre-foot (acre-feet)
CEQA	California Environmental Quality Act
CREP	Conservation Reserve Enhancement Program
C2VSim	California Central Valley Groundwater-Surface Water Simulation model
CVHM	Central Valley Hydrologic Model
CVP	Central Valley Project
CV-SALTS	Central Valley Salinity Alternatives for Long-Term Sustainability initiative
DWR	Department of Water Resources
ECHO	Enforcement and Compliance History Online data portal (US Environmental Protection Agency)
EQIP	Environmental Quality Incentives Program
Flood-MAR	Flood Managed Aquifer Recharge
FSA	Farm Service Agency
GDP	gross domestic product
GSA	groundwater sustainability agency
GSP	groundwater sustainability plan
HCP	Habitat Conservation Plan
HRTW	Human Right to Water data portal (State Water Board)
ILRP	Irrigated Lands Regulatory Program
IMPLAN	Impact Analysis for Planning model
maf	million acre-feet
MCL	Maximum Contaminant Level
mg/l	milligrams per liter
NCCP	Natural Community Conservation Plan
NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
PEIR	programmatic environmental impact report
RCD	resource conservation district
SDWA	Safe Drinking Water Act
SGMA	Sustainable Groundwater Management Act
SNCP	Salt and Nitrate Control Program
SWP	State Water Project
taf	thousand acre-feet
TCP	trichloropropane
USDA	US Department of Agriculture
WDR	Waste Discharge Requirements program (Regional Water Board)

Chapter 1. Introduction

The San Joaquin Valley produces more than half of California's agricultural output. Its diverse crops and animal products are an important part of the nation's—and the world's—food supply. To produce such bounty, the valley depends upon having reliable water supplies. Yet this reliability is decreasing, particularly in times of drought. Today, local and imported water resources support more than 5 million acres of irrigated farmland, a population of more than 4 million, and an economy that generates an average of nearly $160 billion in gross domestic product (GDP).[1] Farming is the region's main economic driver—providing roughly one-fifth of regional GDP and employment—and its predominant water user.

Like many agriculturally dependent regions, the valley faces significant socioeconomic challenges, including a high rate of unemployment and pockets of extreme rural poverty. These challenges increase when the farm economy suffers.

Stress on the valley's water system is growing. Local supplies are limited, particularly in the southern half of the region. To irrigate their crops, many farmers use water imported from Northern California through the Sacramento–San Joaquin Delta. But in many places they have also relied on groundwater overdraft—pumping groundwater in excess of the rate at which it is replenished. The 2014 Sustainable Groundwater Management Act (SGMA) requires local water users to bring use to sustainable levels by the early 2040s (Box 1.1). SGMA will have a broad impact on valley agriculture in coming years. It will spur investments in new water supplies—but also likely entail idling of more than half a million acres of farmland. With the largest groundwater deficit in the state, the valley is ground zero for implementing this law.

In addition to water shortages, the valley must also respond to a variety of water quality issues. The region is a hot spot for unsafe drinking water, a problem that is most acute for small, poor, rural communities. Increased groundwater pumping has also caused many of the shallow wells these communities rely on to go dry. Lasting remedies are urgently needed to provide safe drinking water to all valley residents. Another concern is the buildup of nitrogen and salts in groundwater and soils. Nitrogen loading from fertilizers, and especially manure from dairies, is contributing to drinking water contamination. Salt buildup is threatening long-term agricultural productivity. Under new regulatory requirements, valley farmers must address these issues in conjunction with ending groundwater overdraft—and the solutions are costly.

In these changing times, land and water management present other complex challenges for the region. The San Joaquin Valley is the most altered non-urban environment in California—with one of the highest concentrations of endangered species in the country. Much of the valley floor is now managed for intensive crop production, and many native species are in decline. The valley's remaining riverine, wetland, and upland ecosystems exist in small strips and patches dispersed across the region, and land and water management is often constrained by endangered species protection and recovery mandates. Without careful planning, growing water scarcity could increase conflict between human and environmental water uses. And land idled to achieve groundwater balance could contribute to dust and weed problems that compromise air quality and neighboring farmland. But with effective planning, coordination, funding, and regulatory incentives, new opportunities to manage water and land resources can generate a range of benefits for people and nature.

Valley farmers and residents have a history of creatively adapting to difficult and changing conditions. Although major challenges lie ahead, constructive solutions are in reach. They will require a major ramp-up in cooperation

[1] Irrigated acreage is for 2014 (California Department of Water Resources 2017a). Population is for July 1, 2017 for the eight San Joaquin Valley counties (US Census Bureau 2018). Gross domestic product is value added from all economic production in the eight valley counties in 2015 (MIG, Inc. 2017).

and coordination among a growing circle of stakeholders within the region, as well as state and federal support. Pursuing solutions that deliver multiple benefits will boost the chances of success overall. The entire region, and California as a whole, stand to gain from cost-effective approaches that support the valley's economy while improving public health and the natural environment.

This report is the third installment of a research project by the PPIC Water Policy Center on solutions to the San Joaquin Valley's water challenges.[2] The project has benefited from invaluable input from a wide range of valley stakeholders through interviews, surveys, and workshop discussions.[3] This installment seeks to answer several key questions: What does groundwater sustainability mean for the valley's agriculture sector and the regional economy? How can the region effectively address groundwater quality challenges that threaten public health and longer term agricultural prosperity? And how can sustainable basin planning tools foster water and land use transitions that benefit people and the natural environment? Chapter 1 briefly describes the valley's water management landscape and groundwater overdraft challenge, followed by an overview of material covered in the remaining chapters. A suite of technical appendices elaborates on the data and analysis summarized here.

Box 1.1: Implementing SGMA

The Sustainable Groundwater Management Act directs local agencies and stakeholders to develop institutions, plans, and implementation strategies to manage their groundwater resources sustainably for the long run (Kiparsky et al. 2016). If local agencies fail to act, SGMA directs the state to intervene.

The law defines sustainable management as the avoidance of six "significant and unreasonable" effects: (1) drawing down water levels too far, (2) depleting storage in the aquifer, (3) degrading water quality, (4) allowing seawater intrusion, (5) causing land to subside, or (6) using groundwater in ways that reduce other people's surface water or harm ecosystems.

Local stakeholders are in charge of carrying out the key provisions of SGMA. New or existing agencies overlying important groundwater basins—those designated by the Department of Water Resources (DWR) as medium- and high-priority, and critically overdrafted—have established groundwater sustainability agencies (GSAs), which are tasked with formulating sustainability plans. Any local water or land use agency in a basin can form a GSA, and there may be multiple GSAs in a basin, but they may not have overlapping boundaries. GSAs must engage local stakeholders and coordinate their planning to ensure that the entire basin is sustainably managed.

GSAs in critically overdrafted basins are required to develop plans by January 2020; those in other medium- and high-priority basins have two additional years to do so. With plans in place, GSAs have a 20-year horizon to manage their basins to achieve or maintain sustainability. Although the plans themselves are exempt from review under the California Environmental Quality Act (CEQA), projects that GSAs carry out to attain sustainability will generally require CEQA review.

GSAs must annually provide DWR with data and a description of their progress toward plan implementation. They must evaluate whether their plans are meeting sustainability goals for the basin at least every five years. This provides an opportunity to adapt goals and plans to new information and changing conditions.

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[2] The first report, *Water Stress and a Changing San Joaquin Valley* (Hanak et al. 2017), highlights the importance of water in the valley's economy and describes a range of water-related challenges and potential solutions. The second report, *Replenishing Groundwater in the San Joaquin Valley* (Hanak et al. 2018), analyzes the potential for expanding groundwater recharge to help reduce the valley's overdraft.

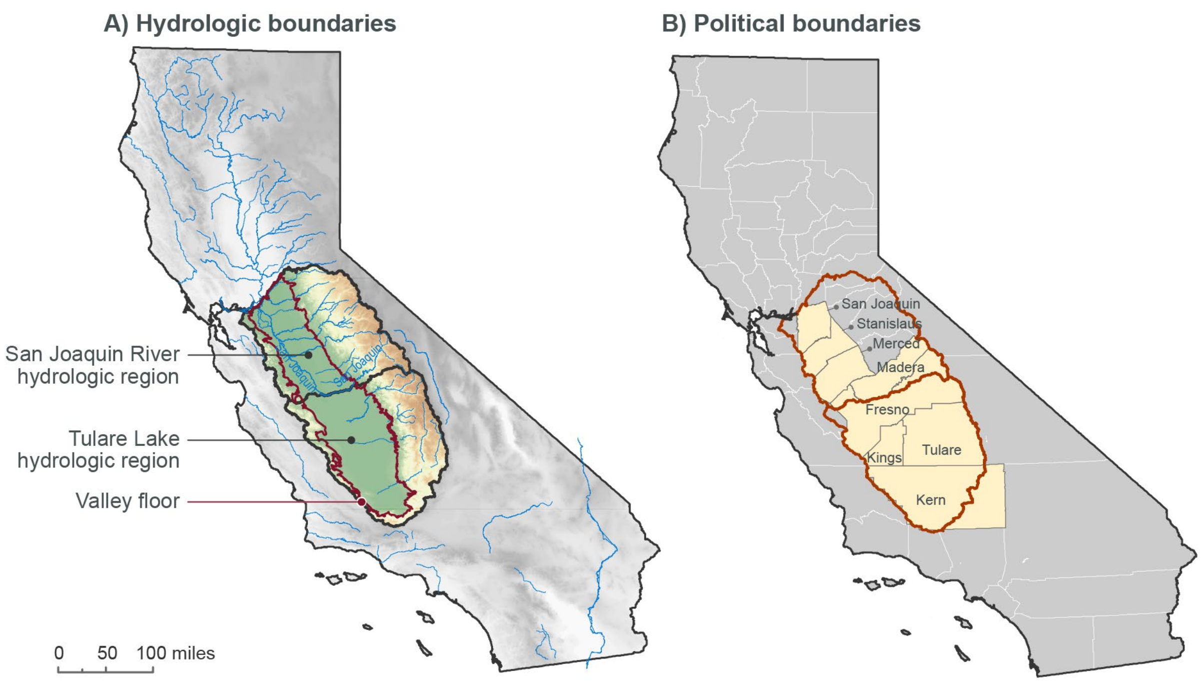
[3] We are especially grateful to members of the project's advisory group, who provided ongoing counsel. They are listed in the acknowledgments.

The Valley's Water Management Landscape

Many elements define the San Joaquin Valley—its long history as a preeminent farming center, its diverse cultures, its geography, climate, and ecology. Two characteristics have a major effect on the valley's water challenges: the hydrological and political boundaries. These dictate how the problems are defined, and who will be tackling them (Figure 1.1).

The first set of boundaries defines the valley's natural watersheds, including the San Joaquin River and Tulare Lake hydrologic regions. These boundaries include the valley floor—where most farming occurs and where most people live and work—as well as the higher elevation parts of the watersheds that drain into it. This definition is most useful for understanding water availability and use, but it does not lend itself to tracking economic activity because it cuts across county boundaries. A second set of boundaries—the political San Joaquin Valley—helps define the regional economy and local governmental response. This includes the eight counties that cover the valley floor: Fresno, Kern, Kings, Madera, Merced, San Joaquin, Stanislaus, and Tulare.

FIGURE 1.1
The San Joaquin Valley



SOURCE: Developed by the authors using information from the California Department of Water Resources.

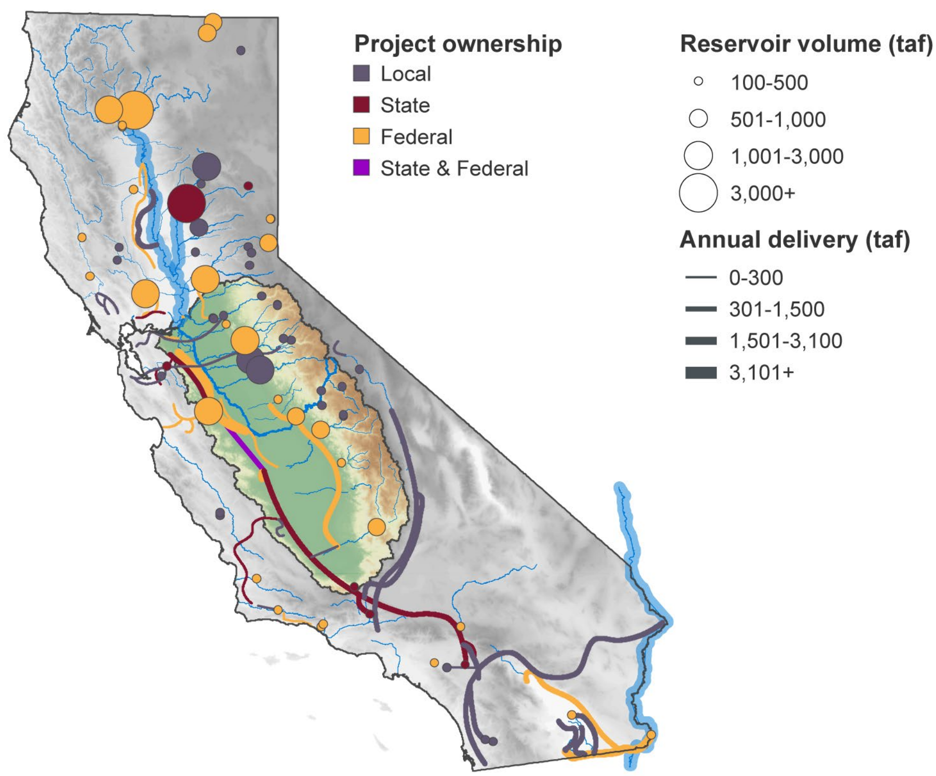
Many other elements figure into the valley's water landscape.[4] The region has nearly 20,000 irrigated farms, ranging in size from under 10 acres at a single location to thousands spread across multiple sites and counties (Hanak et al. 2017). Solutions to the region's resource management challenges must recognize this diversity. There is also a plethora of local water management entities—including hundreds of drinking water suppliers, wastewater districts, and irrigation districts; and the 121 new groundwater sustainability agencies working to balance groundwater supplies and demands within the 15 priority basins identified under SGMA (see Chapter 2).

[4] For a more detailed list of the various local, regional, state, and federal entities engaged in water and land management in the valley, see Hanak et al. (2017), Tables 1 and 2. Where relevant, we have updated the numbers of entities in this report.

New entities to manage groundwater quality add another layer of complexity (see Chapter 3). Eight county governments and more than 60 cities have responsibility for land use decisions inextricably linked to how and where water is used (see Chapter 4). In addition, the state and federal laws, infrastructure, and lands figure into the valley's water landscape.

The valley's growing conditions are among the most favorable in the world, as long as water is available to irrigate crops during the long, dry summers. To support cropland irrigation, a complex array of local, state, and federal infrastructure stores and transports water (Figure 1.2). These projects deliver water under a variety of water rights and contracts, with different levels of reliability when supplies are constrained. The southern part of the valley (Tulare Lake hydrologic region) is much drier and more heavily dependent on surface water deliveries imported from elsewhere. On the east side, these imported water sources include San Joaquin River water conveyed through the Central Valley Project's (CVP) Friant-Kern Canal; and on the west side, imports from the Sacramento–San Joaquin Delta through the CVP's Delta-Mendota Canal and the California Aqueduct, jointly owned and operated by the CVP and the State Water Project (SWP).

FIGURE 1.2
The San Joaquin Valley receives local and imported surface water from a diverse array of projects



SOURCE: Developed by the authors using information from the California Department of Water Resources.

NOTES: "Taf" is thousands of acre-feet. The map shows reservoirs with storage capacity over 100 taf, scaled to size. Built conveyance facilities (canals, aqueducts) are scaled to their average annual deliveries. Rivers are shown in blue. Three major rivers—the Colorado, Sacramento, and Feather—are scaled to their annual deliveries. These rivers each serve a significant conveyance role, connecting surface reservoirs and locations of water use.

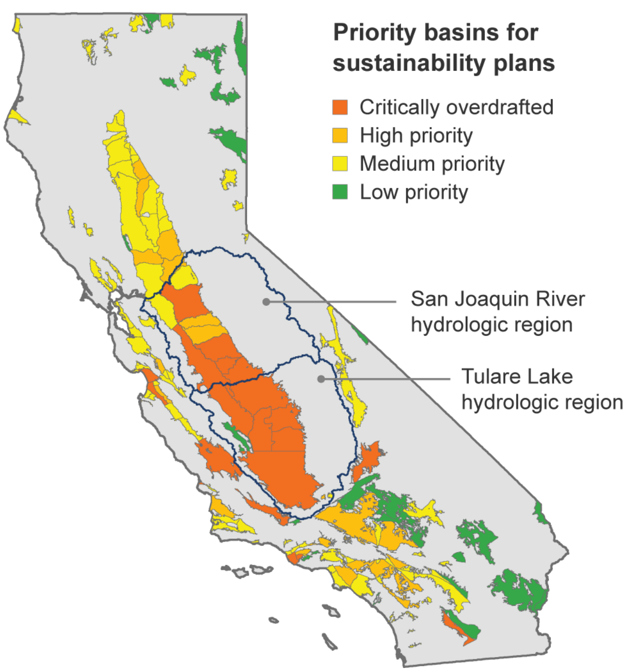
Some farms and communities rarely experience shortages, as they have very senior rights to surface water from local rivers, established more than a century ago. In contrast, the CVP and SWP have relatively junior surface water rights, and many of their contractors are more susceptible to cutbacks.[5] Still others—including many towns and rural communities and many farmers in the eastern side of the valley—rely entirely on groundwater for drinking water and irrigation supplies. Water users in these so-called "white areas" are particularly susceptible to groundwater quality problems and falling water tables, and vulnerable to pumping restrictions with the implementation of SGMA.[6]

The Extent of the Groundwater Problem

Although the pace of groundwater pumping accelerated during the 2012–16 drought, overdraft has been a challenge in the region for many decades (Faunt et al. 2016, Brush et al. 2013). On average, agricultural water use exceeds likely sustainable supplies by nearly 2 million acre-feet per year or 11 percent of net water use (Technical Appendix A). Of the 15 valley basins subject to SGMA, 11 are considered to be critically overdrafted; GSAs in these basins must launch their sustainability plans by 2020 and attain sustainability by 2040 (Figure 1.3). GSAs in four other high- and medium-priority basins in the northern valley have until 2022 to begin implementing their plans, and until 2042 to attain sustainability.

FIGURE 1.3

Most of the San Joaquin Valley's groundwater basins are critically overdrafted



SOURCE: California Department of Water Resources.

NOTES: Due to a basin prioritization update, some changes to basin boundaries and priority levels are likely to occur in spring 2019. One relatively saline basin on the San Joaquin Valley's west side was ranked as low priority in DWR's initial classification, and not required to prepare a sustainability plan.

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[5] The principal exceptions are the "Exchange Contractors," whose CVP water supply contract recognizes their pre-project rights to the waters of the San Joaquin River. They now have preferential contract rights to replacement water pumped from the Delta and delivered through the Delta-Mendota Canal. Some water right-holders on local rivers in the Tulare Lake region have relatively insecure rights.

[6] The "white areas" under SGMA refer to areas not served by an entity delivering surface water.

The long-term declines in the valley's groundwater reserves reflect surface-water scarcity and a lack of formal groundwater management. The regional water balance presented here provides an overall picture of water sources and uses on the valley floor—where most irrigated farming occurs and where most people live.[7] From 1988–2017, annual net water use averaged 16.7 million acre-feet (maf), with 87 percent for farming and the remainder consumed by natural vegetation and managed wetlands (10%) and cities (3%). This water comes from three sources:

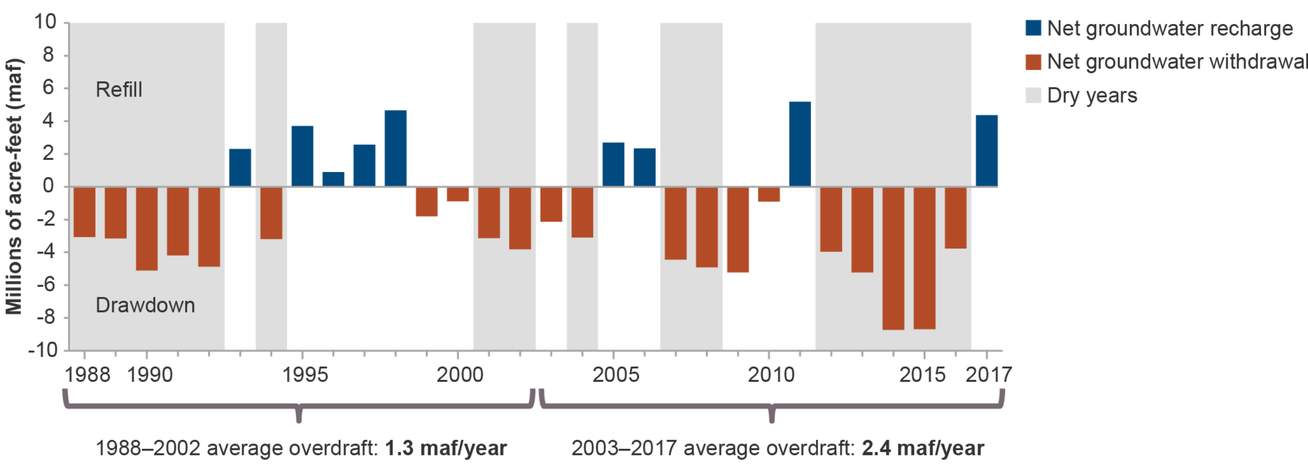
1. **Local supplies (70%).** This includes water flowing in from the local rivers and streams originating in the Sierra Nevada (8.5 maf), plus precipitation falling on the valley floor (6.1 maf), minus exports from local rivers to the Bay Area (0.2 maf) and outflows to the Delta (2.7 maf), for a net total of 11.7 maf. It is consumed both as surface water and as groundwater replenished from these sources.
2. **Delta imports (19%).** On average, 4.9 maf of Delta imports enter the valley through the CVP and SWP pumps in the south Delta near Tracy, and 3.2 maf remain in the valley. The rest is sent onward to the Bay Area (0.2 maf), the Central Coast (0.2 maf), and Southern California (1.2 maf). Most imports originate from the Sacramento River, a much larger river than the San Joaquin. Although this water enters the region as surface water, a portion replenishes the aquifers and is consumed as groundwater.
3. **Groundwater overdraft (11%).** The pumping of groundwater that is replenished by local sources and Delta imports can be considered sustainable groundwater use because it comes from recharge. But on average, valley water users also pumped 1.8 maf per year of additional groundwater. This is the long-term rate of overdraft, or diminishing groundwater reserves.

Over the last 30 years, net water use has been fairly stable, but groundwater overdraft has increased (Figure 1.4). From 1988–2002, overdraft contributed 8 percent of net water used in the valley; from 2003–17, its share rose to 15 percent. Worsening droughts, increasing regulations to protect endangered native fishes, and growing demand for Delta imports in Southern California have compounded surface water scarcity and increased pressure on groundwater resources.[8]

These trends are averages across the entire region. But although water scarcity is a regional problem, it is not experienced equally. As Chapter 2 will show, overdraft is much greater in the southern part of the valley.

FIGURE 1.4

Groundwater overdraft in the San Joaquin Valley has accelerated in recent years



SOURCE: Author estimates using data from several sources (for details, see Technical Appendix A).
NOTE: "Dry years" are those classified as dry or critically dry for the San Joaquin Valley.

[7] For details, see Technical Appendix A. The annual regional water balance data are included in *PPIC San Joaquin Valley Water Balance 1988–2017*.
[8] These changes have particularly affected users of Delta imports, which fell from an average of 3.5 maf/year in 1988–2002 to 2.9 maf/year in 2003–17 (Technical Appendix A).

The Need to Manage Groundwater

Relying on groundwater overdraft to close the growing gap between water supplies and demands is becoming increasingly costly. Chronic groundwater level decline makes drinking water and irrigation wells go dry, increases energy required to pump water, and reduces reserves to cope with future droughts. It also causes subsidence—sinking—that damages major regional infrastructure. As an example, land subsidence from excess groundwater pumping has reduced capacity of two of the valley's critical conveyance arteries—the Friant-Kern Canal and the California Aqueduct.[9] SGMA now requires bringing basins into balance, but the increasing costs of aquifer overdraft would make groundwater management necessary under any circumstance.

In the long run, stabilizing groundwater levels should result in lower costs to the region. As an example, a study focused on the overdrafted Kings and Tulare Lake sub-basins found that implementing groundwater management would incur some initial costs, but lead to net benefits to the agricultural sector over the 88-year implementation horizon (MacEwan et al. 2017). The study understates the benefits of management, because it only considered three costs of overdraft: (1) increased energy use to pump water, (2) replacement of dry irrigation wells, and (3) losing groundwater as a reserve for future droughts. It did not account for other significant costs, such as the impact of land subsidence on infrastructure, and effects of declining groundwater levels on the supply and quality of drinking water. In some areas, overdraft also depletes water supplies for downstream surface water users and the natural environment.[10]

Ending overdraft will bring longer term benefits, but also entails near-term costs. Spreading these costs over a longer period can prevent major disruptions in the regional economy. This gradual approach is often referred to as "glide path" implementation of SGMA, with incremental reductions in excess pumping until 2040. Most GSAs in the valley are likely to adopt this approach, under which groundwater levels would continue to decline, but at a decreasing rate, until they reach long-term balance. This longer implementation timeframe would also allow water and land management institutions to adjust, and respond better to changes expected under SGMA. Once basins attain long-term balance, groundwater levels will still fluctuate with hydrologic conditions—with more recharge in wet years and more pumping in dry years. In exchange for this flexibility, GSAs should plan to mitigate the undesirable effects of groundwater level declines from excess pumping.[11] In Chapter 3, we discuss how to address the risk of drinking water wells going dry.

Overview of This Report

This report focuses on finding solutions to critical water challenges for this important region. Each chapter scopes alternatives and recommends cost-effective and practical management approaches. A central theme is the importance to successful outcomes of cooperation and coordination among multiple valley stakeholders at both the local and regional levels. Here is a summary of the chapters.

- **Chapter 2: Balancing Water Supplies and Demands.** To close the groundwater deficit, groundwater sustainability agencies in the valley's overdrafted basins will have to augment their supplies, reduce their demands, or use some combination of both. This chapter analyzes a suite of options for bringing the

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[9] Subsidence has reduced capacity in the southern reach of the Friant-Kern Canal by 60 percent, to just 3,500 acre-feet/day (Fitchette 2018). Capacity in the southern part of the California Aqueduct has fallen by more than 20 percent near Avenal in Kings County, to 13,000 acre-feet/day, limiting high flow deliveries to Kern County and Southern California (California Department of Water Resources 2017b, Fitchette 2017).

[10] SGMA requires GSAs to prevent significant and unreasonable impacts on these water users (see Box 1.1). Relative to some other regions of California, the San Joaquin Valley likely has fewer areas where groundwater pumping still depletes surface water flows, because sustained overdraft can break the hydrologic connection between groundwater and surface flows. The Nature Conservancy—in partnership with DWR and the Department of Fish and Wildlife—has developed a mapping tool and other resources to help GSAs identify areas that may have groundwater-dependent ecosystems, as reflected in locations of seeps and springs, wetlands, and vegetation likely to depend on groundwater.

[11] To follow a glide path approach, GSAs need to go on record that groundwater levels in January 2015—the baseline conditions under SGMA—were not significant and unreasonable, and articulate why lower water levels would be acceptable. Glide path proposals must consider all six sustainability indicators (see Box 1.1).

valley's basins into balance, and outlines how to devise the best portfolio to minimize the costs of transitioning to sustainable groundwater management. Each option has benefits and costs, but also some associated uncertainties. Actions with the most potential include capturing more local runoff and storing it in the valley's aquifers, and trading water within the region to lower the costs of reduced farm water supplies.

- **Chapter 3: Addressing Groundwater Quality Challenges.** Polluted groundwater impairs drinking water supplies in poor rural communities, reduces long-term agricultural prosperity, and degrades ecosystems. California has been a national leader in seeking to address these problems, with a suite of new regulations adopted over the past decade. This chapter considers ways to tackle groundwater quality challenges, with a focus on providing safe drinking water and managing long term nitrogen and salt loading in groundwater and soils. Safe drinking water solutions include funding and technical support for water treatment, new supplies, and aggregation of water systems. To manage long-term nitrogen loading and salt build up, new management approaches and technologies are needed. And because the most favorable actions to bring basins into balance could affect groundwater quality, it will be necessary to manage water quantity and quality together, to take advantage of synergies and to avoid unintended consequences.
- **Chapter 4: Fostering Water and Land Use Transitions to Benefit People and Nature.** This chapter explores how to harness the impending changes to water and land use management under SGMA to bring broader benefits to people and the natural environment. There are opportunities to put lands coming out of production to good use—and to use environmental water more efficiently and effectively. Multi-benefit approaches to water and land management can yield enhanced groundwater recharge and improved air and water quality. They can also promote healthier soils, new recreational opportunities, additional flood protection, improved habitat, and new revenue streams for private landowners engaging in conservation efforts. Adopting this approach will require valley stakeholders—and their state and federal partners—to engage in much broader and more comprehensive planning than ever before.
- **Chapter 5: Roadmap to a Better Future.** This chapter concludes with our recommendations for action—a roadmap of priorities for local, state, and federal partners to implement promising solutions.

Chapter 2. Balancing Water Supplies and Demands

The Sustainable Groundwater Management Act (SGMA) requires water users to bring their basins into long-term balance. To close the deficit, groundwater sustainability agencies (GSAs) in the San Joaquin Valley's overdrafted basins must augment their supplies, reduce their demands, or combine these approaches. This will entail some additional costs in the near term, but should eventually result in lower costs. The valley's urban communities will need to be actively engaged in this effort. But as the valley's largest water user, agriculture must play a leading role.

The region has a range of options to consider, including investing in new surface and groundwater storage to capture more local and imported supplies, incentivizing urban water conservation, reducing water use on farms, and trading water to lessen the costs of reduced supply. Many options require coordination both within and across GSAs, as well as authorization from state and federal agencies. The feasibility of each option will therefore depend not only on how much it can contribute to reducing the deficit—and at what cost—but also on the ability to reach agreements among local and regional partners and to obtain regulatory approvals.

This chapter identifies the most cost-effective mix of options to bring the valley's water supplies and demands into balance. First, we describe key elements of groundwater basin accounting, and provide estimates of how the valley-wide deficit is distributed across the region. We then outline all available water supply and demand management options. Next we explore which supplies agriculture can afford, and assess cost-effective approaches to managing agricultural water demand.

We find that a portfolio approach—combining both supply and demand management—is most promising. Actions to increase supplies, particularly through more capture and storage of local runoff, could affordably fill roughly one quarter of the historical groundwater deficit. Increasing water trading within the valley to allow water to move to more profitable uses could significantly reduce the costs of managing demand. We conclude with a review of institutional and regulatory actions needed to implement these promising options.

Although we focus our analysis on ending historical overdraft, we also briefly consider other issues that could increase the region's future groundwater deficit, requiring greater adjustments: changing climatic conditions, increased environmental flow requirements under state and federal regulations, and failure of valley cities and suburbs to manage their water demands.

Getting Started: Establishing Water Balances

Bringing basins into balance requires quantifying the water deficit. Although regional estimates of groundwater imbalance are in broad agreement, the current understanding of the gap between supplies and demands at the local level is not as good.[12] Figure 2.1 shows our rough estimate of how the valley's historical overdraft of 1.8 maf/year is distributed across five subregions: two in the San Joaquin River hydrologic region (northwest and northeast), and three within the Tulare Lake hydrologic region (southwest, southeast, and Kern Basin). Overdraft is much more significant in the Tulare Lake region, which is drier and more heavily dependent on surface water deliveries imported from elsewhere.

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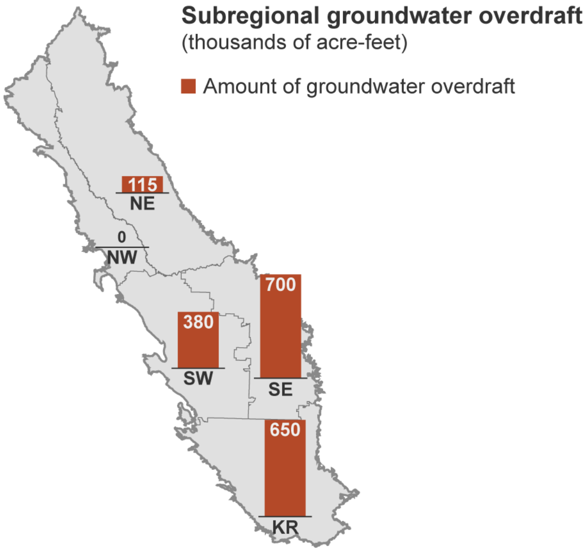
[12] As an illustration, the two regional groundwater models, DWR's C2VSim and the US Geological Survey's CVHM, are in broad agreement with each other about the valley-wide water balance, but they differ considerably in their estimates of overdraft at the subregional scale (see technical appendix Table A2). This reflects greater challenges in understanding the details of local water supplies and use, and the way groundwater moves within and across basins.

FIGURE 2.1

Overdraft is most pronounced in the southern San Joaquin Valley



SOURCE: Author estimates (Technical Appendix A).

NOTES: NE is northeast, NW is northwest, SE is southeast, SW is southwest, and KR is Kern Basin. Our rough estimates of overdraft were developed by adjusting results from a valley-wide model (CVHM) for 1975–2003 to our estimates of the 1988–2017 valley-wide water balance. Numbers are rounded to the closest 5,000 acre-feet. For details, see Technical Appendix A.

As part of their groundwater sustainability plans, water users in each basin will need to estimate how much water is available and how much is being used, and set up systems to monitor changes over time.[13]

In its guidance to GSAs, the Department of Water Resources (DWR) provides information on many of the tools for basin accounting—establishing water budgets, using groundwater models to understand how water moves within and across basins, and defining sustainability criteria to avoid undesirable impacts under the law.[14] DWR has also established monitoring protocols and reporting standards that GSAs will need to follow as they track groundwater metrics in their basins. But the regulations leave a lot of leeway, including on the timeframe for water accounting: plans are only required to include 10 years of water balances, and GSAs can pick the period of analysis.

This flexibility will make it easier for GSAs without ready access to good data and models to develop their first plans, but it also raises two significant challenges. The first is reconciling information across the valley's 121 GSAs and 15 basins. DWR expects GSAs within the same basin to use consistent timeframes and accounts. Yet this is not the case for GSAs in adjacent basins, even though they are required to consider how their management actions affect each other's groundwater supplies. Coordination will be harder if they are using different accounting timeframes and assumptions.

The second challenge is including an adequate period of analysis to develop realistic plans. As an illustration, consider our estimate of the 30-year regional groundwater deficit for 1988–2017, averaging 1.8 million acre-feet (maf)/year (Chapter 1, Figure 1.4). The picture would look very different if we had just included the first 15 years (1.3 maf/year) or the last (2.4 maf/year). Water balances that are too short are less likely to capture a

[13] The regulations introduce the concept of minimum thresholds—a numeric value used to define undesirable results such as declining groundwater levels, reduced groundwater storage, and land subsidence. To avoid exceeding these thresholds, GSAs in overdrafted basins will need to track water supplies and use on an ongoing basis, and incentivize water users to avoid excess pumping.

[14] Here is a link to these resources.

representative range of hydrologic variability. And although there are uncertainties inherent in using any historical period—since future conditions could change—balances that exclude the 2012–16 drought are likely to underestimate the extent of future overdraft, especially given the expected impacts of climate change on hydrological conditions in California (Mount et al. 2018). Over time, it will be important to continue strengthening basin-level groundwater accounts. DWR can foster this process with groundwater accounting standards that enable comparability and auditability (Escriva-Bou et al. 2016).

Identifying Options to Balance Supplies and Demands

Despite uncertainties in estimates of groundwater deficits, the math of balancing supplies and demands is simple: overdrafted basins must expand supplies, reduce demands, or use some combination of the two. A range of options is being considered in the San Joaquin Valley (Table 2.1). On the supply side, this includes capturing and storing more local inflows in surface reservoirs and aquifers, increasing local runoff by managing upper watersheds, increasing imports, decreasing the amount of water leaving the region, and treating and reusing local water supplies. On the demand side, options include reducing agricultural, urban, and environmental water uses, reducing losses from water infrastructure, trading water to reduce use in ways that are less costly, and taking a gradual and flexible approach to ending overdraft.

TABLE 2.1
Water portfolio options for the San Joaquin Valley

Supply management options	Demand management options
Capture and store more local runoff – Expand local surface reservoirs* – Expand groundwater storage* – Reoperate surface and groundwater storage*	**Reduce agricultural water use** – Increase irrigation system efficiency – Shift to less water-intensive crops** – Reduce irrigated acreage**
Increase local runoff – Increase inflows by managing forests in upper watersheds*	**Reduce urban water use** – Expand residential indoor conservation – Convert to less water-intensive landscapes*
Increase imported water from the Delta – Expand Sacramento Valley storage* – Expand Delta and South-of-Delta storage* – Increase cross-Delta conveyance capacity* – Reoperate the whole Central Valley system*	**Reduce water use on non-irrigated lands and wetlands** – Reduce net use on these lands
Reduce flows leaving the San Joaquin Valley – Reduce San Joaquin River outflows* – Reduce exports to other regions*	**Reduce losses from water infrastructure** – Reduce evaporation losses – Reduce leakage and seepage
Reuse and repurpose local water supplies – Expand recycled water reuse* – Desalinate brackish groundwater – Reuse water produced in oil and gas wells*	**Increase flexibility** – Expand water trading** – Reduce overdraft gradually

SOURCE: Developed by the authors (Technical Appendix B and Technical Appendix C).
NOTES: Options denoted with * are analyzed in greater detail in Technical Appendix B for potential water supply yields and likely costs. Agricultural water use reductions denoted with ** are analyzed in greater detail in Technical Appendix C.

These options are not likely to be equally effective or practical. Selecting effective approaches requires distinguishing between applied and net water use, and tracking return flows (Box 2.1)—both key elements of a robust water accounting system.

Box 2.1: Some Key Water Accounting Concepts for Implementing SGMA

Accounting systems are most precise when they distinguish between two types of water use: "applied" or "gross" and "net" or "consumptive" (Escriva-Bou et al. 2016).

- "Applied" use is the amount of water initially delivered for a given purpose.
- "Net" use is water consumed at the place of use. This includes water consumed by people or plants, embodied in manufactured goods, or evaporated into the air, along with discharges into saline water bodies, where it is not reusable without significant treatment. This water does not return to the system.
- "Return flow" is water that returns to rivers, streams, or aquifers and is available for reuse. It is the difference between applied and net use. Return flows come from sources such as urban wastewater discharges, unlined canals, and irrigation water not consumed by crops. These flows are often substantial.

Accounting for these differences can help identify realistic approaches to augmenting supplies and managing demands. In particular, actions to save water must account for net—not applied— water savings. Otherwise, they may merely result in reallocating return flows, rather than improving the water balance. Some examples:

- "Inefficient" irrigation with surface water is a major way to recharge aquifers. Converting flood irrigation to drip or micro-spray technologies reduces the amount of applied water, but it doesn't usually increase overall water availability (Ward and Pulido-Velazquez 2008, Perry and Steduto 2017, Grafton et al. 2018). Indeed, more efficient irrigation systems can actually *increase* the amount of water consumed because they enable farmers to expand irrigated acreage or increase yields on existing acreage (e.g., by adding an extra cutting of alfalfa or planting trees more densely).
- Similar issues arise with lining earthen canals and making that water available for other uses; this can reduce recharge.
- In inland areas, recycling urban wastewater may simply be reallocating return flows to aquifers or rivers that were already being used by others in the basin or downstream.

Even if these actions do not produce net water savings, they can still have value. For instance, irrigation efficiency can help manage water quality and raise crop productivity, and lining canals in places where groundwater quality is poor can put the water to better use elsewhere. But their contribution to balancing the groundwater basin depends on their *net* water savings.

If basins bring in new surface water supplies, the entire volume can contribute to reducing overdraft. The new supplies enable water users to pump less groundwater, and they contribute new return flows that can recharge local aquifers.

Expanding Usable Supplies

Historically, water scarcity in the valley has been addressed by expanding water supplies—including capturing flows from local rivers and investing in projects to import water from Northern California through the Delta (Hanak et al. 2017). As a result, most of the largest and most affordable supply options have already been developed. Growing environmental awareness also limits development of some new supplies, and the need to produce *net* increases in water limits the value of options like water reuse. Yet there is some potential to expand usable supplies to reduce the groundwater deficit. Here are the options under consideration:

Capture and store more local runoff. The valley's rivers are already intensively managed to capture and store water for local uses, with more than 130 surface reservoirs and some of the world's most advanced groundwater banks. However, there is potential to capture even more water, especially during very wet years (Hanak et al. 2018). This water can be captured by expanding surface reservoir capacity, such as the proposed Temperance Flat Reservoir, and by increasing groundwater recharge. The latter involves channeling water into dedicated recharge basins and unlined canals, or flooding suitable cropland and open space. Changing reservoir operating rules to coordinate the use of surface and groundwater storage can also increase storage: releasing more water from surface reservoirs during the fall to replenish aquifers increases these reservoirs' capacity to capture water from winter storms.

Because capturing and storing more local runoff reduces river flows, the State Water Board will generally need to authorize these actions—after ensuring that the new diversions do not harm downstream water right-holders or the environment.[15] The board has recently required water users on three San Joaquin River tributaries—the Merced, Stanislaus, and Tuolumne—to augment environmental flows to protect endangered salmon.[16] We consider the possibility of reduced water availability for these parties when assessing the costs of adaptation to a larger future water supply deficit.

Expanding both local and regional conveyance infrastructure may also be necessary to facilitate recharge. In particular, there are capacity constraints to moving large volumes of water quickly from the wetter, northern part of valley (where most available flows are located) to the drier southern part (where the demand for recharge is higher and conditions are generally more suitable) (Hanak et al. 2018). Land subsidence has reduced the capacity of the Friant-Kern Canal and the California Aqueduct, making this even more challenging.

Increase local runoff. An option that has generated significant interest in recent years is to manage upstream forests to increase runoff to the valley floor. By reducing the risk of extreme, damaging wildfires, forest management in mountainous headwaters can have many other benefits: lower fire-fighting costs, improved air and water quality, improved natural habitat, and better timber harvest and recreational benefits for local economies (Butsic et al. 2017). The idea behind the water supply benefit is that thinning overly dense forests can reduce the water consumed by trees (Roche et al. 2018). There is significant uncertainty, however, regarding the potential to realize such benefits and whether investments needed to increase water supply make economic sense.[17]

Increase water imported from the Delta. About a fifth of the water used in the San Joaquin Valley during the past 30 years was imported through the Delta by the Central Valley Project (CVP) and State Water Project (SWP). Almost all of this water originates in Northern California.[18] Imports to the valley have declined since the early 2000s, reflecting drier conditions, stricter regulatory standards in the Delta to protect endangered fish, and increasing demand for imports in Southern California.[19]

Several options to increase imports have been considered; most are relatively costly. The general goal is to make it easier to capture and convey extra water when it is available, and move water in ways that are more compatible with regulatory goals. Options include:

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[15] The exception is when the diversion of high flows is already authorized by an existing water right.

[16] State Water Resources Control Board (2018a) provides the detailed staff proposal for mandated environmental flows. The board left open the possibility of approving a negotiated settlement, rather than these flow levels, as part of a comprehensive agreement on flow management in the Sacramento–San Joaquin Delta watersheds in 2019 (State Water Resources Control Board 2018b).

[17] Another way to increase local runoff would be to reduce surface water diversions in upper watersheds currently being used for farming, including irrigated pasture. However, relatively little water is diverted upstream for this purpose.

[18] On average, about 90 percent of Delta imports are from the Sacramento River hydrologic region; 10 percent is outflow from the San Joaquin River recaptured at the pumps in the South Delta. A small portion of Sacramento River flows to the Delta originate in the Trinity Alps, in the North Coast hydrologic region.

[19] Imports to the valley declined from an average of 3.5 maf/year from 1988–2002 to 2.9 maf/year from 2003–2017. See Technical Appendix A for a discussion of the various factors contributing to this decline.

- Increase storage capacity to the north of the Delta pumps, as with the proposed Sites Reservoir and an expanded Shasta Reservoir in the Sacramento Valley, and an expanded Los Vaqueros Reservoir in the Bay Area.
- Increase CVP and SWP storage in the San Joaquin Valley—such as expanding San Luis Reservoir—to enable more water to be stored locally when Delta conditions are favorable for importing.
- Improve cross-Delta conveyance capacity. The proposed California WaterFix would provide more operational flexibility by diverting Sacramento River water north of the Delta and drawing it through two tunnels to the south Delta pumps.
- Reoperate the whole Central Valley system of surface and groundwater reservoirs and conveyance infrastructure to increase storage and supplies.

As with capturing more local runoff, making use of these options will generally require State Water Board authorizations for new diversions and storage. The board is considering increased requirements for Delta outflow from the Sacramento River to support salmon, steelhead, and smelt, which could reduce water available for increased imports (State Water Resources Control Board 2016). We consider the possibility of reduced imports when assessing the costs of adaptation to a larger future water supply deficit.

Reduce flows leaving the valley. Two main options are to reduce San Joaquin River flows into the Delta, and to decrease the share of Delta imports that go to other regions. The first is equivalent to capturing and storing more local runoff, as described above. The second could be accomplished if urban residents in Southern California, the San Francisco Bay Area, and the Central Coast reduce their use of Delta imports, now averaging roughly 1.7 maf per year, and Tuolumne River water, now averaging roughly 0.2 maf per year. This would mean reversing the recent trend for Southern California, where average imports have increased by more than 0.5 maf per year since 2000.[20] In our detailed analysis, we examine the potential contribution to valley water supplies of increased urban conservation in coastal regions. Other options, such as more investments in recycled water and stormwater capture, could also reduce their demand for Delta imports.[21]

Reusing and repurposing local water supplies. In much of the valley, treated urban wastewater is discharged to land, where it contributes to groundwater recharge. But there is also growing interest in an irrigation water supply derived from recycling wastewater that flows into east-side rivers. Unfortunately, this option does not generally increase regional supplies, because most treated wastewater is already used downstream by other water right-holders or as environmental flows (Box 2.1).[22] Similarly, desalting brackish groundwater could make more water available to some users, but it would not help achieve balance because pumping it would add to extraction from the aquifer. In contrast, the water produced by oil and gas mining could augment net supplies, because affected aquifers are much deeper and usually disconnected from those for water supply. Some of this water is already used for irrigation; treatment costs can limit the viability of expanding its use (Meng et al. 2016).

Managing Water Demand

When supplies are limited or too expensive, the only remaining option is to reduce net water use. To improve the water balance, it is essential to identify opportunities for net—not just applied—water savings (Box 2.1). Since

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[20] This shift mainly reflects the region's increased use of its SWP contracts to increase local storage. Some Southern California communities also purchased long-term contracts from irrigation districts in the valley. See Technical Appendix A for details.

[21] We assume that valley farmers would pay for these investments in exchange for the water. These options generally cost as much or more than water conservation investments, so some of the same considerations of affordability for valley farmers come into play (McCann et al. 2018). Another longer term possibility would be for Southern California urban communities to purchase more water from irrigation districts with rights to Colorado River water, making more Delta imports available in the valley. This would require addressing environmental problems from reduced agricultural drainage inflows to the Salton Sea and local community concerns about the economic impacts of additional farmland fallowing, and it could also require new investments in conveyance infrastructure.

[22] This issue arose in a recent sale of recycled water from the City of Modesto to the Del Puerto Water District. Some other valley water users charged that the sale reduced outflows from the San Joaquin River—and hence Delta imports, and Del Puerto settled the claim (Morain 2015).

most water use in the valley is for cropland irrigation (87%), agriculture faces the largest reductions under SGMA. Cities (with just over 3% of net use) can also help, but at a much smaller scale. Decreasing water use in the natural environment (10%) is more challenging. So is reducing net losses in surface reservoirs and the conveyance and distribution system. Water trading makes it possible to manage demands more flexibly, at lower cost. And stretching out the time to achieve sustainability can lower adjustment costs. Here are the options:

Reduce agricultural water use. The valley has more than 5 million acres of irrigated cropland. Idling cropland and switching to crops that use less water are the best options for net water savings. In our detailed analysis, we consider how valley farmers can employ these two strategies to minimize their economic losses from groundwater cutbacks.

It is commonly thought that increasing irrigation efficiency—for instance by switching from flood to drip irrigation—is also an important way to save water. Valley farmers have been switching rapidly towards these low-water systems, which now cover more than 40 percent of all acreage.[23] However, greater irrigation efficiency often just reduces applied—not net—water use. This is because most irrigation water not consumed by plants returns to rivers or recharges aquifers where it is available for reuse (Box 2.1). Investments in irrigation efficiency will remain worthwhile for other reasons—including to protect water quality.

Reduce urban water use. The valley's population in 2015 was 4.3 million, and cities and suburbs occupy more than 500,000 acres of land on the valley floor. Water use fell from 226 gallons per capita per day (gpcd) in 2013 to 161 gpcd at the height of the drought, and then rose to 179 gpcd in 2017.[24] Roughly half of this water is for landscape irrigation. In inland areas like the San Joaquin Valley, saving water indoors has other benefits—such as reducing energy demands and treatment costs—but it generally does not increase net water supply for the region. This is because the return flow (wastewater) already goes back to rivers or aquifers after treatment. Reducing water used on landscaping—especially by decreasing area covered by lawns and shifting to plants that use less water—is the most effective way to achieve net water savings. Under legislation enacted in 2018, urban areas across California will be required to make long-term reductions in both indoor and outdoor water use. In our detailed analysis, we consider the potential for outdoor water savings to accommodate population growth and make water available for agriculture.

Reduce water use on non-irrigated lands and managed wetlands. On average, roughly one-tenth of net water use in the valley is on non-irrigated lands and managed wetlands. The largest portion is for natural vegetation on unirrigated lands, which occupy more than 3 million acres on the valley floor.[25] The main water source is precipitation, and both vegetation growth and net water use vary substantially between wet and dry years. These landscapes already provide an array of services, including rangeland for livestock grazing and habitat for many species. As Chapter 4 demonstrates, it is possible to enhance these benefits as part of a coordinated strategy for managing the valley's drylands. There are no practical proposals to reduce this water use.

The valley also has roughly 130,000 acres of managed wetlands—a network of federal, state, and private wildlife refuges to support waterbirds of the Pacific Flyway (California Department of Fish and Wildlife 2015). As discussed in Chapter 4, these refuges are allocated water through the Central Valley Project under a 1992

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[23] In 2010, 46 percent of fields in the valley had gravity/flood irrigation (down from 55% in 2001), 42 percent used low-volume/drip methods (up from 36% in 2001), 8 percent used sprinklers (7% in 2001), and 4 percent used subsurface irrigation (2% in 2001) (Department of Water Resources Statewide Irrigation Systems Methods Survey). Federal and state grants have supported continued expansion of drip systems since that time, and some farmers fully fund the transition on their own. Technical appendix Figure E4 reports irrigation systems by crop type in the early 2010s, and technical appendix Figure F18 shows recent US Department of Agriculture funding for irrigation efficiency.

[24] This total includes both residential and non-residential uses. Estimates are updated from Escriva-Bou et al. (2017), using monthly reports to the State Water Board.

[25] Land use data is for 2014 from California Department of Water Resources (2017a).

federal law.[26] Although there is little potential to generate net water savings from them without harming wildlife, cooperative water management projects could improve the timing and availability of water for the refuges and neighboring irrigation districts.[27]

Reduce losses from water infrastructure. From 1998–2010, roughly 720 thousand acre-feet (taf) per year evaporated off reservoirs, natural lakes, and ponds, and roughly 550 taf per year during the water delivery process.[28] Controlling these losses seems unlikely, although there might be some scope for using solar panels to reduce evaporation on canals. The distribution system also loses water to seepage—around 460 taf annually over this same period. Lining canals and making other investments to reduce leaks are sometimes employed to reduce seepage losses. However, this approach has similar limitations to irrigation efficiency for achieving net water savings, because it reduces return flows and the recharge of aquifers.[29]

Increase trading to improve flexibility. Trading water could ease the transition to sustainable groundwater use. It compensates water right-holders with less profitable water uses for foregoing their own use and shifting water to others who generate more value from the water. Water trading is already common in the valley—both at very local scales and across wider distances. During the latest drought, trading helped keep orchards alive in the most water-stressed areas. In our detailed analysis we consider how expanding surface water trading within the valley could lower the costs of ending overdraft. We assume that valley water users will develop programs to trade groundwater allocations within basins, another way to reduce these costs (Bruno 2018). In addition to simplified approval processes, investments to expand conveyance capacity may be warranted to facilitate trading.

Reduce overdraft gradually. Another way to reduce the costs of demand management is to stretch out the time needed to end overdraft. This flexible approach—sometimes called the "glide path"—entails progressively ramping down excess pumping over SGMA's 20-year horizon for attaining sustainability, rather than ending overdraft right away. Most GSAs in the valley are likely to adopt this approach. This could cause some additional negative impacts by further lowering groundwater levels. However, it will likely also lower the costs of adaptation, by giving water users more time to implement effective supply and demand management strategies. In addition to the glide path, groundwater sustainability plans are likely to include flexibility to pump more groundwater during dry years, when surface water is in short supply.

To comply with SGMA, GSAs will need to address undesirable consequences of the additional overdraft from these flexible approaches. In Chapter 3, we discuss ways to mitigate the risk of shallow domestic wells running dry, which will be an important issue in some areas. Finding ways to mitigate or avoid land subsidence will also be a priority for some GSAs.[30]

Selecting the Best Portfolio of Actions

Each option involves costs and provides benefits in terms of new water available or net water savings. Because estimates of these costs and benefits are uncertain, the investments entail some risks. For instance, the water

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[26] A 2009 study estimated that average water deliveries to the refuges increased by about 21,000 acre-feet (af) (up from 422,000) after the enactment of the Central Valley Project Improvement Act, and that reliability of deliveries improved (Central Valley Project Improvement Act Refuge Water Supply Program 2009).
[27] For a discussion of some opportunities, see the panel on "Partnerships for healthy ecosystems" at PPIC's fall 2017 water policy conference.
[28] These estimates are from regional water balances in the California Water Plan Update (Department of Water Resources 2013). Because they occur above the valley floor, losses in upstream reservoirs are not included in our estimates of net water use in the valley. Evaporation losses from conveyance are apportioned to agriculture, the natural environment, and urban areas based on their water deliveries. Water that seeps back into aquifers from unlined canals is counted as part of recharge in our water balance.
[29] Our 2017 survey of water managers found that unlined canals were a major tool for recharging groundwater in some parts of the valley (Hanak et al. 2018).
[30] For instance, it might be possible to limit pumping—and substitute groundwater with surface water—around hot spots close to vulnerable infrastructure. The agreement among several parties in the San Joaquin River region to limit subsidence damage to Sack Dam may be a useful model to follow elsewhere (San Joaquin River Exchange Contractors Water Authority 2017).

yielded by proposed reservoirs and other big infrastructure projects is usually given as a range that depends on future climatic conditions. Regulations can also affect the scale at which some options are feasible—for instance, the ability to capture more high-flow water for recharge. Water trading, groundwater banking partnerships, and reservoir reoperation will also require cooperation among different parts of the valley and the state.

The following sections analyze the costs and benefits of options to bring basins into balance and identify the portfolio of actions that can minimize the costs of making this transition. Although we focus on agriculture, we assume that the urban sector will achieve significant reductions in net per capita water use in response to SGMA and new state conservation policies. At the regional scale, this can enable the valley to accommodate expected population growth of 1.4 million new residents by 2040, without increasing overall water scarcity.[31] In practice, urban water agencies will also participate in the development of new water supplies, and potentially fund some supplies that cost more than valley agriculture can afford.

Cost-Effective Options for Expanding Water Supplies

Every drop of additional water makes it possible to bring basins into balance with fewer reductions in water use. But some supplies will be too expensive to justify the investment. Here we explore which options are likely to be viable for agriculture.[32]

Our economic model of valley agriculture (described below) provides some guidance on how much farmers would be willing to pay for additional long-term water supplies. This price is the profit farmers can earn with an additional acre-foot of water; above this level, it is more economical for them to reduce water use and irrigated acreage. A small number of farmers might be willing to pay a very high price—as much as $900/acre-feet (af)—to avoid long-term fallowing of some very profitable lands. And to cope with temporary shortages—such as at the height of the 2012–16 drought—some farmers will pay top dollar for water to keep their orchards alive.[33] But with available options, most valley farmers will not be willing to pay more than $300 to $500/af for new long-term supplies.[34]

To see how much water supply expansion might be feasible, we look at the potential yield and costs of portfolio options listed in Table 2.1. For projects like Sites Reservoir and California WaterFix, which would also supply water to parties outside the valley, we focus on the portion that could be available for use within the valley. We include urban conservation in coastal regions and within the valley, because the net water savings beyond what is needed to support population growth could be used to increase farm water supplies.

We compare new water supply costs of different options in similar terms, as dollars per acre-foot/year. For multi-benefit investments that would be co-funded by other beneficiaries—such as storage projects eligible for state

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[31] Assuming the same per capita use as in 2013, valley urban water demands would increase by almost 350 taf per year. A 38 percent reduction in net water use from outdoor landscaping could accommodate this growth without increasing urban water demand.

[32] Technical Appendix B provides more details on water volume and cost ranges of different options, drawing on information from public reports and the scientific literature. Technical Appendix D describes options likely to be viable investments for agriculture, considering both agriculture's willingness to pay and the likely range of costs and supplies.

[33] In 2014, for instance, some water changed hands in Kern County for $1,250/acre-foot (Henry 2014).

[34] For more than half of valley cropland, the cut-off price would be much lower, because an additional acre-foot of water would generate less than $200 in added profits. This difference in the profitability of water in different uses drives incentives to trade water. When valley-wide surface water markets are allowed, the price of water in the market falls to about $185/af. In our analysis of willingness to pay, we consider farmers' water demand with and without valley-wide trading under current conditions, and we also consider the possibility that profitability of farm water use may increase by up to 25 percent from shifts toward more profitable crops, higher prices for farm output, or cost-reducing technology. With this higher profitability and no valley-wide water trading, some farmers would be willing to pay more than $500/af to acquire up to 340 taf of new supplies. With more limited increases in profitability and some valley-wide trading, farmers would only be willing to pay this price for up to 100 taf. We assume farmers would seek to invest in less expensive projects where feasible, however. This reduces the likelihood of investments in projects costing more than $500/af. See Technical Appendix D for details.

bond funding to provide new flows for the environment—we look at the share of costs water users would cover.[35] For multi-benefit investments where such funding commitments are not available, we allocate the entire project cost to water users. This is the case for forest management in the Sierra headwaters, for instance, which could have other benefits from reduced wildfire risks.[36] If funding became available to support such benefits, this would lower the water supply costs.

Finally, to determine the likely range of new supplies farmers will acquire, we take into account the uncertainties in both the yield and cost of different options, as well as farmers' willingness to pay for them. Given these uncertainties, our estimates should be viewed as a rough guide to investments that valley agriculture could support.

Table 2.2 summarizes our findings about the likely supply portfolio. The "potential increase" column reports the range of water that might be *physically* available within the San Joaquin Valley—*without* considering affordability. The "likely increase" and "most likely increase" columns report the range of supplies for which farmers might be willing to pay.[37] The low end of the range shows the amount of new supplies farmers would invest in even when they have low willingness to pay and the supply costs are high. The high end shows the other extreme: investments that would be worth making when supply costs are low and the profits farmers could earn with the additional water are high.

This analysis supports several conclusions about new supply investments:

- **Capturing more local runoff has the most potential for augmenting valley water supplies.** In particular, an increase in groundwater recharge could deliver significant new supplies at a cost farmers can afford (up to 490 taf/year). Limited studies done to date on reoperating surface and groundwater reservoirs in the valley also show small additional increases are possible (less than 10 taf/year)—and the potential is likely greater.[38] In contrast, investing in the Temperance Flat Reservoir appears too costly. Although this project could capture more than 200 taf/year of local runoff, the cost ($565/af) is more than most farmers would be willing to pay.[39]
- **Forest management could significantly increase local runoff, but at a very high cost.** The potential yield of forest management is very uncertain, but could reach more than 500 taf/year. However, this water would be much too expensive (more than $4,500/af) if the costs had to be covered solely by water users. Co-funding partnerships would be needed to make this a feasible option, with most costs covered by entities seeking to reap other benefits of forest management, including timber harvest and reduced cost of firefighting and air quality risks from wildfires.

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[35] For instance, for new water storage investments eligible for funding under Proposition 1, we exclude the water these projects would make available for environmental flows, along with the funding the state will make available for these and other public benefits. Where information was available, Technical Appendix B also provides the value of co-benefits for multi-benefit projects.

[36] We do include the benefits to hydropower production, but these are small. Major potential co-benefits are related to wildfire risk reduction, as described below.

[37] As described in Technical Appendix D, we do this by taking the range of yield and costs for each supply option, and the range of farmers' willingness to pay, and evaluating 500 combinations of supply and demand outcomes. The "likely increase" water availability range includes supplies with costs that farmers are willing to pay for in at least one combination. The "most likely" water availability range includes options that appear feasible in at least half of all combinations.

[38] DWR's analysis of reoperation in the valley, used for our estimates, only considers reoperating reservoirs on the Merced River (see Technical Appendix B).

[39] Given the importance of recharge in the portfolio, we examine several scenarios for how much water might be available from this option. Lowering the potential volume of recharge reduces the "most likely" volume of investments in new supplies and increases investment costs, but it does not make large infrastructure projects like Temperance Flat or California WaterFix cross the affordability bar. See technical appendix Table D2.

TABLE 2.2

Farmers will likely be willing to invest in just a subset of potential new water supply options

Strategy	Action	Potential supply increase (taf)	Likely supply increase (taf)	Most likely supply increase (taf)
Capture and store more local runoff	Temperance Flat Reservoir	197–257	0–0	0–0
	Groundwater recharge	0–550	184–492	303–376
	Reoperating surface and groundwater storage in the San Joaquin Valley	2–8	2–8	4–6
Increase local runoff	Forest management	0–512	0–0	0–0
Increase imported water from the Delta	Sites Reservoir	28–33	0–0	0–0
	Shasta Reservoir expansion	27–59	0–0	0–0
	San Luis Reservoir expansion	7–43	0–0	0–0
	Los Vaqueros Reservoir expansion	8–13	0–0	0–0
	California WaterFix	127–261	0–0	0–0
	Reoperating surface and groundwater storage in the whole Central Valley	17–100	17–100	43–77
Reduce exports to other regions	Urban water use reduction in coastal regions	0–144	0–34	5–17
Reuse and repurpose local water supplies	Urban reuse (recycling)	0–16	0–2	0–1
	Oil and gas wells	0–8	0–4	1–2
Reduce non-farm water use	Urban water use reduction in the San Joaquin Valley	0–86	0–24	4–10
Total		–	**247–570**	**380–467**

SOURCES: Author estimates using multiple sources (for details see Technical Appendix B, Technical Appendix C, and Technical Appendix D).

NOTES: Potential supply increase is the additional water that might be physically available in the San Joaquin Valley, not accounting for cost. Likely and most likely supply increase are the amount valley farmers may be able to afford, taking into account costs, yield, and farm-level profitability of additional supplies. For options that can be implemented through many small projects, the minimum potential increase starts at zero and goes up to the highest amount that might be available by combining all possible projects. For options that involve large investments, such as new reservoirs, the table reports the range of potential yield from the project.

- **Projects to increase imports will likely be too costly, but reoperating the system could pay off.** Most additional imports from expanding surface storage (Los Vaqueros, San Luis, and Sites Reservoirs) would go to parties in the Bay Area and Southern California. Projected increases in imports from California WaterFix would also be small for the valley. These options are also relatively expensive for valley agriculture, as reflected in limited local interest to invest in them. Expanding Shasta Reservoir would principally benefit valley farmers, but it is likely too costly for them without federal or state financial support. The best option appears to lie in reoperating the entire Central Valley network of surface and groundwater reservoirs as an integrated system. This could augment imports to the valley by up to 100 taf/year, yielding nearly half as much new water as building a new reservoir at Temperance Flat, at a much lower cost.
- **Water reuse provides little additional water supply.** Although urban wastewater reuse projects can increase deliveries to some water users, this does not generally result in net water savings for the valley, since most wastewater is already reused for aquifer recharge or streamflow. The potential for increasing usable water from oil and gas wells also appears to be very limited.
- **Greater urban conservation would mainly support population growth.** Even if half of current outdoor water use in coastal areas and within the valley is conserved—a significant goal—most of these savings will support urban population growth.[40] Costs can also be an issue. Although some conservation is low-cost,

[40] Population within the valley is expected to increase 32 percent from 2015 to 2040. Over this same period, population in coastal areas that use Delta imports is expected to grow by 24 percent in the Bay Area, 17 percent in the Central Coast, and 16 percent in the South Coast.

reports from conservation programs show that the median cost of savings can exceed $1,000 per acre-foot. On balance, a small amount of urban savings is likely to be available and affordable for valley agriculture.

We recognize that some investments that do not appear likely in our analysis may take place. To capture local runoff, some farmers may prefer investing in Temperance Flat over recharge, since the projected cost of this reservoir is only slightly above the affordability cutoff, and it provides more flexibility to manage supplies than recharge projects do. There may also be reasons for investing in WaterFix we have not fully considered.[41] In particular, improved Delta conveyance would make it easier to trade water, both within the valley and with partners in the Sacramento Valley. It would also make it possible to take advantage of more opportunities to recharge groundwater basins with high-flow Sacramento River water, which is more plentiful than flows in the San Joaquin River (Kocis and Dahlke 2017, California Department of Water Resources 2018).

On balance, however, the new water available to valley agriculture will be much less than the region's 1.8 maf/year long-term groundwater imbalance. Combining various feasible options, the likely total increase is 250–570 taf/year, and the most likely range is 380–470 taf/year. This means that reductions in agricultural water use will have to cover most of the valley's groundwater deficit.

Agricultural Adaptation to Using Less Groundwater

Sustainable groundwater management should result in higher long-term benefits to the valley's agricultural sector and regional economy, but making this transition will entail some near-term costs. This section first reviews the valley's agricultural economy, and then estimates the impacts of bringing basins into balance exclusively by reducing farm water use.

Agriculture and the Valley's Economy

The San Joaquin Valley produces more than half of California's agricultural output. The farm sector constantly evolves to adapt to changing commodity and labor markets, technology, and water availability. The region produces a wide range of agricultural commodities—including fruits, nuts, vegetables, cotton, alfalfa, dairy, and beef—with more than $30 billion in farm gate sales. When related food and beverage manufacturing is included, agriculture constituted 20 percent of the valley's total GDP, 18 percent of jobs, and 29 percent of revenues in 2015.[42]

Agriculture's role is even larger if one considers related activities in transportation, farm inputs, and finance, along with multiplier effects on the region's economy. Agricultural innovations and rising commodity prices have enabled the valley's farm economy to maintain its share of regional economic activity since the early 1990s, even while the valley has experienced rapid urban growth (Hanak et al. 2017).

Since the early 1980s, the value of the valley's farm output—after adjusting for inflation—has increased by more than 70 percent despite relatively stable irrigated area, averaging 5.3 million acres (Figure 2.2). This growth reflects continued expansion of animal production (especially dairy) and tree crops (especially almonds and pistachios). Milk, with almost $5.5 billion in cash receipts in 2016, has long been the valley's leading commodity. Almonds were a close second at $5.3 billion, and with expanding almond acreage and falling milk prices, they are soon likely to replace milk as the leading product. Grapes ($3.8 billion), citrus ($2.6 billion), cattle ($2.3 billion), and pistachios ($1.8 billion) are also top commodities.

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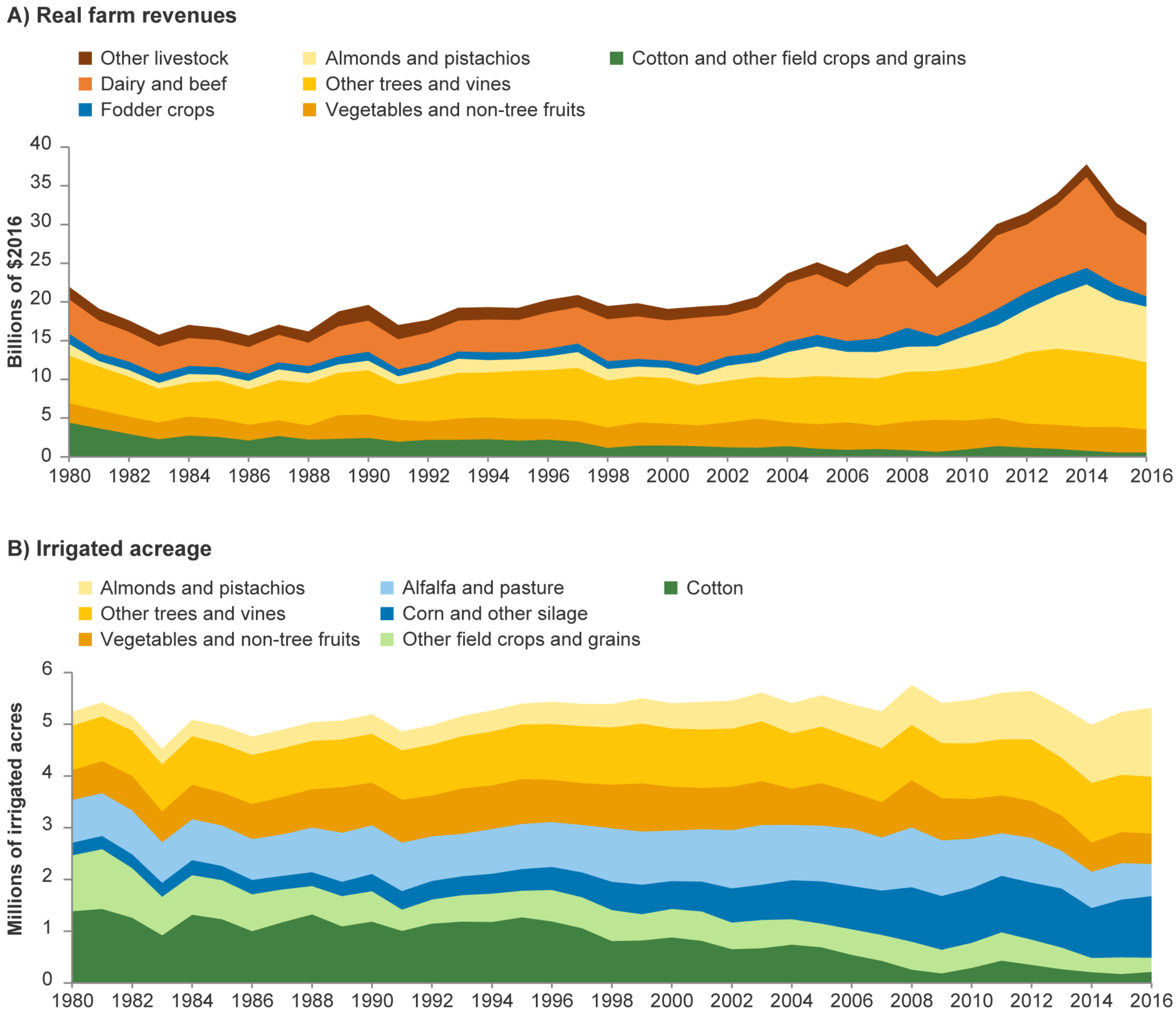
[41] WaterFix would reduce the salinity of water imports. We factor this co-benefit into our analysis of affordability (Technical Appendix B and Technical Appendix D).

[42] Estimates are from the IMPLAN model (MIG 2017). Comparable shares of agriculture in the California economy are much lower: 3.3 percent of jobs, 2.7 percent of GDP, and 4.6 percent of revenues. In 2015, food and beverage processing accounted for 21 percent of the valley's 311,000 agricultural jobs and 24 percent of its $30 billion in GDP. Its share of total revenues of $78 billion was higher (49%), because this sector's sales must cover the cost of purchasing crop and livestock products.

In 2016, 75 percent of irrigated cropland in the valley supported these six commodities, either directly or by supplying inputs for milk and beef production. Corn and other silage—used primarily for dairy—grew from 7 to 23 percent of irrigated acreage. Alfalfa and pasture—also used as feed—hovered around 16 percent before the latest drought, which reduced the footprint of these relatively low-revenue, water-intensive crops. Almonds and pistachios occupied roughly a quarter of irrigated lands in 2016, up from about 5 percent in 1980. Grapes remain stable at about 10 percent. Citrus has grown steadily, from 130,000 acres in 1980 to nearly 240,000 in 2016. The region saw sharp declines in less profitable field crops, including cotton—once a major commodity—and some other grains.

FIGURE 2.2

Real farm revenues have been rising, with growth in perennial crops and fodder for the dairy and beef industries



SOURCE: Developed by the authors using data from USDA's National Agricultural Statistics Service.

NOTE: Fodder crops (panel A) include corn and other silage (key inputs to the dairy industry), and alfalfa and irrigated pasture (key inputs to the dairy and beef cattle industries).

Costs of Groundwater Cutbacks to the Farm Economy

We estimate the farm-related costs of ending overdraft by looking at a chain of effects. We first explore how farmers may change their cropping decisions when they have less groundwater to use, and the consequences for acreage, output, and several measures of the economic value of production: revenues, profits, employment, and value added. Value added—the contribution of a business or industry to regional GDP—is the best measure of a sector's contribution to the overall economy.[43] We then look at related changes in downstream sectors: effects of reduced feed crop output on the valley's dairy and beef industries, and effects of reduced crop and animal products on local food and beverage processing.[44]

Modeling Farmers' Decisions to Reduce Groundwater Use

Farmers have always adapted to changing agricultural markets, technology, and water availability, and this will continue as the region implements SGMA. We use an economic model of valley agriculture to simulate how farmers may adapt to reducing groundwater use. (For details, see Technical Appendix C.) The model assumes that farmers have the best knowledge of their business, and that their cropping choices reflect the optimal response to a variety of economic considerations, including, but not limited to, profit margins on individual crops. For instance, although almonds might be more profitable, there are reasons why farmers keep planting alfalfa, including much lower initial investment and greater flexibility in the face of a variable water supply.

We use farmers' cropping decisions in 2010—a year with average water deliveries—as a benchmark. With groundwater shortages, farmers can reduce irrigated acreage or switch to crops that use less water. We assume they will make cropping changes to minimize the loss in profits from water shortages.[45] We look out to 2040, and assume that GSAs implement SGMA using a glide path approach. This way, farmers needing to reduce acreage of perennial crops can plan this over time, so they do not suffer large investment losses from removing productive orchards.

We focus on two scenarios for farm water management. In the first case, we assume that all farm water—along with other inputs—is used efficiently at the local level. This approximates conditions in which all surface and groundwater used by farms can be traded freely within a local basin.[46] In the second case, we also allow farmers to trade surface water across the entire valley.[47] This gives them more flexibility to move surface water to the most profitable uses, and draws water from the northern valley to the south, where the groundwater deficit is greater. We assume that groundwater trading is only possible locally, within the same basin.

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[43] Value added includes profit, compensation to employees, and taxes paid. It excludes the cost of goods and services purchased from other vendors or sectors, which have their own value added. The sum of value added from each sector equals total GDP for the region.

[44] We focus on the direct economic effects of reducing groundwater use on crops, livestock, and related food and beverage processing industries. When farm output is reduced, there can be additional effects on sectors that supply farms—such as transportation, fertilizer, irrigation services—as well as spillovers to the broader economy because people have less money to spend. We do not include these other multiplier effects, which are much more difficult to estimate accurately. The estimates often overstate the impacts of policy change, because they assume that businesses will not adapt to changing economic conditions.

[45] In recognition that dairy farmers have incentives to maintain corn silage production that are not reflected in the market price of corn, and that some perennial crop farmers may be willing to accept lower profits to keep their investments alive when faced with water scarcity, the model includes some restrictions on the share of land that may be fallowed for these crops.

[46] The model includes 14 local areas within the San Joaquin Valley, with boundaries broadly similar to the 15 groundwater basins (technical appendix Figure C1).

[47] For this analysis, we exclude the Delta portion of the San Joaquin River hydrologic region because this area also receives some of its water from the Sacramento River region. Expanding trades from farmers in the Delta, like trades from Sacramento Valley farmers, could also help close the valley's groundwater deficit.

Our assumptions about flexible water management may be optimistic. There is already significant local and regional farm water trading within the valley.[48] Yet restrictive rules and infrastructure constraints could limit its expansion. In the local trading case, adjusting to reduced groundwater pumping will be more costly than our estimates show if GSAs do not allow within-basin trading. SGMA presents new opportunities to develop such trading, but it has yet to be launched. And in the valley-wide trading case, the volume of trading will be lower—and the costs of adjustment higher—if communities in the northern valley restrict surface water trades, or if infrastructure is not available to move all the water farmers would like to buy. We discuss these potential constraints below. As a very rough indicator of the added costs of inflexible local water management, we also compare our results with the costs of ending overdraft if valley farmers have no opportunities to adapt their water use through trading and on-farm changes in crop choices.[49]

The continued expansion of perennial crop acreage since 2010 (especially almonds)—which lowers farmers' flexibility to reduce water use—could also make the costs of adjustment higher than we show.[50] In some other respects, however, our assumptions about adjustment costs may be pessimistic. To focus on the effects of reducing groundwater use, we assume no changes in technology or crop prices. Continued improvements in crop productivity, and favorable demand for California's farm products, could result in continued growth in farm revenues and profits despite lower overall water use and output. For crops in which California has a special advantage—like almonds and pistachios—reduced output could actually raise prices, helping to offset revenue losses. And as we discuss below, farmers may also be able to lower the costs of using less groundwater by employing some water management techniques not formally included in our analysis.

Modeling Impacts on Downstream Sectors

To feed their milk cows, many dairies rely heavily on corn silage, which must be grown near the dairies because it is costly to transport. So reduced corn production can reduce milk production. Similarly, beef cattle graze on local irrigated pasture. We assume that the dairy and beef industries will purchase alfalfa from elsewhere, but that they will experience some losses when acreage of corn silage and irrigated pasture crops goes down.[51] Reduced output of these animal products (notably milk) and some crops (notably almonds, tomatoes, and some fruits) can also affect local food and beverage processing. We assume that these industries will lower output when the supply of these local raw materials falls. This may overstate the costs of adjustment; some businesses would likely replace some local inputs with (higher cost) inputs from elsewhere instead of reducing output. Factors unrelated to water scarcity could also lower the profitability and size of California's dairy industry, including water quality management challenges (see Chapter 3).

Expanded Surface Water Trading Reduces Costs

Balancing the groundwater budget without new supplies requires reducing consumptive water use—the amount evaporated from soils and consumed by plants (Box 2.1). For agriculture, this requires a somewhat greater

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[48] Hanak and Stryjewski (2012) describe water trading patterns in the valley and statewide from 1987 to 2011. From 2003–11, an average of nearly 500,000 af/year was traded across districts within the valley (Tables B6 and B7). This understates total trading, because it excludes trades between farmers within the same water district, and trades occurring among parties within the same wholesale water agency (notably, Kern County Water Agency, which serves the entire Kern Basin). Some valley agricultural districts also sold water to urban agencies in Southern California (over 80,000 af/year) and the San Francisco Bay Area (nearly 40,000 af/year), as well as water for the environment, including the wildlife refuges (170,000 af/year) (Table B6c).

[49] This scenario assumes that acreages of all crops grown in a local area are reduced in the same proportion. It produces higher adjustment costs than would occur if all trading were disallowed. Even if farmers could not trade water locally, many have diversified crop mixes on their own farms, and would reduce acreage of less profitable crops first. However, it is a useful bookend to consider the potential economic risks if local surface and groundwater trading is not facilitated within basins. For details, see Technical Appendix C.

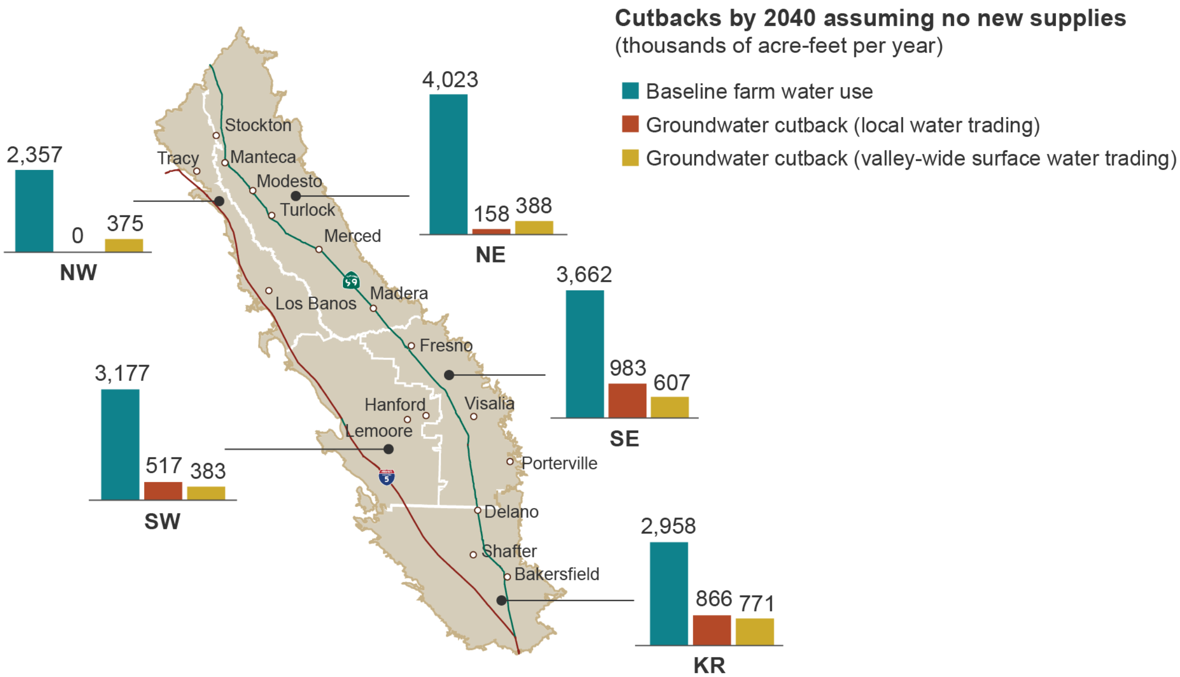
[50] From 2010–16 harvested acreage of all perennials grew by more than 500,000 acres (+27%); almonds grew by more than 300,000 acres (National Agricultural Statistics Service).

[51] Reduced alfalfa production within the valley has already prompted expansions in other western states (Dumas 2018). We assume that dairy sector losses will be proportional to declines in corn silage output. This may overstate dairy losses, if improvements in feed technology make it possible for the sector to reduce its reliance on corn. For beef cattle, we assume that a one percent reduction in irrigated pasture will lead to a one-quarter percent reduction in the herd.

reduction in applied water use—and groundwater pumping—than the amount of overdraft, because farmers need to apply more irrigation water to their fields than the amount crops consume. Ending the historical overdraft of 1.8 maf/year will therefore require a pumping cutback of roughly 2.5 maf/year—or 16 percent of applied farm water use. The cutback is higher in the southern valley, which relies more heavily on overdraft to sustain farming (Figure 2.3). In the Kern Basin and the southeast, more than a quarter of supplies are from groundwater overdraft. Valley-wide surface water trading would move about 600 taf/year to the southern valley from the northern valley—where overdraft is much more limited.

FIGURE 2.3

Valley-wide surface water trading would reduce groundwater cutbacks in the southern valley



SOURCE: Author estimates (Technical Appendix C).

NOTES: NE is northeast, NW is northwest, SE is southeast, SW is southwest, and KR is Kern Basin. "Baseline farm water use" includes estimated surface and groundwater availability in an average water year (2010). "Groundwater cutback (local water trading)" is the pumping reduction needed to close the subregion's historical groundwater deficit (shown in Figure 2.1) without water transfers across basins. "Groundwater cutback (valley-wide surface water trading)" is the pumping reduction needed to close this deficit after taking into account surface water trading across basins. Pumping cutbacks needed to close the deficit reflect estimated irrigation efficiencies in each subregion.

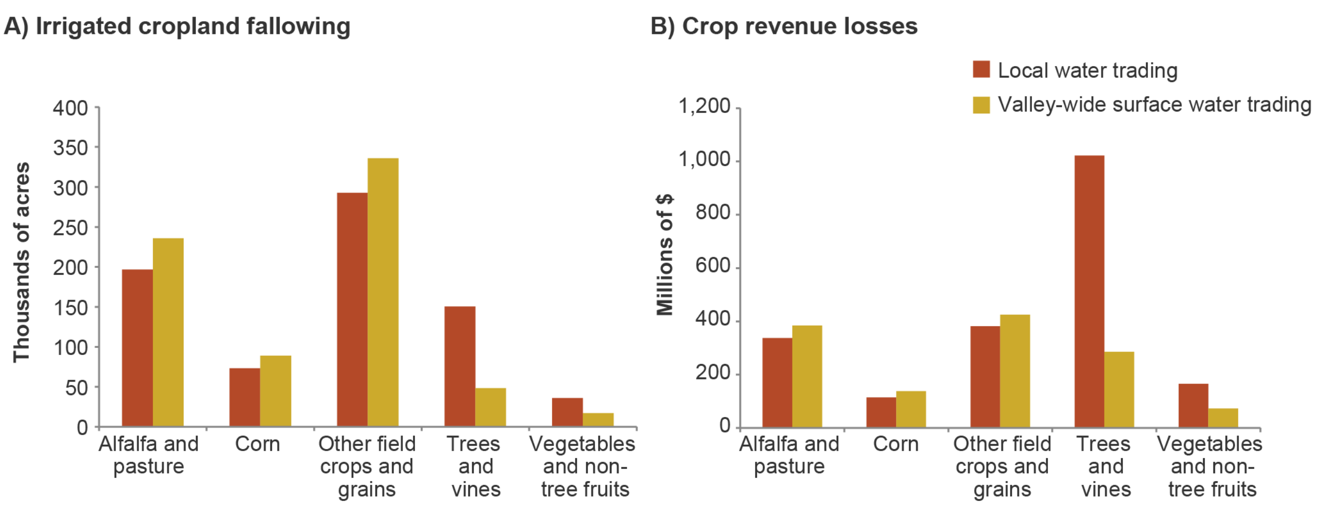
Local water trading only: Ending groundwater overdraft with only local water trading would require fallowing 750,000 acres, or 14 percent of current San Joaquin Valley cropland. To protect their bottom line, farmers would try to adapt by first reducing acreage of less profitable crops, and avoiding cutbacks in nuts, fruits, and vegetables. But in areas with high shares of these crops and large water cutbacks, some would need to be fallowed, at significant cost.

Fallowed acreage would include almost 300,000 acres of field crops and grain, nearly 200,000 acres of alfalfa and pasture, 150,000 acres of trees and vines, 73,000 acres of corn, and 36,000 acres of vegetables and non-tree fruits (Figure 2.4). Crop revenue would fall by about $2 billion per year, with half the losses from trees and vines. Next-highest in revenue losses are other field crops and grains ($380 million) and alfalfa and pasture ($340 million). Vegetable and non-tree fruit revenues would fall by more than $160 million, and corn by more than $110 million.

Although this revenue decline is substantial relative to current levels (10% loss), it is less than the cutbacks in acreage (14%) or water use (16%). This reflects the fact that farmers have some flexibility to focus the water on activities with the highest returns. This flexibility would be lower—and the costs of adjustment higher—if they were not able to freely trade surface and groundwater within the basin. Indeed, if farmers had no flexibility to trade water locally or adapt their crop choices, ending overdraft would require fallowing an additional 30,000 acres and cause an additional $1.5 billion in crop revenue losses.[52]

Valley-wide surface water trading: Valley-wide surface water trading increases flexibility significantly and reduces the costs of balancing supply and demand. Land fallowing falls slightly—to 725,000 acres—as trading creates more opportunities to shift to crops that use less water. But trading's main contribution is to lessen the need to fallow the most profitable crops in the southern valley. Fallowing of trees and vines falls by two-thirds, and vegetable and non-tree fruits by more than half. Acreage in the other, less profitable, crop groups declines by an additional 15 to 20 percent. The net result is much lower crop revenue losses, falling from $2 billion to $1.3 billion per year. Crop employment losses also fall, from 14,000 jobs with only local trading to 9,000 jobs with valley-wide trading, because the more profitable crops also tend to use more labor (Medellín-Azuara et al. 2015).

FIGURE 2.4
Valley-wide surface water trading would shift which crops are fallowed and decrease revenue losses



SOURCE: Author estimates (Technical Appendix C).
NOTE: "Other field crops and grains" include cotton, other grains, and silage other than corn.

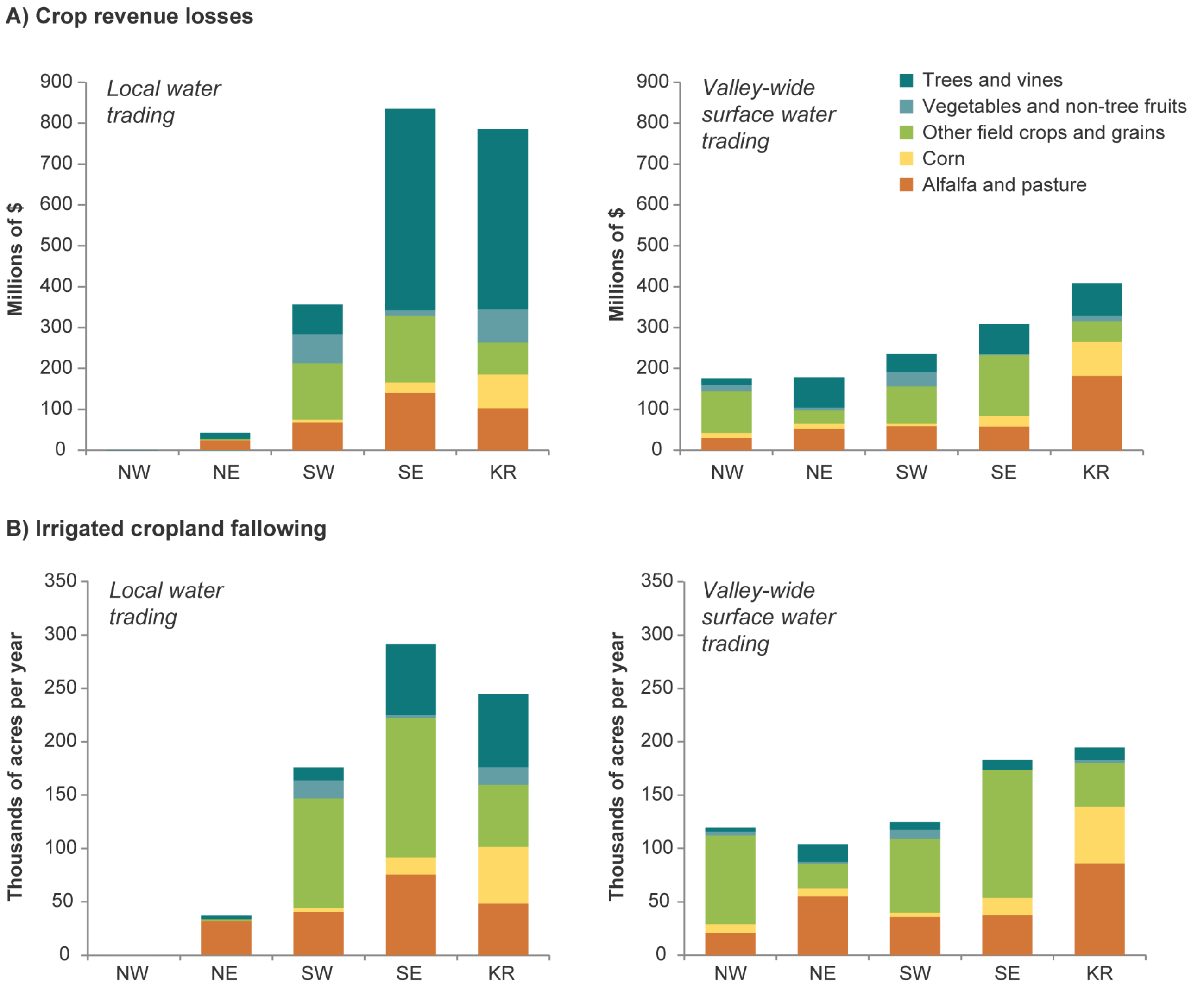
As expected, valley-wide trading significantly shifts the distribution of land fallowing and crop revenue losses across the region (Figure 2.5). With local trading, losses are concentrated in the southern valley, with revenue declines most significant in the southeast (nearly $840 million, or 14% of crop revenues), and the Kern basin (nearly $790 million, or 20%). Valley-wide water trading cuts these losses dramatically by shifting some fallowing to less profitable fields in the northern valley. This also means crop revenues—and farm employment—fall somewhat in the locations that sell water. However, farmers only sell if it makes them better off than using the water on their lands. With valley-wide surface water trading, farm profits increase across the entire valley, by more than $225 million overall (up 4%). The largest gains are in the northwest, where farmers earn roughly $100 million from

[52] As noted earlier, this estimate overstates likely costs of not allowing local trading. Even if farmers are unable to trade water, many have some flexibility to adapt crop choices on their own lands. See Technical Appendix C.

selling water, and in the Kern Basin, where they earn roughly $80 million by buying water and keeping more cropland in production.

FIGURE 2.5

Valley-wide water trading would spread out declines in crop acreage and revenues from implementing SGMA



SOURCE: Author estimates (Technical Appendix C).

NOTES: NE is northeast, NW is northwest, SE is southeast, SW is southwest, and KR is Kern Basin. The figure shows reductions in irrigated crop acreage (panel A) and crop revenues (panel B) with a reduction in groundwater pumping of 2.5 maf/year, the level required to eliminate historic overdraft of 1.8 maf/year through demand management. The left-hand charts depict results with efficient farm water use at the local level, including local surface and groundwater trading. The right-hand charts depict results with efficient farm water use across the entire San Joaquin Valley, including within-region surface water trading.

Because it increases fallowing of corn and pasture, valley-wide trading raises losses by about one-quarter for the downstream beef and dairy sectors. However, trading substantially reduces losses for the food and beverage processing sector as a whole, because it maintains more acreage of crops used as inputs. Overall, regional GDP and employment losses are roughly a third lower with valley-wide trading than without it.

The fact that water trading can reduce economic activity in some areas and industries, even though it improves farm profits and overall economic outcomes, is one reason why some communities object to selling water. However, these third-party impacts can often be mitigated.[53] Such concerns are often greatest when water is sold to other regions, which reap many of the broader economic benefits of trading. They should be easier to address when both buyers and sellers operate within the same regional economy—as would be the case for valley-wide trading within the San Joaquin Valley. From a regional land management perspective, valley-wide trading could present advantages, by expanding opportunities to convert fallowed lands to productive new uses including solar energy and habitat restoration (see Chapter 4). Of course, all transfers will also have to comply with applicable laws to protect other water users and the environment.[54]

Conveyance infrastructure is another practical constraint that could limit trading. Although the volume of water that would move from north to south is not large compared to total surface water, capacity constraints in the main north-to-south conveyance systems could be an issue. This could make it especially hard to move water from the northeast to the south.[55] The main way to get water to the southeast is through the Friant-Kern Canal, which has lost up to 60 percent of its capacity because of land subsidence from excess groundwater pumping. Districts to the north of this canal have few options besides sending water through the Delta pumps to the large aqueducts on the valley's west side, and Delta pumping operations are often constrained (Gartrell et al. 2017). Evaluating conveyance capacity, and determining where investments may be warranted, will be one priority for making trading work well. This may include expanding east-west conveyance options that circumvent the Delta, such as the pipeline recently built to connect the City of Modesto with the Del Puerto Irrigation District to transport recycled wastewater (Westsideconnect.com 2018).

Other Approaches to Reduce Costs of Ending Overdraft

Our results capture how selective land fallowing and water trading can reduce the costs of using less groundwater. Several other management strategies can also help. For some fruits and nuts, deficit irrigation—which uses slightly less water than optimal without significantly affecting yields—can lower net water use, increase crop output per unit of water, and increase farm profit (Fereres and Soriano 2007, Geerts and Raes 2009). In some cases, efficient irrigation technologies also can reduce net water use—particularly when more precise water application decreases evaporation from the soils.[56]

In the future, technical advances in plant breeding may also help reduce crop water needs. Better understanding of drought tolerance characteristics already shows promise for using genetic engineering to create commercial-grade, lower-water cultivars for key valley crops (Yang et al. 2010).

Finally, some cropping choices might enhance system flexibility, allowing more acreage to be kept in production and farmed more intensively in wetter years. In particular, alfalfa is a perennial that can be watered and harvested somewhat flexibly. When water supplies are tight, farmers can reduce irrigation and the number of cuttings without killing the plants. This approach also creates the opportunity to trade the water saved in drier years.

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[53] For example, the Metropolitan Water District of Southern California and the Palo Verde Irrigation District, both in Southern California, established a $6 million local development fund to mitigate the impacts of land fallowing on the Palo Verde Valley, as part of a long-term water transfer agreement (Hanak and Stryjewski 2012, Doherty and Smith 2012). For a broader discussion of third-party issues and mitigation options, see Hanak (2003) and Rey et al. (2018).

[54] Beyond prohibitions against injury to other legal water users and unreasonable harm to the environment (Water Code §§ 1702, 1725 & 1735), this includes some rules specific to the use of groundwater. Groundwater substitution transfers—where sellers of surface water increase their own use of groundwater—may not contribute to long-term overdraft (Water Code §§ 1745.10). Under SGMA, such transfers must also be consistent with the sustainability plan for the basin from which the water is transferred.

[55] Moving water from northwestern districts to the south is less likely to be constrained, given the availability of two large aqueducts—the Delta-Mendota Canal and the California Aqueduct.

[56] As noted earlier, more efficient irrigation technologies can actually *increase* net water use by enabling farmers to intensify production on existing fields or expand acreage with the same quantity of applied water (Box 2.1). Fortunately, many valley GSAs are looking to track net agricultural water use as part of basin monitoring and accounting. GSAs may need to set up incentives to avoid unintended consequences of these investments for the water balance (Li and Zhao 2018).

Alfalfa fields can be ideal for recharging groundwater in wetter years, too, because they generally take flood irrigation. Alfalfa also provides valuable habitat for some native bird species. And unlike most other crops, it does not require the nitrogen fertilizer that can cause water quality issues on recharge lands (see Chapter 3).

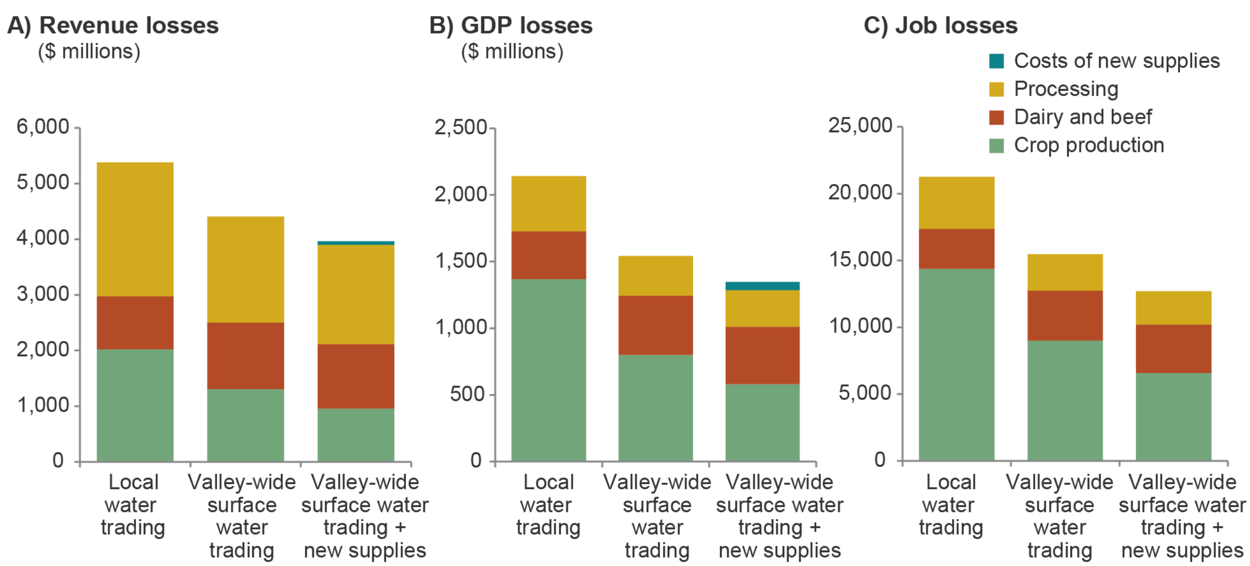
The Optimal Supply and Demand Portfolio

To minimize the regional economic burden of bringing supplies and demands into balance, the valley's best bet is to adopt a portfolio approach. This means investing in cost-effective new supplies—especially capturing and recharging more local runoff and managing the Central Valley water storage and conveyance system more efficiently to increase water imports—and managing demand with expanded valley-wide surface water trading. To see the benefits of this portfolio, we compare the two earlier cases that focused exclusively on demand management with and without valley-wide trading, to a final case where 25 percent of the historic overdraft is filled by new supplies (Figure 2.6). This represents about 460 taf/year of new supplies, at the upper end of the most likely range of expansion.

This combined approach could reduce land fallowing by more than one-quarter, from 750,000 acres to 535,000 acres. Annual revenue losses from crops, dairy, beef, and processing would fall from $5.3 to $3.9 billion (26% lower). Annual declines in regional GDP would fall from $2.1 to $1.3 billion (37% lower). And annual job losses would fall from 21,000 to less than 13,000 (40% lower). With this portfolio, GDP and job losses equal roughly 4 percent of today's agricultural economy, and less than 1 percent of the total regional economy.

FIGURE 2.6

Valley-wide surface water trading and cost-effective supplies would significantly reduce the economic burden of ending overdraft



SOURCE: Author estimates (Technical Appendix C).

NOTE: Estimates of GDP and job losses for crops, dairy, and beef include direct farm employees and contract labor.

Other Threats to the Water Balance

So far, our analysis has focused on the effects of ending historical overdraft. But other factors could affect future water supplies in the valley, requiring greater adaptations. These include the changing climate and modifications to required environmental flows in local rivers and the Delta as part of the State Water Board's update of the Bay-Delta Water Quality Control Plan. Water scarcity could also increase if urban areas expand their net water use to accommodate population growth, or if other urban water sources decline.

Climate change. Although average precipitation is not expected to change, rising temperatures, shrinking snowpack, shorter and more intense wet seasons, and more volatile precipitation will all bring water management challenges (Mount et al. 2018). Earlier, more intense winter and spring runoff will put pressures on surface storage systems (Swain et al. 2018). With less snowpack and greater need to store floodwaters in surface reservoirs for flood protection, increased groundwater recharge will likely be needed to maintain existing levels of water storage. Rising temperatures and longer dry seasons may also increase crop water demands (Pathak et al. 2018). Rising seas will increase salinity in the Delta, requiring more outflow from upstream reservoirs to keep water fresh enough for imports and other uses. More water may also need to be released in rivers to keep temperatures cooler and compensate for reduced local runoff, to support native fish populations.

Increased environmental flows. As noted earlier, the State Water Board recently voted to require an increase in instream flows for three San Joaquin River tributaries—the Stanislaus, Tuolumne, and Merced Rivers. This will reduce water available for agricultural and urban users in the northeastern part of the valley. The board is also considering flow increases in the Sacramento River system, which could reduce Delta imports.[57]

Increased urban water demand. If the valley's urban sector can reduce net outdoor water use by a bit more than one-third relative to pre-drought levels, the region should be able to accommodate anticipated population growth over the next two decades without worsening the regional water balance. The same would be true with lower water savings, as long as urban residents and businesses help fund more supply expansion projects than agriculture can afford on its own. Otherwise, urban growth could add to water scarcity in the region.

Economic impacts from a more water-stressed San Joaquin Valley. To provide a rough sense of how increased water scarcity would affect the valley's economy, we apply the same methods used earlier. For Delta imports, we assume an average reduction of 375 taf/year relative to the 1988–2017 average. For the San Joaquin River tributaries, we assume an average reduction of 290 taf/year in surface water supplies, as in the State Water Board's new flow mandate. This level could decline if negotiated settlements are successfully completed and approved by the board.

Relative to filling the historical groundwater deficit, these changes increase the water supply gap by roughly one-quarter, and land fallowing by roughly 200,000 acres.[58] The same adaptation tools—efficient allocation of farm water at the local level, valley-wide water trading, and a cost-effective set of new supply investments—would help minimize the added costs to the valley economy. With this portfolio, annual revenue losses from crops, animal products, and processing would increase from \$3.9 to \$4.7 billion, GDP losses would rise from \$1.3 to \$1.7 billion, and job losses would rise from 13,000 to 16,000. This represents roughly 5 percent of the valley's current farm economy, and 1 percent of the overall regional economy.

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[57] On the other hand, various recent or pending operational and regulatory changes could increase Delta imports to the valley. This includes the recently approved change in the Cooperative Operating Agreement between the CVP and the SWP, which should increase the share of imports remaining in the valley. Federal regulatory changes, including implementation of the 2016 Water Infrastructure for Improvements to the Nation (WIIN) Act and the update underway of requirements under the federal Endangered Species Act, could increase Delta imports. See Technical Appendix A for details.

[58] For details, see technical appendix Table C6.

The Path to Sustainable Groundwater Management

In this chapter we have shown that bringing groundwater basins into balance in the San Joaquin Valley will entail some costs for the region's economy in the early decades of SGMA implementation. These impacts are lower than the longer-term costs of continued groundwater overdraft. But for the first time, farmers will be accountable for the full expense of contributing to overdraft. The good news is that the burden of reducing groundwater use can be significantly lessened by implementing local and valley-wide water markets and investing in supplies farmers can afford—mainly, groundwater recharge and reoperation of the system of surface and groundwater storage and conveyance. Over time, technological improvements may also enable farmers to reduce net water use without reducing output.

Here are six key steps that can help smooth the path to sustainability:

Adapting to uncertainties. There are major uncertainties in water budgets and groundwater modeling, and in California's increasingly volatile precipitation. Our results are based on a static scenario of supply and demand options, but water managers will face annual variability and many unknowns regarding the long-term availability of both existing and new supplies. Adaptive groundwater sustainability plans that use buffers can help reduce economic disruptions from complying with SGMA.

Strengthening basin accounting. Formal, standardized, and transparent accounting systems are foundational to many promising actions. Although GSAs have the frontline responsibility for this work, DWR can foster improvements by promoting good groundwater accounting standards (Escriva-Bou et al. 2016).

For instance, GSAs will need to set up incentives to avoid overpumping. An effective way to do this is to allocate shares of groundwater that each user can pump—similar to the practice in adjudicated basins.[59] These shares can facilitate local water trading. They can also be used to assess water users who exceed their allocations, with the funds supporting projects that increase supply or reduce demand (e.g., buying and fallowing land).

Strong accounting will also be needed to incentivize farmers to recharge groundwater on their lands—a cost-effective practice that is underutilized (Hanak et al. 2018). Giving farmers a "SGMA credit"—in water or in cash—is a good way to do this, and it requires a standardized system for tracking recharge and water use. Better accounting—along with flexible rules on transferring water—can also encourage private sector investments in water banking projects. This could help fund recharge investments both on-farm and in dedicated basins.

Enabling groundwater recharge. State action is needed to address several important questions associated with groundwater recharge. These policies are essential if water managers are to take advantage of the increasingly constricted periods of high surface runoff and capture surplus flow for groundwater recharge (Hanak et al. 2018). For example, the State Water Board should define the hydrologic conditions under which surface water may be diverted for recharge. This guidance should include protections for senior surface water right-holders, water quality, and fish and wildlife. It also should include guidelines for local water managers to delineate between native groundwater and imported supplies.[60] Clarifying and enabling legislation may be necessary to address the legality of diverting surface water for the purpose of groundwater recharge. Once this legal guidance is in place, the State Water Board can adopt policies that facilitate expedited review and approval of surface water diversions for recharge.

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[59] For methods to allocate groundwater shares, see Babbitt et al. (2018).

[60] These guidelines may be useful because water imported into a groundwater basin is owned by the importer and is not subject to the same hierarchy of rights that governs rights to native groundwater (for which overlying rights have priority) (California Supreme Court 1975).

Promoting water marketing and banking. Local water districts and GSAs will need to develop a healthy trading culture, with rules that ensure transparency and fairness. Farmers and water managers who have participated in water trading and banking can take the lead by spreading the word about how this can work. Both state and federal agencies can also play important roles in promoting valley-wide water trading and groundwater banking.

California law already recognizes the transfer of conserved water (including water produced by land fallowing and retirement) as a beneficial use, and it provides strong protections for the transferor's retained water rights both during and after the completion of the transfer.[61] GSAs and other parties interested in expanding valley-wide transfers should work with the State Water Board to prepare programmatic environmental impact reports (PEIR) that evaluate the potential adverse effects of such transfers on the source areas. This would enable the board to more expeditiously review and approve individual transfer applications that are consistent with the PEIR (Gray et al. 2015).

DWR could assist this process by preapproving transfers that are consistent with meeting goals in groundwater sustainability plans. And as owners and operators of the two largest water projects in the valley, DWR (for the SWP) and the US Bureau of Reclamation (for the CVP) can smooth the way for transfers by working with the State Water Board and local agencies to consolidate places of use assigned to different water rights, to provide blanket permitting for regional water sharing (Gray et al. 2015). A useful model is the temporary consolidation of place of use for the CVP and the SWP in the valley during the last two droughts.

These agencies can also facilitate the development of off-site groundwater banks— an important means of augmenting local recharge and addressing overdraft (Hanak et al. 2018, Hanak and Stryjewski 2012).[62] Off-site banking faces many of the same constraints as transfers, including timely approvals to use conveyance infrastructure and authorization to store and use water in the most suitable locations. Local agencies in Kern County provide a model for how this can work.

Assess infrastructure needs and modernizing operations. A key constraint for groundwater recharge—and likely also for some water trading—is regional conveyance capacity, which limits the ability to move available water from the wetter northern part of the valley to the drier south. There is also a need to rethink how infrastructure is operated, to manage groundwater and surface storage together to increase their joint potential to store more water. Exploring opportunities to stretch out the timing of high-volume flows would be valuable—for instance, by moving water stored in reservoirs into groundwater basins in the fall to free up storage space for winter and spring flood flows. Analysis of new surface storage opportunities should be considered in this light. Another important area is updating dam operations to work with advanced weather forecasting technology. Regional entities that own and operate storage and conveyance infrastructure can play a key role in helping to assess system capacity issues and potential, along with state and federal agencies that own and regulate infrastructure. This will be increasingly important with a warming, more variable climate, which is likely to concentrate winter and spring runoff in shorter periods (Mount et al. 2018).

To make the most of recharge opportunities, GSAs will also need to address local infrastructure gaps. This includes local conveyance to get water to recharge lands, dedicated recharge basins in suitable areas, and irrigation systems that can handle large volumes of water for recharge in very wet periods.[63]

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[61] Water Code §§ 1011-1011.5 and 1014-1018.
[62] As described in Chapter 4, there may also be potential for recharge projects to improve flood protection by mitigating peak flood flows, along with other benefits. This is an area DWR is investigating, along with partners, as part of its initiative on "Flood-Managed Aquifer Recharge" (Flood-MAR), described here.
[63] These issues were all identified as constraints to expanding recharge by agricultural water suppliers surveyed in 2017, a very wet year (Hanak et al. 2018). More than 40 percent of respondents considered the inability to spread water on fields that use drip irrigation a constraint.

Coordinating to maximize benefits. SGMA is forging new local partnerships for managing groundwater. Most of the GSAs charged with developing and implementing groundwater sustainability plans comprise multiple agencies. And since their authority often extends to just a fraction of each groundwater basin, multiple GSAs will have to cooperate and coordinate their actions to meet SGMA's sustainability requirements. Developing partnerships at the basin scale will be essential for reducing the costs of transitioning to sustainability. Broader, regional orchestration of these various strategies can bring economies of scale for some investments and create a more diversified portfolio. Coordination at the watershed and basin level is required for some tools to be effective, such as groundwater basin recharge (including off-site banking projects), local and valley-wide water markets, and most large infrastructure projects.

The level of coordination needed to comply with SGMA is not only key to balancing supplies and demands, it also provides opportunities to address other major water challenges in the valley more effectively. The next chapter looks at approaches to managing water quality and supply together, and steps needed to provide safe drinking water for rural residents. This is followed by a chapter that explores how to manage scarce water resources and lands coming out of production in ways that provide multiple benefits for people and nature.

Chapter 3. Addressing Groundwater Quality Challenges

The San Joaquin Valley's poor groundwater quality impairs drinking water supplies in disadvantaged rural communities, threatens long-term agricultural prosperity, and degrades ecosystems. California has been a national leader in addressing these problems, with a suite of new regulations adopted over the past decade. The Sustainable Groundwater Management Act (SGMA) requires groundwater sustainability agencies (GSAs) to protect water quality while balancing groundwater supplies and demands. Tackling these issues will necessitate a portfolio of new management approaches, technologies, and agronomic practices. Parties will need to manage water quantity and quality together, in order to take advantage of opportunities for achieving multiple benefits and to avoid undesired consequences.

Decades of investments and regulations have taken on some of the worst water quality impacts to the valley's rivers and streams—particularly to control "point sources" of pollution from urban wastewater and industrial discharges, and "non-point" runoff from agricultural fields. Some surface water quality issues linger, however, and may lead to tighter standards in the future. At certain times of the year, water flowing out of the San Joaquin River into the Delta contains relatively high levels of salts and nutrients. This contributes to management difficulties in the Delta.[64] And as the climate warms, maintaining appropriate water temperatures for salmon in the valley's rivers will also be increasingly difficult.

More recently, policy attention has focused on addressing contaminated groundwater. Key issues include:

- **Safe drinking water.** Providing safe drinking water to rural communities is the valley's most urgent water quality challenge. Groundwater contamination is widespread in the valley. Rural towns and small communities are especially vulnerable to groundwater degradation and to health problems from using polluted water. Affected communities will require technical, financial, and managerial assistance. Solutions with the best potential provide economies of scale to small water systems: consolidation with larger systems and other institutional arrangements that aggregate smaller systems and promote sharing of expertise.
- **Agricultural productivity and sustainability.** The major water quality management challenges for valley agriculture are accumulations of nitrate in groundwater and of salts in both groundwater and soils. Nitrate in drinking water wells, which originates primarily from inorganic nitrogen fertilizer and manure used in farming, poses significant public health risks. Salinity is a growing threat to local agriculture. Failure to achieve local and regional salinity balance will lower crop yields, increase production costs, and eventually reduce availability of groundwater and lands suitable for irrigation.
- **Water for ecosystems.** Water quality in wetlands and rivers can be affected by salinity and a host of chemicals found in agricultural drainage. This restricts how drainage can be managed in the valley.

California has adopted regulations designed to improve monitoring and management of dairy manure (since 2007) and other fertilizers on farmland (adopted for surface water in 2003, and extended to groundwater in 2012). These will be now be folded into the Salt and Nitrate Control Program (SNCP)—a comprehensive program adopted in 2018 to manage salinity and nitrogen and to provide safe drinking water in affected communities.

The confluence of these groundwater quality programs with SGMA's requirement to manage supplies sustainably brings opportunities to integrate water quality and quantity management more effectively within the valley. Both

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[64] Nitrogen and phosphorus—two main ingredients in fertilizers—are the main sources of nutrient pollution. Monsen et al. (2007) show that salinity increases in the interior Delta at times when export pumps draw in more high-salinity San Joaquin River water to replace lower-salinity Sacramento River water, with implications for habitat and water quality for municipal and farm uses. Levels of nutrients in the San Joaquin River are high, and have risen rapidly since the 1950s (Cloern 2001). However, the extent to which this is contributing to harmful algal blooms in the Delta (a public health issue) and proliferation of invasive aquatic plants (which degrade recreation and habitat for native fish) is still uncertain.

SGMA and the SNCP seek to organize local governance within basins, which could facilitate this integration. But there will be institutional hurdles to overcome, because the various governance and regulatory programs that address water quality do not all neatly align with each other's mandates—nor with the water-quantity goals of SGMA. There will also be unavoidable trade-offs between management approaches that work best for replenishing aquifers and those that have the most potential to improve water quality. For example, some recharge practices could flush legacy pollutants present in the soils deeper into the aquifer, causing short-term spikes in groundwater contamination. Effectively addressing these trade-offs will be key to protecting the sustainability of the region's groundwater resources.

This chapter explores the valley's groundwater quality problems. It discusses pros and cons of different management approaches, and outlines practical solutions to address key problems. We begin with an overview of major water contaminants, followed by a review of the regulatory landscape. Next are sections describing priority action areas: we first look at providing safe drinking water to rural communities, and then focus on managing groundwater quality on farms. Finally, we describe opportunities to coordinate management for quality and quantity. Box 3.1 provides a brief overview of water quality issues for the valley's freshwater ecosystems.

Box 3.1: Water Quality for Ecosystems

Water quality is an ongoing issue for valley ecosystems in two primary areas: surface water flowing to aquatic ecosystems, and groundwater that supports vegetation, wetlands, and springs for terrestrial ecosystems.

The quality of water in the valley's remaining streams is usually tied to its quantity. In the San Joaquin River tributaries and main stem it is often impaired for native species under most flow conditions, with particular problems of increased salinity, temperature, and chemicals from agricultural drainage (Deacon et al. 2015). Excessively warm temperatures are a major problem for cold-water fishes such as salmon, which are now blocked by dams from accessing naturally cold-water habitats. In addition to possibly affecting future flow regulations in valley tributaries (e.g., increased flows needed for dilution), this issue could affect the volume of water imported to the valley—for example, from Shasta Reservoir, which must conserve cold water to support an endangered run of salmon (Mount et al. 2017a).

Water quality in wetlands can be affected by a host of compounds and chemicals found in agricultural drainage, as well as salts. In the historic Kesterson crisis, selenium—a naturally occurring salt found in some valley soils—accumulated in drainage water delivered to wetlands used as wildlife sanctuaries. The selenium levels rose to toxic levels for many waterbirds frequenting the region. This led to major changes in the management of agricultural drains and the closure of many drains serving selenium-rich soils (Presser and Barnes 1984).

An Overview of Major Contaminants

Water quality problems in the San Joaquin Valley stem from both naturally occurring contaminants and those introduced by human activity (Table 3.1). Geologically, the region has high amounts of salts, arsenic, and other contaminants in some of its soils and aquifers. Irrigation and groundwater development have mobilized many contaminants and brought additional pollutants from outside the valley. Among imported contaminants, fertilizer use has led to large accumulations of nitrate in valley groundwater. Imported irrigation water from the Delta has increased salt loads draining to San Joaquin Valley groundwater and streams. And the lowering of groundwater levels permanently traps these salts in basins throughout much of the valley.

TABLE 3.1

Major groundwater contaminants in the San Joaquin Valley come from a variety of sources

Contaminant	Main sources			Main impacts		
	Natural	Agriculture	Urban & industrial	Drinking water	Ecosystems	Agriculture
Arsenic	●			●		
Nitrate		●	◐	●		
Uranium	●			●		
Perchlorate	●		●	●		
Hexavalent chromium	●		●	●		
1,2,3 Trichloropropane (TCP)		●	●	●		
Salts	●	●	●	◐	●	●

SOURCE: Developed by the authors based on the literature.

NOTE: Half circle indicates that a source is a less significant contributor to pollution, or that it poses secondary impacts.

Arsenic

Arsenic is a common naturally occurring contaminant in valley groundwater, and the most prevalent in local drinking water supplies.[65] It has been linked to heart disease, diabetes, and cancer. With arsenic standards tightening since 2001, many drinking water systems in California have had to change operations, water sources, or treatment protocols. As of July 2018, California still had 106 public water systems not in compliance with arsenic drinking water standards; most of these (62%) are in the San Joaquin Valley.[66] Most systems that currently violate arsenic standards are small and rural. Although arsenic occurs naturally, groundwater overdraft can increase the amount released into the aquifer (Smith et al. 2018). As overdraft lowers water levels, it can also result in pumping from deeper aquifer zones with higher natural arsenic levels.

Nitrate

Nitrate is a pervasive and prominent water quality concern in the valley, with significant health risks from levels exceeding state and federal drinking water standards. "Blue baby syndrome" (reduced oxygen in the blood) is among the most acute, with other health effects including thyroid disease and cancer (State Water Resources Control Board 2017a). High concentrations of nitrate in valley groundwater come mostly from decades of intensive cropland treatment with inorganic nitrogen fertilizers and dairy manure.[67] The nitrate problem is most acute in places with shallow community and domestic wells, where concentrations are often highest (Figure 3.1). Removing it can be costly—especially for smaller water systems that lack economies of scale. Although practices have improved, ongoing nitrate loading is expanding contamination. Levels are often highest on manured acreage

[65] State Water Resources Control Board (2013) provides an overview of contaminants in public water supply wells.

[66] This includes 95 community water systems (serving about 118,000 people), and 11 schools (serving about 5,500 people) (author calculations using data from the State Water Board's Human Right to Water portal). Of the 95 community water systems, 73 serve populations of fewer than 500 people.

[67] For shares of potential nitrogen loading to groundwater over time in the entire Central Valley, see Harter et al. (2017), Table 11.30. In 2005, the shares were: cropland (93%), urban lands (<3%), septic systems (<2%), wastewater treatment plant percolation systems (<1%), dairy lagoons used to store manure (<1%), livestock corrals (<1%), and food processing plant percolation systems (<1%). In the San Joaquin Valley, agricultural sources likely have slightly higher shares; the same is true for urban sources in the Sacramento Valley.

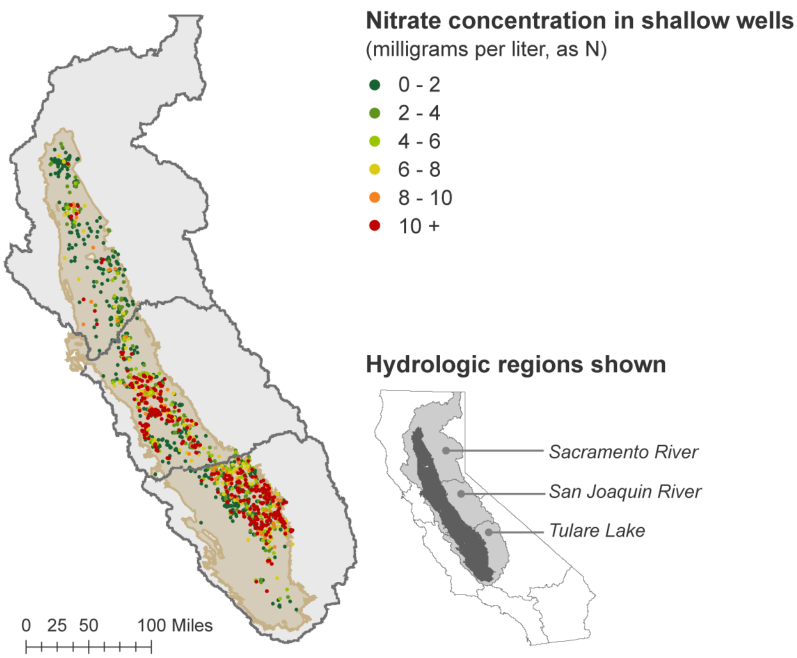
farmed by dairies, for whom solutions have been elusive (see Box 3.2). Changes in farming practices can reduce new nitrogen loading into soils and groundwater. But this will rarely clean up today's polluted wells, because much current nitrate contamination is a legacy of past farming practices.

Other Drinking Water Contaminants

Several other contaminants are of significant concern for drinking water. For example, uranium occurs naturally in some valley soils, and can increase risks of kidney damage and cancer. Irrigation water seepage into aquifers can disturb this uranium, causing it to enter groundwater supplies (Jurgens et al. 2014). Contaminants of emerging concern for the valley include perchlorate and hexavalent chromium (found naturally and from industrial activities) and 1,2,3 trichloropropane (from industrial activities and a legacy pesticide).[68] New contaminants generally require additional and often more expensive treatment technologies. As with nitrate, treatment is often disproportionately costly for small rural systems and domestic wells.

FIGURE 3.1

Nitrate contamination is a big problem for shallow domestic wells



SOURCE: Ransom et al. (2017).

NOTE: Of the 1,400 private wells sampled with a depth of 180 feet or less, 27 percent exceeded drinking water standards for nitrate (10 milligrams per liter, shown in red on the map).

[68] Regulation of contaminants of emerging concern is evolving. In 2014, the State Water Board established a maximum contaminant limit (MCL) for hexavalent chromium (10 micro-grams per liter), but the standard was withdrawn in 2017, while the board conducts additional economic analysis. According to board data, of 8,765 wells sampled from 2007 to 2017, 3,778 wells had at least one detection of hexavalent chromium (detection value is 1 microgram per liter). Most wells with detections were in Los Angeles, San Bernardino and Fresno counties (State Water Resources Control Board 2017b). In 2017, a new standard was established for 1,2,3 TCP. 1,2,3 TCP was detected in 395 of 5,863 wells sampled statewide from 2007–17. Most wells with detection were in Kern, Fresno, and Los Angeles counties (State Water Resources Control Board 2017c).

Salts

Salt accumulation is the valley's largest long-term water quality challenge for agricultural productivity, and a secondary concern for drinking water. Salt buildup in soils reduces crop productivity, and can lead to eventual retirement of irrigated lands. Because many fruit, nut, and vegetable crops are less salt-tolerant than some lower revenue crops, salt accumulation can disproportionally reduce farm revenues, even when lands are still suitable for some crop production (Figure 3.2). These problems cost valley farmers around $370 million per year in lost revenue, and are expected to become much more expensive in the future (MacEwan et al. 2016).[69] Salts also degrade urban water infrastructure—especially pipes—and cause taste problems, potentially requiring costly desalting.

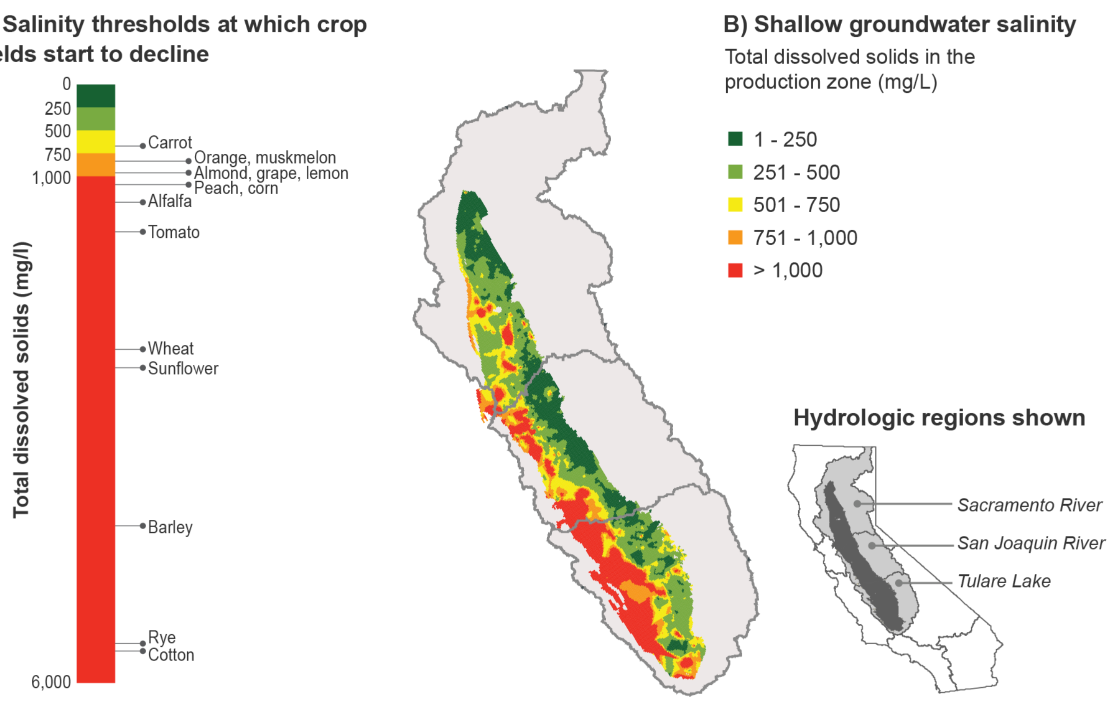
There are several main sources of groundwater salinity in the valley:

- It occurs naturally in some groundwater.
- Irrigation mobilizes naturally occurring salts in local soils—especially on the valley's west side.
- When crops use irrigation water, they leave most minerals—including salts from fertilizers—in their root zone.
- Water imported from the Delta has a relatively high salt content.

Salts can also accumulate on lands with poor drainage. Irrigation raises the water table, so groundwater rises, leaving a thick crust of salt on the surface.

FIGURE 3.2

High groundwater salinity in parts of the valley reduces yields of many fruits, vegetables, and nuts



SOURCES: Panel A: Grieve et al. (2012). Panel B: CV-SALTS (2016b).

NOTES: Panel A shows levels of salinity at which crop yields start to decline, and panel B shows shallow groundwater salinity on the valley floor. Mg/l is milligrams per liter. The secondary drinking water standard for salinity in California is 1,000 mg/l of total dissolved solids; secondary standards affect taste and appearance, but do not pose significant safety concerns.

[69] Using a different approach, Welle and Mauter (2017) estimate slightly higher losses in 2014 from salinization (roughly $500 million—see Table H1). Analysis done as part of the ongoing regulatory process has projected direct economic costs for the Central Valley as a whole of more than $1.5 billion annually by 2030 if salt accumulations are not managed (Howitt et al. 2009).

Beyond the accumulation of salts in soils, the gradual increase in groundwater salinity throughout the valley threatens to make groundwater unsuitable for irrigation in the future. The problems salts cause are more pronounced in areas with overdrafted basins, such as those in the central and southern valley.[70] Net accumulation is roughly 5.9 million tons per year (CV-SALTS 2014). Roughly 250,000 acres of Central Valley lands have been retired due to salinity accumulation in soils, and another 1.5 million acres are considered salt-impaired (CV-SALTS 2017). Most of these lands are on the west side of the San Joaquin Valley (Figure 3.2). If lands are retired after significant impairment, this can make them unsuitable for other uses, such as habitat.[71]

The Regulatory Landscape

Water quality is managed under both federal and state laws initially adopted in the late 1960s and early 1970s. Safe drinking water is regulated under the federal Safe Drinking Water Act and related state laws. Surface water pollution is governed by the federal Clean Water Act, and the state's Porter-Cologne Act applies to both surface and groundwater pollution.

The Central Valley Regional Water Quality Control Board ("regional board") creates and implements a water quality control plan for the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions, and issues permits for the discharge of pollutants to surface water and groundwater basins.[72] The regional board also has authority over a variety of other water quality programs described below.

The State Water Board creates and implements the water quality control plan for the Delta and has regulatory jurisdiction over the exercise of all water rights.[73] It exercises this authority to protect water quality for all beneficial uses of water and to provide essential flows to support migratory fish. It also has authority to review decisions made by regional boards. Since 2014, it oversees safe drinking water programs.[74]

In addition, numerous local and regional entities—some of which have overlapping responsibilities and geographic boundaries—implement water quality programs (Table 3.2 and Figure 3.3).

Here are some program highlights:

Safe Drinking Water Act (SDWA). Under the SDWA and related state laws, the State Water Board regulates community water systems with more than 25 people or 15 connections, and other public systems such as schools. The eight valley counties have 654 community water systems, including 549 that serve fewer than 3,300 people, and 443 that serve fewer than 500 people. Even smaller systems with less oversight serve many rural residents. Counties oversee "state-small" water systems (5–14 connections). Private domestic wells that serve fewer than five homes receive no oversight, aside from county well construction standards and permits. The lack of oversight

[70] In these basins, salts flushed from the root zone to groundwater are trapped and concentrated in a closed loop: groundwater is pumped for irrigation, crops remove water as they grow, salts are left in the root zone and flushed back to groundwater. Each pumping and recharge cycle increases salinity, causing long-term aquifer degradation. In contrast, areas with no or only short-term overdraft—such as some parts of the northeastern valley—naturally flush salts continually back to streams, thereby exporting accumulated salt out of the region to the Delta.

[71] The *Recovery Plan for Upland San Joaquin Valley Species* (Williams et al. 1998) includes a variety of criteria, including depth to groundwater and selenium concentration that should be considered before dedicating lands for species recovery. In their analysis of west-side, drainage-impacted lands suitable for restoration efforts, Purkey and Wallender (2001) note that shallow water tables can cause soil waterlogging and salt accumulation that degrade habitat value. Scudiero et al. (2016) find increasing salinity in soils on the west side after irrigation stops.

[72] Permits issued under the Porter-Cologne Act are called waste discharge requirements (WDRs). Surface water discharge permits under the federal Clean Water Act are called NPDES permits, because they implement the National Pollutant Discharge Elimination System. Permits that implement both state and federal law are classified as combined WDR/NPDES permits.

[73] The board issues permits and licenses for all non-riparian surface water diversions that commenced on or after December 14, 2014. Although other surface and groundwater rights are exempt from the board's permitting and licensing authority, it has regulatory authority over all water rights under Article X, Section 2 of the California Constitution, which states that all water rights must be exercised reasonably and for beneficial uses (Gray 2015).

[74] This responsibility was formerly with the Department of Public Health.

and information for very small systems and domestic wells is a serious impediment to ensuring safe drinking water in the valley.

Regional Water Quality Control Plan. The most recent water quality control plan establishes water quality standards for the valley's surface waters and sets out a strategy for addressing a range of surface and groundwater problems (Central Valley Regional Water Quality Control Board 2016a and 2016b). These programs focus on urban and industrial wastewater and stormwater, as well as agricultural discharges, described next.

Irrigated Lands Regulatory Program (ILRP). Under the ILRP the regional board regulates discharges from irrigated agricultural lands. The program initially focused on surface water (since 2003) and then in 2012 added groundwater. ILRP gives permits to 13 agricultural coalitions and to individual farms in the valley. Coalitions must come up with groundwater assessment plans that identify vulnerable areas and outline practices required to reduce and control discharges, along with monitoring and reporting requirements. Farmers are responsible for implementing management practices, keeping records, and reporting to their coalition or the board.

Central Valley Dairy Order. This framework, established by the regional board in 2007, regulates dairy discharges of nutrients and salts to surface water and groundwater. It requires dairies to prepare nutrient and waste management plans, implement practices to reduce and control discharges, and annually report nutrient budgets for individual fields, tonnage of manure exports, and water quality of on-site wells. Individual dairies are responsible for complying with the requirements. The program also includes a monitoring and reporting program led by a region-wide coalition of dairy producers (Dairy Cares).

Salt and Nitrate Control Program (SNCP). This far-reaching new regional water quality program was adopted by the regional board in May 2018 and is pending final approval by the State Water Board. Whereas the IRLP and Dairy Order address prevention of nitrate and salt pollution, the SNCP also addresses legacy nitrate and salt impacts. The program is based on the Salt and Nitrate Management Plan developed by a broad coalition of interests known as CV-SALTS, and includes agricultural, industrial, and urban sources of pollution.[75] In a break with past pollution control programs, the SNCP seeks to directly address urgent problems of nitrate contamination in drinking water wells. Starting in 2020, the program incentivizes dischargers of nitrate in contaminated groundwater basins to establish new "nitrate management zones." In exchange for providing immediate interim safe drinking water supplies (for instance, bottled or trucked-in water), these dischargers will have more time to develop long-term drinking water solutions, implement measures to reduce nitrate and salt loading, and ultimately improve and restore the quality of groundwater to the extent "reasonable, feasible, and practicable."

This approach is a compromise that allows the continued operation of farming under the new regulations. Even with best management practices, some nitrate loading from farm fertilizer is inevitable, and under the SNCP no additional loading would otherwise be allowed in areas with unhealthy nitrate levels. In recognition of the challenges of meeting the longer term pollution control goals for salt cost-effectively, the program calls for further study of management options to reduce salt loading in its first decade, with projects to be implemented in later decades.[76] The SNCP will serve as an umbrella for all dischargers of nitrate and salt to valley groundwater, including those regulated under the Dairy Order and the ILRP. All water quality permits will require some updates to best comply with the new rules.

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[75] CV-SALTS stands for Central Valley Salt Alternatives for Long-Term Sustainability. The State Water Board's website describes the process and links to key documents, including this presentation summarizing the SNCP's key provisions. Pitzer (2018) provides an overview of the program and stakeholder perspectives.
[76] This effort will build on a multi-year study of options to address salinity by the CV-SALTS coalition.

SGMA. Unlike the other programs described here, SGMA does not fall directly under federal and state water quality laws. Yet under SGMA the valley's GSAs will also have requirements regarding water pollution prevention and the protection of safe drinking water. GSAs must avoid significant and unreasonable impacts of groundwater management on water quality. This could be an issue, for instance, when pumping mobilizes pollutants like arsenic or salt, or when recharge increases nitrate concentrations in well water. Beyond water quality impacts, GSAs must also avoid undesirable effects of pumping on the *supply* of drinking water—an issue when pumping lowers aquifer levels near shallow community and domestic wells.[77]

Institutional fragmentation makes it harder to implement water quality programs, and to coordinate groundwater quality and quantity management (Table 3.2, Figure 3.3). Fragmentation also stretches thin the capacity of local managers, many of whom serve in multiple entities. In principle, the SNCP provides an opportunity for more efficient coordination within groundwater basins: its initial boundaries for 17 nitrate management zones largely coincide with the 15 basins regulated under SGMA. However, dischargers may request smaller boundaries. The regional board should resist the proliferation of these zones.[78] Proliferation has created a major governance challenge under SGMA. Most of the valley's basins have multiple GSAs, and many are too small to effectively deal with water supply and quality issues. Although GSAs within each basin must coordinate, the sheer number of GSAs makes this difficult.

TABLE 3.2
Major water quality mandates and programs in the San Joaquin Valley

Mandates and programs	Regulator	Implementing entity	Safe drinking water	Pollution prevention
Safe drinking water regulations [a/]	State Water Board	Public water systems, counties	x	
Regional Water Quality Control Plan [b/]	Regional Water Board	Various local entities		x
Dairy Order (2007) [b/]	Regional Water Board	Individual dairies and Dairy Cares		x
Irrigated Lands Regulatory Program (2003, 2012) [b/]	Regional Water Board	Agricultural coalitions		x
Salt and Nitrate Control Program (2018) [b/]	Regional Water Board	Nitrate management zones	x	x
SGMA (2014) [c/]	DWR and State Water Board	Groundwater sustainability agencies	x	x

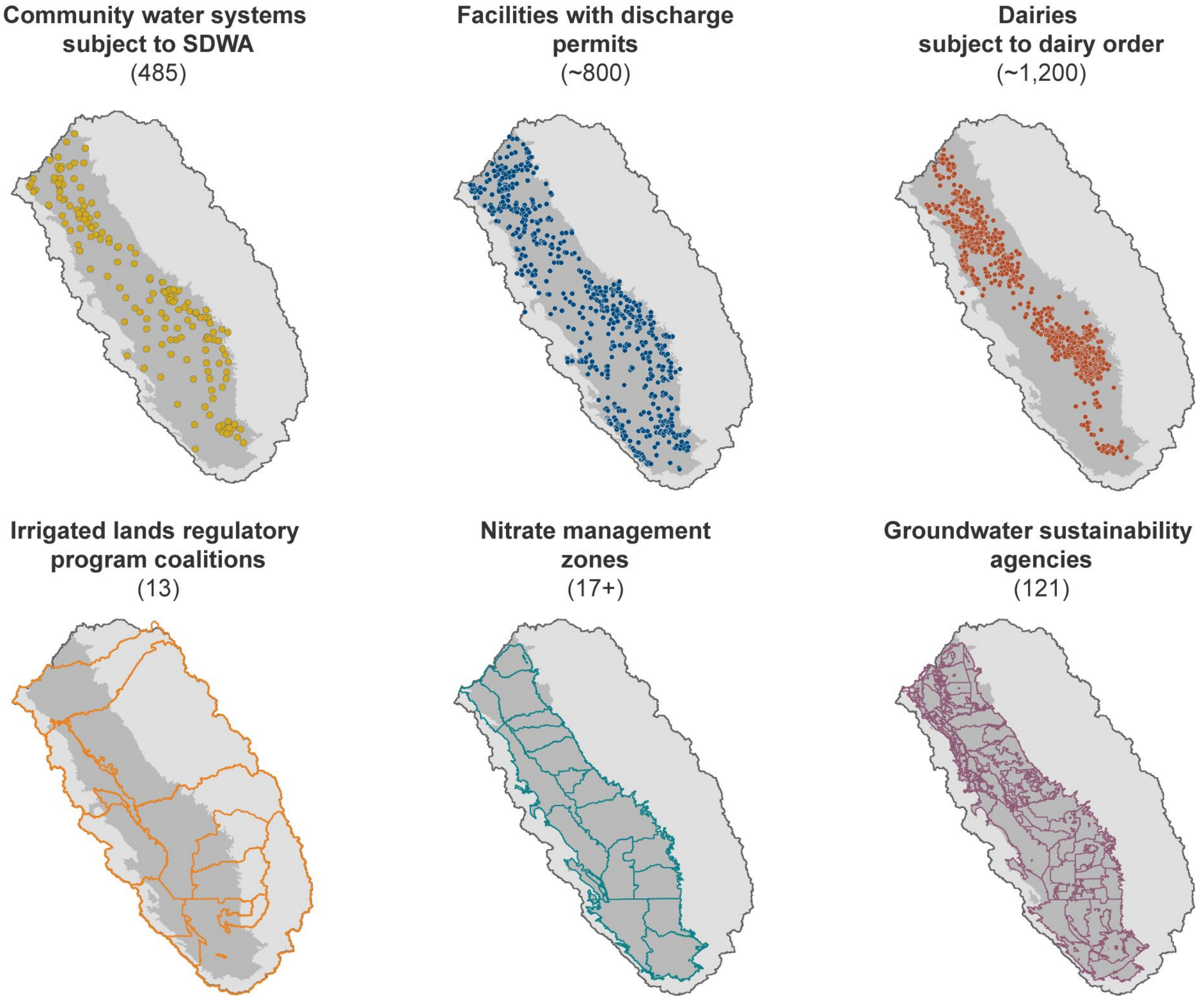
SOURCE: Developed by the authors.

NOTES:
a/ Regulated under the federal Safe Drinking Water Act (1974) and related state laws. Counties have oversight over systems with 5–14 connections, not regulated under the federal law.
b/ Regulated under the federal Clean Water Act (1972) and the state Porter-Cologne Act (1969). The federal act only regulates surface water pollution; California's Porter-Cologne Act also has jurisdiction over groundwater quality.
c/ The Department of Water Resources (DWR) has responsibility for reviewing the adequacy of groundwater sustainability plans; the State Water Board has authority to take over basin management if groundwater sustainability agencies fail to develop or implement plans adequately to meet SGMA goals (see Box 1.1).

[77] California Water Code § 10721(x) defines undesirable results under SGMA that GSAs must seek to avoid. For a summary, see Box 1.1.
[78] In contrast to SGMA, where GSAs were free to form in smaller areas within basins, dischargers will need to seek regional board approval to form smaller nitrate management zones, and this change will require new analysis under the California Environmental Quality Act.

FIGURE 3.3

The various entities to manage groundwater quality have dissimilar boundaries, mandates, and responsibilities



SOURCE: Developed by the authors from various sources.

NOTES: The map shows 485 community water systems on the valley floor; the 8 San Joaquin Valley counties contain an additional 186 systems in the Sierra foothills and eastern Kern County. Facilities with discharge permits include wastewater treatment and industrial facilities (including many food and beverage processors) and other entities with WDR and/or NPDES permits; most will be subject to the SNCP. The map shows the 17 initial areas for nitrate management zones under the SNCP, which have similar boundaries to the 15 groundwater sub-basins regulated under SGMA (the Kern basin is split into three SNCP zones). The final number of nitrate management zones could be higher, because dischargers may propose different boundaries, subject to regional board approval.

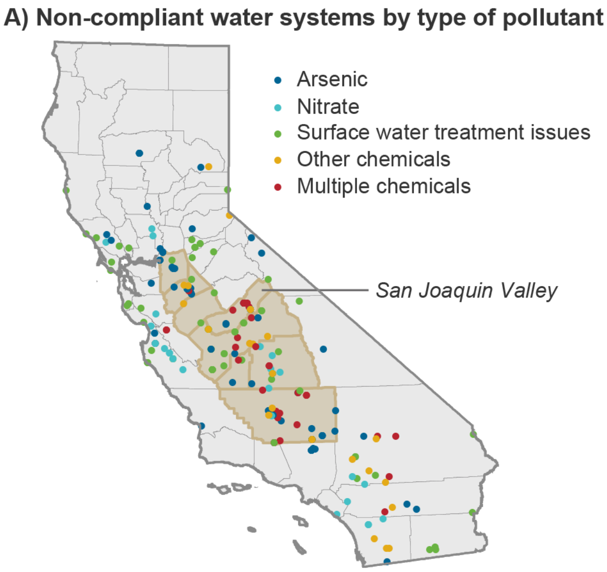
Providing Safe and Reliable Drinking Water

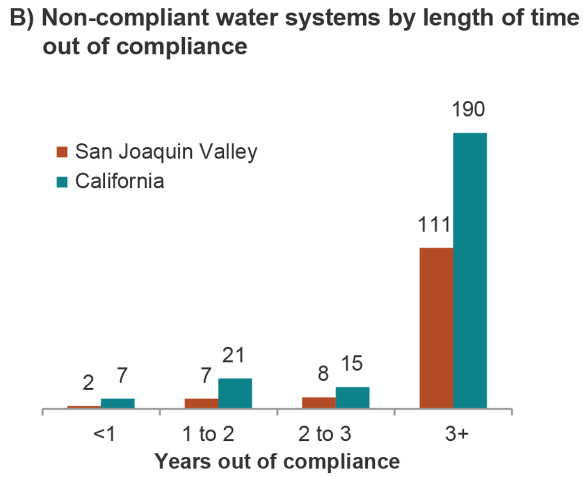
The valley's safe drinking water problems are not only about managing pollutants: an equally important challenge is disadvantaged rural communities' lack of capacity to address their water quality problems. Although groundwater contamination is widespread, larger communities have mostly been able to provide safe drinking water to their residents by investing in water treatment to remove contaminants, drilling deeper wells to access safe groundwater, or shifting to new, treated water sources. Such solutions are often unaffordable for smaller communities.

Assessing the full extent of these challenges is not straightforward. Water quality information is most comprehensive for water systems regulated under the Safe Drinking Water Act. As of July 2018, 128 of the region's 654 community water systems—serving roughly 175,000 residents—were out of compliance with drinking water standards.[79] This was more than half of all non-compliant public water systems in California, although the region has only 10 percent of the state's population (Figure 3.4). The leading causes of contamination include arsenic, nitrate, uranium and other radioactive elements, and disinfection by-products (this last mostly for systems that use surface water supplies). Over 90 percent of non-compliant systems are small (serving less than 3,300 residents), and most are very small (serving less than 500). The overwhelming majority of these small systems have been out of compliance continuously for at least three years; many have violations for more than one contaminant, which can increase the cost of solutions.[80]

FIGURE 3.4

The San Joaquin Valley has more than half of California's non-compliant drinking water systems





SOURCES: Developed by authors using data from the State Water Board's Human Right to Water (HR2W) portal and USEPA's ECHO portal.

NOTES: Panel A shows the 233 community water systems statewide (including 128 in the San Joaquin Valley) that were out of compliance in July 2018 as reported in the state's HR2W portal. Panel B matches these systems with ECHO to get details on quarters out of compliance. Since HR2W data is updated monthly and ECHO data is updated quarterly, the two data sets do not match up perfectly.

Less is known about water quality challenges of the valley's 267 state-small water systems, which are overseen by counties, and some 70,000 domestic wells. The state does not require private well owners to test their water quality. In a 2006 study, the State Water Board found that 40 percent of wells sampled in Tulare County exceeded drinking water standards for nitrate, and more recent analysis highlights the prevalence of nitrate in shallow domestic wells across the region (Figure 3.1).[81] Better information on the location and depth of wells and their water quality problems is needed to improve access to safe drinking water.

Wells Running Dry: Another Challenge in Rural Communities

In addition to pervasive water quality issues, some well-dependent valley residents also experience drinking water shortages. Shallow domestic wells can dry up as groundwater levels decline. The problem is exacerbated during

[79] Authors calculations using the State Water Board's Human Right to Water data for July 2018. This number includes community water systems in eight San Joaquin Valley counties, and represents just under 5 percent of the regional population.

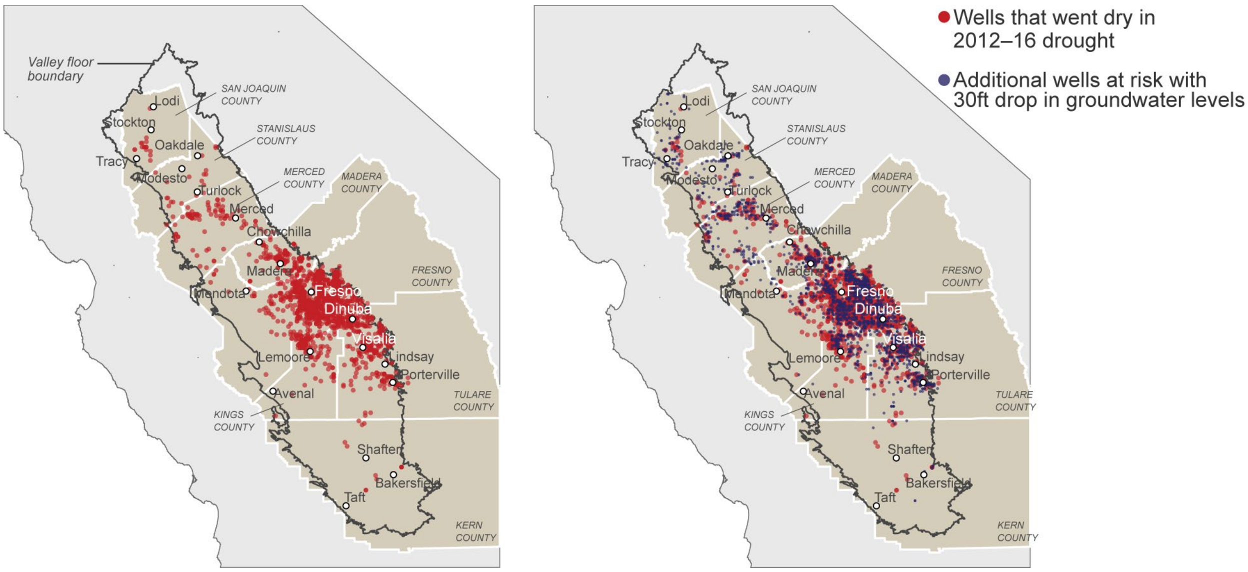
[80] Small water systems serve fewer than 1,000 connections (or 3,300 people). Of 116 non-compliant small water systems in July 2018, 100 had been out of compliance for at least 12 quarters (see notes to Figure 3.4 for sources and methods). Nearly a quarter of all non-compliant systems had violations for multiple contaminants.

[81] The 2006 study results are reported in State Water Resources Control Board (2013).

droughts, when farmers pump more groundwater. During the 2012–16 drought, more than 2,000 valley households experienced some type of water shortage. Many additional wells are vulnerable to continued lowering of groundwater levels (Figure 3.5). Small community wells are also vulnerable.[82]

FIGURE 3.5

Domestic wells tend to be shallow, and are particularly vulnerable when pumping lowers the water table



SOURCES: Author calculations using data from well completion reports and groundwater level data reports (Department of Water Resources).

NOTES: We estimate that during the 2012–16 drought, roughly 2,300 domestic wells went dry on the valley floor (panel A). During this period, groundwater level declines ranged from 0 to more than 150 feet in different parts of the valley (See technical appendix Figure E1). Another 2,600 well would go dry with an additional 30-foot drop in groundwater levels (panel B).

Solutions to Drinking Water Problems

Many affected communities will need both financial and technical assistance to address problems of drinking water contamination and wells running dry. The state, environmental justice advocates, local governments, urban water systems, and the agricultural sector will all need to play a part in finding expeditious solutions.

Physical connections. In some cases, physical consolidation can be a cost-effective solution to both quality and supply problems.[83] A 2015 law allows the State Water Board to pursue consolidation with larger systems when other solutions are not appropriate, and provides protection against liability issues that may make larger agencies unwilling to consolidate.[84] One notable example is the voluntary merging of 1,800 water-stressed homes in

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[82] Mount et al. (2018, Figure 3) shows a map with the locations of nearly 150 small community water systems statewide that requested emergency assistance to address water shortages during the 2012–16 drought, along with households that reported water shortages. The San Joaquin Valley was one of the hardest hit areas in the state for both measures. Technical appendix Table E1 summarizes the household water shortage data by county.

[83] In the Tulare Lake hydrologic region, Honeycutt et al. (2012) estimated that roughly half of the systems serving less than 10,000 people are within five miles of a larger system. This makes physical consolidation a potentially viable and cost-effective option for a significant share of rural systems. London et al. (2018) identified 321 disadvantaged unincorporated communities in the eight San Joaquin Valley counties which either had no community water system or contained a non-compliant community water system. Sixty-three percent are located within three miles of a community water system of any size that was meeting safe drinking water standards. While this suggests even greater potential for physical consolidation, connecting smaller systems together may not provide the same degree of scale economies as connecting smaller systems to larger ones.

[84] Subsequent legislation has expanded the board's authority to encourage physical and administrative consolidations. For legislation highlights see McCann and Chappelle (2015 and 2018) and McCann and Hanak (2016).

unincorporated East Porterville with the larger and more resilient water system serving the nearby city of Porterville (Klein 2016).

Management help. When physical consolidation is difficult because systems are too remote or dispersed, on-site solutions are needed. Yet these can be prohibitively expensive for the rural poor families and communities that are most affected (Hanak et al. 2014).

For example, costs for rehabilitating and deepening wells that went dry on Tulare County's valley floor during the latest drought were estimated at $10–$18 million, not including the costs of providing temporary substitute water supplies to affected people (Gailey 2018). Water treatment is also expensive to build and operate. State and federal programs can help pay for capital improvements, but small water systems often lack the ongoing funding and technical capacity to sustain them over time.[85] Fresno County's unincorporated community of Lanare (589 people) provides a cautionary tale. Lanare's water supply has high arsenic concentrations. In 2007, the county built a $1.3 million water treatment plant for the community. But the facility shut down after six months, leaving the community with a $100,000 debt—because Lanare lacked funding to continue operating the expensive technology (Romero and Klein 2017).

In such cases, administrative consolidation—or other institutional arrangements that provide technical and managerial economies of scale to smaller systems—may help. One promising option is to form a joint powers authority—an umbrella organization that could provide technical and managerial support to smaller member systems. The systems would retain their governance structure and a level of independence, but benefit from expertise and resources of the broader organization.

Funding. Beyond technical and managerial support and one-time funds for capital investments, it is essential to establish reliable ongoing funding to support safe drinking water solutions in disadvantaged rural communities. If it proves politically infeasible to establish a statewide fund with contributions from the urban and agricultural sector—as proposed in recent bills—it will be necessary to find other sources of state or regional funding.[86] Under the new SNCP management zones, both valley farmers and urban communities may be called on to help financially in addressing drinking water quality problems. And as part of their obligation to avoid undesirable impacts from groundwater pumping on groundwater levels, GSAs should help fund—or directly arrange—mitigation of dry drinking water wells caused by extra pumping during future droughts. Some models for mitigation exist in Kern and Yuba counties.[87] This will also be important in basins that authorize extra pumping during the transition to sustainable basin management—the glide path approach to SGMA implementation.

Managing Groundwater Quality for the Long Run

Long-term nitrate contamination of groundwater and salt accumulation in soils and aquifers are major challenges for the valley. Yet managing for these contaminants is costly. This requires balancing between protecting water and land resources for the long run and maintaining the viability of agricultural production in the present, while also ensuring safe drinking water solutions.

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[85] In addition to the state revolving fund—a program funded by the US Environmental Protection Agency and run by the State Water Board—recent state bonds have increased funding for capital projects in disadvantaged communities (Hanak et al. 2014, Jezdimirovic and Hanak 2017). Technical Appendix F describes funding for rural drinking water systems from the US Department of Agriculture.

[86] In the 2017–18 legislative session, Senate Bill 623 and a 2018 budget trailer bill both proposed establishing a fund including surcharges on agricultural sources of nitrate (fertilizer, dairies, and feedlots) and about $1 per month on urban water bills, to raise roughly $140 million per year for safe drinking water programs. Governor Newsom's January 2019 proposed budget reintroduced this idea (Sencan and McCann 2019). The agricultural sector has supported the proposal as a preferred alternative to State Water Board enforcement actions requiring individual farms to provide safe drinking water in areas with high nitrate levels. Urban water agencies have generally objected to the proposal and called for the use of alternatives such as appropriations from the state's General Fund.

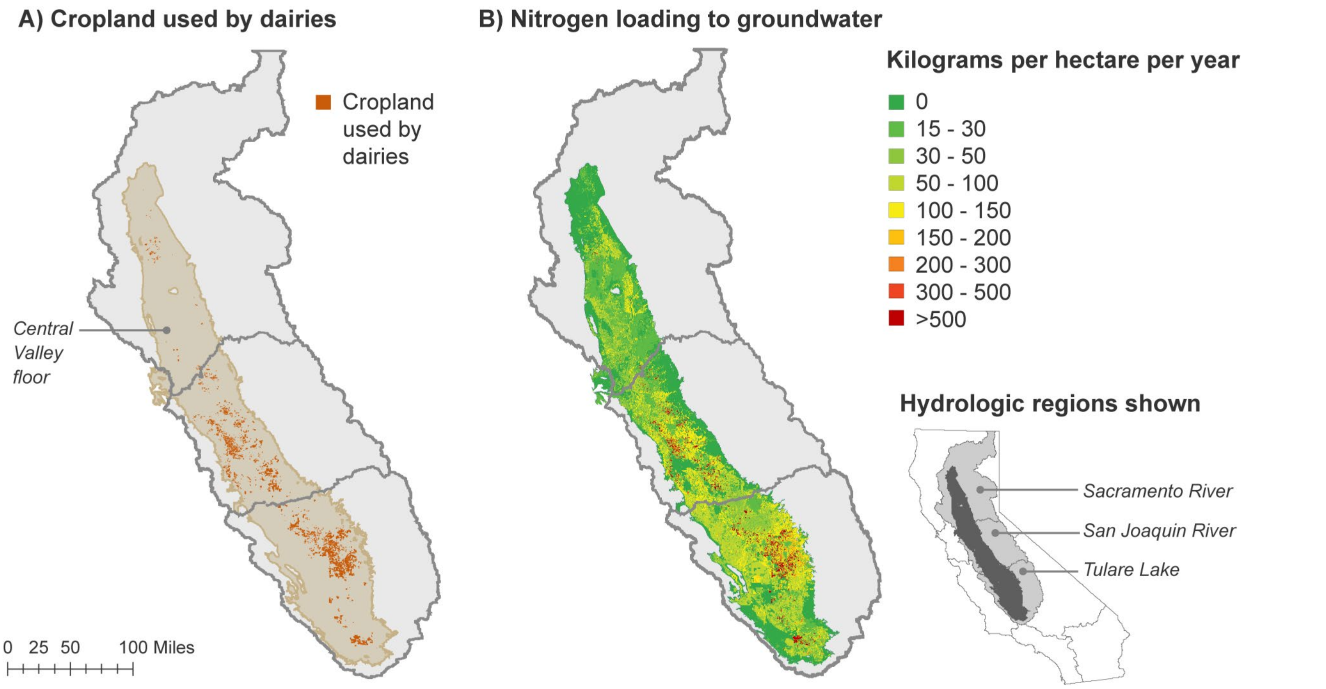
[87] The Yuba County Water Agency in the Sacramento Valley has long had a practice of deepening wells that go dry as part of its groundwater management program. In Kern County, the Rosedale Rio Bravo Water Storage District has a similar practice (Pottinger 2018a). Gailey and Lund (2018) use a case study from Tulare County to consider how GSAs might manage the trade-offs between economic benefits from agricultural pumping and costs to domestic well users.

Long-term Nitrate Solutions

Given the large accumulations of nitrate in soils and groundwater from historic farming practices, what can reasonably be expected on nitrogen management by valley agriculture is an open question. The central issue is balancing the costs and benefits of reducing further degradation. Whereas leguminous crops like alfalfa or beans require little to no fertilizer, most of the valley's crops do require nitrogen fertilization to thrive. The ILRP is promoting the adoption of the "4 Rs" to reduce excess application of nutrients on fields: right fertilizer, right amount, right time, right place. The Dairy Order has broadly similar objectives for dairy farmers. Because they reduce fertilizer use, these agronomic practices can be economical for growers, especially those using drip irrigation. They are most challenging for dairies, in part because it is much harder to manage manure fertilizer precisely (Box 3.2). Cropland used by the valley's dairies accounts for just 6 percent of all lands, but 88 percent of lands with the highest concentrations of nitrogen loading (Figure 3.6).

FIGURE 3.6

Nitrogen loading is particularly high on cropland fertilized with dairy manure



SOURCE: Harter et al. (2017).

NOTES: The benchmark to separate "low-intensity" from "high-intensity" loading is 35 kilograms (kg) of N per hectare per year (about 31 pounds per acre) (Viers et al. 2012). In panel B, all areas shaded in yellow, orange, and red are experiencing high-intensity loading. Although inorganic fertilizers also contribute to nitrogen loading, cropland fertilized with dairy manure shows the highest levels of loading; about half of dairy lands have N loading above 300 kg per hectare.

Although current farming practices use fertilizers more efficiently, they do not completely end nitrogen loading. This reality is reflected in the SNCP's new approach to nitrogen management. Under the program, growers must continue to reduce loading. But by allowing them the alternative of directly providing safe drinking water solutions in high-nitrate areas, the program gives them flexibility to keep farming on nitrate-affected lands. There are questions, however, about how the SNCP will implement nitrogen loading regulations over the longer term. The plan only provides growers the safe drinking water alternative to enforcement for an initial 15-year period, and the objectives of the ILRP and the Dairy Order will both need to be updated to comply with the SNCP.

Box 3.2: Special Challenges for Dairy Farms

Solutions to reduce groundwater pollution under dairies have been elusive. Regulations have improved nutrient management, but not to the level needed to protect groundwater quality. Many dairy farmers now find themselves unable to maintain production levels while staying within regulatory limits. Valley dairies face the real possibility of being forced to move out of state or leave the dairy business.

Many factors limit a dairy operator's ability to reduce nutrient pollution. These include sandy soils; irrigation systems that cannot apply water slowly enough to minimize nitrate leaching; fluctuating nitrogen concentrations in manure lagoons; difficulty and complexity of measuring, recording and calculating application rates; uncertainties in predicting and accounting for manure and soil organic nitrogen availability; inadequate land base for the amount of manure generated; and limited resources to implement improvements even where proven technology exists. No one approach will fit all situations. In general, effective nutrient management systems for dairies include these essential components:

- Reasonable irrigation efficiency and uniformity to prevent excessive leaching;
- Accurate accounting of applied water and nutrients, and removal of excess nutrients;
- Ability to apply manure at the rates and times needed;
- Decision support for estimating nitrogen processes throughout the year, both to make an application plan and to identify the need for in-season adjustments.

Implementing each component has significant challenges, and the technology and science are often inadequate or nonexistent. And even when the best irrigation technology is implemented to minimize leaching, groundwater quality may not improve enough to meet regulatory expectations because some leaching is unavoidable and necessary to prevent salt buildup in the soil. The sheer volume of manure produced, relative to the land areas farmed by dairies, is also a fundamental constraint.

Possible solutions: New technologies will be needed to help the dairy sector manage manure, which causes air pollution and greenhouse gas emissions in addition to nitrate in groundwater. The valley's dairies produce enough manure to fertilize a significant share of the state's cropland, but the manure is heavy to transport, and difficult to apply precisely. Advances are needed not only to improve the efficiency of manure fertilization on dairy cropland, but also to develop environmentally safe, cost-effective manure-based fertilizer products that can be marketed to other farms. Technologies like dry composting could make manure lighter and easier to transport (Sustainable Conservation 2017). Technologies like biodigesters offer the possibility of harvesting other manure ingredients (in this case, methane for energy production), and could work in tandem with the development of new fertilizer products from the nitrogen. Regulatory programs for water and air quality may need to take more coordinated approaches to facilitate this industry transition. Developing markets for these new manure products will also be important.

This box draws on presentations made by Marsha Campbell, UC Cooperative Extension, at "Toward Sustainable Groundwater in Agriculture: An International Conference Linking Science and Policy" (2016) (video link here; abstract link here on p. 33) and J. P. Cativiela, Water quality: What's next and how to prepare for the coming challenges and opportunities, at "California Dairy Sustainability Summit" (2018). The website newtrient.com serves as an industry clearinghouse for new manure management technologies and products.

In developing these new objectives and longer term regulations, it will be important to consider what levels of loading are reasonable in a heavily agricultural region. This is a potentially difficult question in light of

California's strong policy of preventing future degradation of surface and groundwater resources.[88] However, regulators have some flexibility to allow practices that continue to degrade water quality if the costs of pollution prevention are higher than the broad societal benefits of prevention.[89] It may be preferable to continue aiming to limit nitrogen loading, while also ensuring safe drinking water solutions through other pathways.

Long-term Solutions to Salt Accumulation

Farmers and regulators will also face a balancing act to manage salts cost-effectively in the valley. One set of solutions includes actions to help farmers adapt to increasing salt buildup in groundwater and soils—for example, adopting agronomic practices that minimize harm to crops, switching to more salt-tolerant crops, and eventually retiring lands where farming is no longer profitable. Another set of solutions includes investments to reduce salt buildup—for instance, reducing salt imports, isolating or "sequestering" salts within the valley, or exporting them out of the valley, including through expensive desalination and drainage. Both approaches will reduce farm profitability. In principle, the solutions in the second group can keep the valley's on-farm productivity higher, but if they are too costly relative to their value in increased farm revenues, the first set of methods may be preferable.

Solutions to reduce salt buildup include the following:

- **Reducing salt imports.** A sizable amount of salt comes from irrigation water imported through the Delta. The greatest potential for reducing salt imports without reducing water supply would come from building new Delta conveyance, such as California WaterFix.[90] Tapping export water upstream of the Delta where it is fresher would slow the pace of salt accumulation (Medellin-Azuara et al. 2008). This could be an important co-benefit of new conveyance investments.
- **Sequestering salts.** Salt sequestration is accomplished by using evaporation ponds or other means to separate salts from water and isolating them from surface and groundwater sources. This is already done in some parts of the valley (Tanji et al. 2002). Advanced physical and chemical methods are emerging that could drive down the costs of salt separation, but finding suitable ways to dispose of the salts could still be an issue.[91]
- **Exporting salts.** Desalination and export of salts is sometimes considered to improve the valley's water and salt balances, but it is currently an expensive option, with costs of roughly $1,500-$2,000/af, including costs to treat water and to export salts from the valley through a brine line (CV-SALTS 2016a).[92] As we saw in Chapter 2, these costs far exceed the current willingness of growers to pay for irrigation water. The CV-SALTS study envisioned that one way of paying for desalination would be to export the water to coastal urban areas, but a key drawback to this solution is that it would entail shipping the fresher water out of the valley—thus negating any benefits to local salt balances.

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[88] The Regional Water Quality Control Board has broad discretion to adopt water quality objectives that "in its judgment will ensure the reasonable protection of beneficial uses and the prevention of nuisance" (Water Code §§ 13241). In setting these standards, the regional board must consider all beneficial uses (including domestic, municipal, and agricultural water supplies), as well as the existing quality of water within the basin and economic considerations (Water Code §§ 13050(f) & 13241). It then must regulate dischargers to ensure that these objectives are not exceeded.

[89] The State Water Board's antidegradation policy declares that water of "existing high quality will be maintained until it has been demonstrated . . . that any change will be consistent with maximum benefit to the people of the State, will not unreasonably affect present and anticipated beneficial use of such water and will not result in water quality less than that prescribed in the [current or new water quality] policies" (State Water Resources Control Board 1968). If discharges would violate the state's antidegradation policy, the board must require dischargers to apply the "best practicable treatment or control" measures to maintain the highest water quality possible consistent with the overall public benefit.

[90] There may be some scope for changing operations to import water more when Delta salinity is low, although this could often conflict with the timing of both irrigation and ecosystem water demands. Delta waters are freshest in the winter and spring months when runoff is highest. Pumping restrictions to protect Delta fishes could limit big shifts toward pumping more irrigation water during these times (Gartrell et al. 2017). This water would also need to be stored south of the Delta for use during the main summer irrigation season.

[91] For a discussion of treatment and disposal options, see CV-SALTS (2014 and 2016a). Rigali et al. (2016) provide an overview of desalination and treatment research at the Sandia National Laboratories.

[92] Welle et al. (2017) find that desalination is only likely to be profitable during droughts for 4 percent of Central Valley fields; ecosystem service benefits of reduced agricultural drainage would need to be valued between $800 and $1,200 per acre-foot for the technology to be profitable from a societal perspective.

Given the high costs of major capital investments to remove salt from the valley, adaptation actions—including eventual retirement of salt-impacted lands—may be a more economical approach for many growers. Some farming practices can limit the costs of salinity (MacEwan et al. 2016). Integrated management programs that employ a combination of fallowing, planting salt-tolerant crops, and irrigation management can help mitigate the impacts of salt accumulation in soils (Schwabe et al. 2006).

For salts, the long-term solutions required by the SNCP should also weigh the costs and benefits of water quality management. To date, regulators have recognized the challenges of avoiding continued salt buildup in the valley's groundwater, and have focused on limiting the rate of quality decline.[93] The SNCP's phased approach to implementing new salt management regulations also has promise. Efforts in the first 10 years will continue to explore economically viable options for salt management, with pilot actions to follow. It is possible that some more cost-effective solutions will emerge as technologies continue to advance. But if salt loading and removal approaches remain too costly for agriculture to bear, it may be necessary to accept some form of managed salt accumulation—as the regional board has proposed—to allow significant agricultural production to continue in the valley for the foreseeable future. And if the region is unable to find economical ways to export salt over the much longer term—within the next century or more—agriculture's footprint would likely need to shrink considerably. Where groundwater resources become too salty for irrigation, this footprint will be confined to the area that can be irrigated with surface water.

Land fallowing raises the potential for synergies in the management of salt and water balances over time. Indeed, there are numerous ways in which managing water quality and quantity can converge, as well as areas where they are in conflict.

Managing Water and Land for Both Quality and Quantity

The water quality issues facing the valley are complex, and intricately linked to agricultural land and water use. Here we highlight some of the key issues water users and managers will need to consider in bringing groundwater basins into balance under SGMA while addressing three of the valley's central water quality challenges: providing safe drinking water, and preventing long-term accumulation of both nitrogen and salt in groundwater (Table 3.3). We focus on the key tools for managing supply and demand outlined in Chapter 2.

Demand management and water quality. The two core demand management tools—reducing pumping and fallowing land—will also help meet water quality goals. Reducing pumping could also decrease the mobilization of arsenic and salt in some places. Land fallowing reduces nitrogen loading; although it won't improve the overall salt balance, it can be a cost-effective way to manage groundwater salinity. In contrast, the flexibility tools for managing demand—water trading and the glide path—will need to be implemented with an eye to potential trade-offs. By shifting the location of water use, water trading also shifts the location of both pumping and land fallowing. Depending on local conditions, this could be beneficial (e.g., if fallowing is moved to areas where salt mobilization is more likely) or problematic (e.g., if it results in more pumping in areas near shallow domestic wells). Glide path practices—along with basin management strategies that allow more pumping during

[93] In its 2016 revisions to the Central Valley Water Quality Control Plan, the regional board determined that "no proven means exist at present that will allow ongoing human activity in the [Tulare] Basin and maintain ground water salinity at current levels" (Central Valley Regional Water Quality Control Board 2016b). The board therefore concluded that, consistent with the antidegradation policy's requirement of maximum public benefit, "controlled ground water degradation by salinity is the most feasible and practical short-term management alternative for the Tulare Lake Basin" (Ibid.). The staff report that accompanied the board's incorporation of the SNCP into the water quality control plan in 2018 explained that the plan has two objectives: (1) "Control the rate of degradation through a 'managed degradation' program," and (2) "protect beneficial uses by applying appropriate antidegradation requirements for high quality waters." The SNCP would be consistent with the antidegradation policy because it would "implement salinity management activities to achieve long-term sustainability and prevent continued impacts to salt sensitive areas" and would protect beneficial uses "by maintaining water quality that meets applicable water quality objectives and pursuing long-term managed restoration where reasonable, feasible and practicable" (Central Valley Regional Water Quality Control Board 2018).

droughts—are likely to benefit the local and regional economy, but they could increase problems associated with pumping, including more arsenic and salt mobilization and more dry wells. Groundwater sustainability plans will need to mitigate such effects.

TABLE 3.3

Tools to balance groundwater supplies and demands can affect safe drinking water and groundwater quality

SGMA tools for balancing supplies and demands	Drinking water contamination	Drinking water shortages from wells running dry	Nitrate pollution	Salt pollution
Supply enhancement				
– Groundwater recharge (on-farm or with recharge basins)	Could increase if crop has high nitrogen use or if soils and water table have high legacy presence of nitrogen	Prevents wells from going dry	Could increase if crop has high nitrogen use or if soils and water table have high legacy presence of nitrogen	Could increase if using salty water for recharge
Demand management				
– Reduced pumping	Reduces mobilization of arsenic	Prevents wells from going dry		Reduces mobilization of salt
– Land fallowing*		Prevents wells from going dry	Reduces nitrogen loading	Won't improve salt balance, but can be cost-effective way to manage salt buildup
– Water trading	Could shift effects of pumping, fallowing	Could shift effects of pumping, fallowing	Could shift effects of pumping, fallowing	Could shift effects of pumping, fallowing
– Glide path practices and flexible pumping during droughts**	Could result in more arsenic contamination	Could result in more wells going dry		Could result in more salt mobilization

SOURCE: Developed by authors.

NOTES: Areas shaded in gray indicate cases where there could be trade-offs to address between water supply and quality management. Unshaded areas show complementarities.
*Land fallowing to reduce overall water use could include temporary fallowing of lands in rotation or permanent retirement of lands.
**Glide path refers to gradual practices to reduce overdraft by 2040, with some continued overdraft pumping in the interim.

Aquifer recharge and water quality. The tool with the best potential for augmenting water supplies—aquifer recharge—poses some potential trade-offs with water quality goals if not managed properly.[94] Under certain conditions recharge can accelerate the migration of agricultural chemicals in the soil (especially nitrate) and impair drinking water quality. This is likely to be an especially significant issue for recharge on some active cropland or fallowed fields (including irrigated areas converted to recharge basins). It requires not only considering where the most suitable lands are (including suitable irrigation systems), but also a set of factors that could affect water quality: which crops are most likely to load nitrogen, the existing quality of the groundwater and presence of legacy contaminants in the soil, and the location of potentially vulnerable drinking water wells.[95] The quality of the water used for recharge can also be an issue—for instance, relatively saline sources such as recycled wastewater and Delta imports could pose problems in areas already facing high salinity. There may also be some potential to clean up groundwater basins by recharging with high-quality water, such as winter and

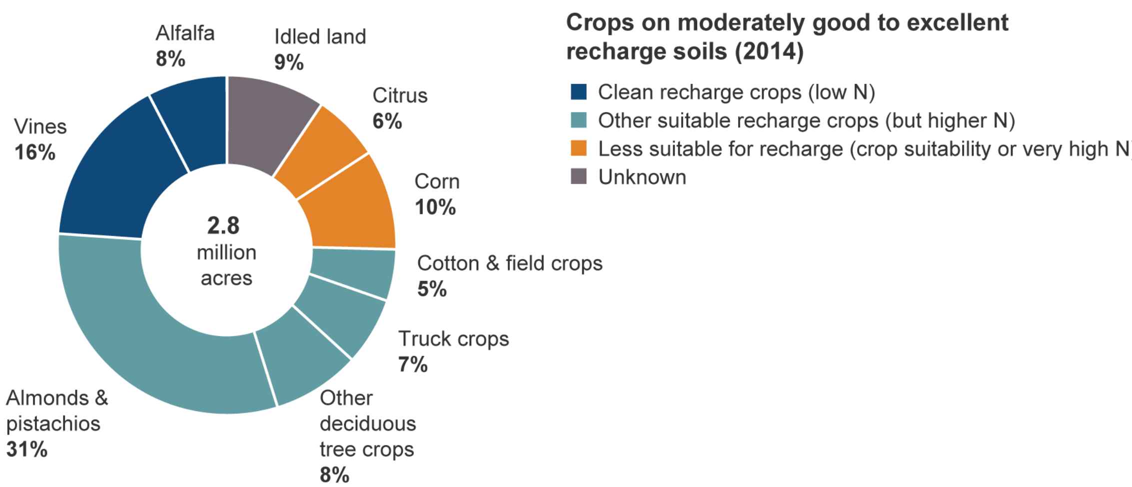
[94] Water quality concerns are one of the impediments to recharge noted in a 2017 survey of valley water managers (Hanak et al. 2018).
[95] See technical appendix Figures E2 and E3 for soil suitability for recharge by different land uses.

spring flood flows from the Sierra. Pilot efforts are now underway to see whether focused recharge can improve well water quality for small disadvantaged communities.[96]

Careful planning is required to maximize benefits and avoid negative effects of recharge. In all, roughly half of the valley's cropland has soils that are at least moderately good for recharge.[97] About a quarter of these lands are planted to alfalfa and vines—"clean crops" that use little or no nitrogen fertilizer (Figure 3.7). Another half grows crops that could be suitable, as long as nitrogen fertilizer is carefully managed. Avoiding recharge altogether is best for certain crops: citrus trees do not do well with winter flooding, and corn is often fertilized with high quantities of manure, leading to very high nitrogen loading (Figure 3.6). In all cases, there is a need to consider legacy chemicals in soils—reflecting historical land uses—that would be moved downward along with recharge water.[98]

FIGURE 3.7

Groundwater recharge on cropland must consider potential water quality impacts



SOURCES: Author estimates using California Department of Water Resources (2017a) for land use, and University of California, Davis Soil Resource Lab, Soil Agricultural Groundwater Banking Index (modified version) for soil suitability for recharge.

NOTES: See technical appendix Figure E4 for the distribution of crop acreage by soil suitability for recharge and types of irrigation systems. Alfalfa is particularly suitable for recharge, because it uses no nitrogen fertilizers and usually has flood irrigation systems.

Ensuring coordination. Reaping the most benefits from potential synergies between water supply and quality management—and avoiding the harmful consequences of trade-offs—will require strong coordination among all the players. GSAs will need to collaborate with other entities working on groundwater quality, such as the coalitions regulating runoff and leaching from irrigated lands under the ILRP, and the new nitrate management zones under the SNCP. Developing a clear interface between GSAs and other programs will ensure clear roles and

[96] Mayzelle et al. (2015) show how small communities with nitrate contamination might establish a groundwater recharge "buffer zone" surrounding their water supply wells for crops that require no additional nitrogen fertilizer or for direct recharge with cleaner water. One recharge pilot project aiming to improve local groundwater quality involves Tulare Irrigation District and the unincorporated community of Okieville.

[97] This share is similar for a measure of recharge suitability based on surface soil conditions from UC Davis (used for Figure 3.7) and one that also considers suitability of conditions at deeper levels within the aquifer from the mapping company Land IQ.

[98] Preliminary analyses by Bachand et al. (2017) suggest that legacy contaminants near the surface pose the greatest risks, along with nitrogen loading from ongoing crop fertilization. Recharge can flush a large proportion of legacy contaminants in the first year; continued dilution over the next 10–20 years of recharge can result in improved groundwater quality. This suggests that in areas with groundwater quality issues, recharge should continue to be practiced on the same locations, rather than moving to new locations every time water is available.

responsibilities and broaden the opportunities to get multiple benefits (and avoid unintended harms). This will be challenging in the highly fragmented local institutional landscape—particularly with the large number of GSAs in many of the valley's basins (Figure 3.3).

There are also important roles for state and federal regulatory agencies. In particular, water managers and growers will need guidelines for implementing on-farm recharge of cropland and fallowed land in ways that are consistent with water quality rules.[99] Under the SNCP, the Regional Water Quality Control Board has the potential to administer these rules flexibly where recharge may cause temporary worsening of groundwater quality, if it leads to longer term improvements in groundwater quantity and quality.[100]

Beyond the water supply and quality entities we've highlighted here, fallowing land to achieve groundwater balance in the most beneficial ways will require additional parties to be involved—including city and county land use agencies, and other stakeholders. The next chapter reviews the land retirement issue in more detail, and explores ways to harness the impending changes to land and water use management under SGMA to bring multiple benefits to the economy, public health, and the natural environment.

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[99] Pilot work is investigating how to manage water quality and plant health in flooded fields (Mohan 2016, Dahlke et al. 2018) and other recharge sites. Sustainable Conservation has also developed a preliminary field guide for growers on managing the timing of extra irrigation of cropland, using information from a study of nitrate leaching (Bachand et al. 2017).

[100] The SNCP provides the regional board new regulatory flexibility by allowing the use of "exceptions." Exceptions allow water quality objectives to be exceeded provided certain things happen, e.g., drinking water users are protected, or actions and plans are in place to minimize harmful impacts and ensure water quality improvements in the future. Such exceptions may be in place for many years; they are required to be reviewed and renewed. Although the SNCP does not specifically mention use of recharge as a potential exception, an alternate compliance project could propose the recharge of higher quality water to a groundwater basin impacted by nitrate as a long-term effort to help improve or restore groundwater quality, even if this quality could be harmed in the near term. An approved exception would allow this to happen (Central Valley Regional Water Quality Control Board 2018, p. 101).

Chapter 4. Fostering Water and Land Use Transitions to Benefit People and Nature

Achieving groundwater sustainability will bring major changes to water and land use in the San Joaquin Valley over the next 20 years—along with opportunities to forge a new path for the natural environment. Managing these changes effectively and taking advantage of the opportunities will require a shift in thinking, new approaches to planning, and a focus on cost-effective solutions that benefit people and nature.

As described in Chapter 2, even with ambitious investments in new supplies, to end overdraft the irrigated footprint of the valley may need to shrink by more than 500,000 acres by the early 2040s. Without careful planning, growing water scarcity could increase conflict between human and environmental uses of water. Land idled to achieve groundwater balance could occur piecemeal—contributing to dust and weed problems that compromise air quality and neighboring farmland. And the region could miss out on many possibilities for improvement that require more coordinated decisions about water and land use—from harnessing floodwaters for aquifer recharge, to keeping the most valuable farmlands in production, to reaping the most benefits from lands to be idled.

Setting a goal to improve ecosystem health as part of the coming change presents both special challenges and distinct promise. Impending water and land use transitions will occur within a landscape that has been radically altered over the past two centuries. The transformation of the region's historic network of rivers, wetlands, and desert ecosystems has resulted in a growing list of vulnerable native plant, wildlife, and fish populations. Efforts to protect these endangered and at-risk species have had mixed success. And these efforts have at times generated conflict over the use of water and land resources, pitting farmers and others against agencies and environmental organizations focused on species and habitat protection.

An approach called "reconciliation ecology" offers the prospect of shifting this trajectory in a more positive direction. Reconciliation ecology is the "science of inventing, establishing, and maintaining new habitats to conserve species diversity in places where people live, work, and play" (Rosenzweig 2003). Rather than focusing solely on protecting or restoring natural areas, reconciliation ecology emphasizes strategies that increase the habitat value for native plants and animals both within and outside of traditional protected areas. And by seeking approaches that benefit people *and* nature, it holds promise for expanding partnerships and reducing controversy over the use of water and land for ecosystems and species.

Beyond improving conditions for wildlife, a reconciliation ecology approach can provide many other benefits: enhanced groundwater recharge, improved air and water quality, increased soil health and carbon storage, new recreational opportunities, and additional flood protection. It could also generate new revenue streams for private landowners engaging in resource conservation efforts. Broader, long-term plans for ecosystem management can bring more regulatory flexibility for landowners, producers, and water managers. Together, these benefits offer significant motivation for a diverse group of stakeholders to come together and develop creative solutions to reinvigorate the valley's natural environment.

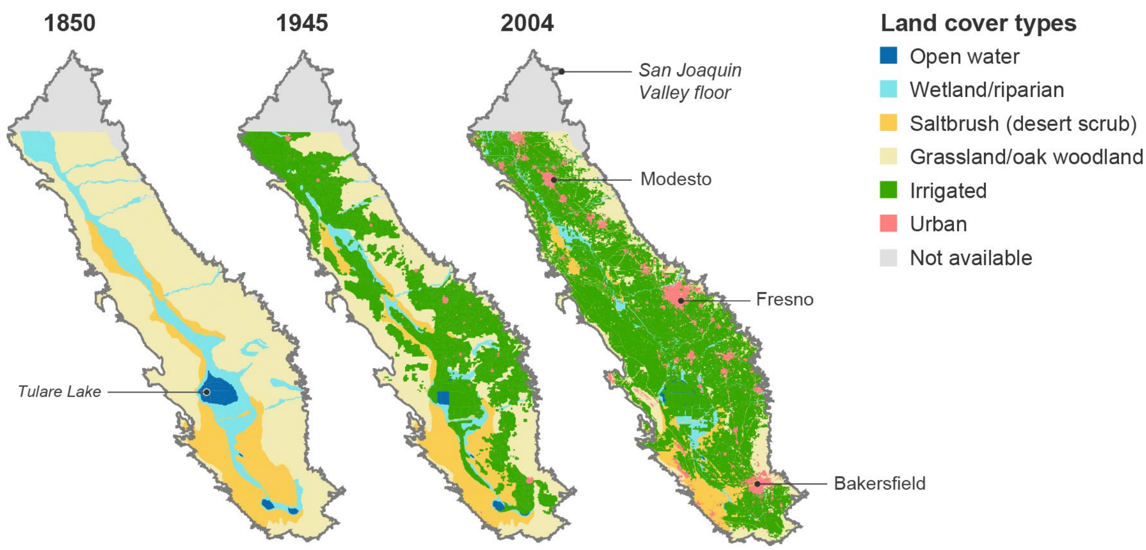
Stewarding the valley's water and land resources to benefit people and nature will not need to start from scratch; numerous ongoing programs already include aspects of reconciliation ecology. But making this approach work well will require a broad cross-section of valley stakeholders—together with their state and federal partners—to engage in much wider and more comprehensive planning than ever before. It will also require creative application of existing tools—including funding and technical support—and some regulatory changes.

This chapter explores the opportunities for making this shift in water and land stewardship as part of a comprehensive approach to tackling the valley's resource management challenges. We begin by reviewing the current conservation status and challenges of the valley's river, wetland, and upland ecosystems. We then provide examples of reconciliation ecology already underway. We highlight ways to manage scarce water resources for the environment more effectively, and to manage idled farmlands for multiple benefits. We close by identifying planning, regulatory, funding, and technical tools that can help move the management of natural resources in the San Joaquin Valley toward reconciliation, and the steps needed to launch an ambitious regional multiple-benefit planning effort.

The Current Status of Valley Ecosystems

Land conversion in the San Joaquin Valley has been extensive since the mid-19th century (Figure 4.1). The landscape is now dominated by irrigated agriculture, which occupies more than half of the valley floor (California Department of Water Resources 2017a). The urban footprint is also significant and growing. The valley's urban areas expanded dramatically in the postwar period, reflecting broader urbanization trends.[101]

FIGURE 4.1
The valley's land uses have changed dramatically since the mid-19th century



SOURCE: Phillips et al. (2004).

NOTES: This mapping exercise examined land cover below the 38°N latitude; unmapped parts of the valley floor are shown in gray. The original area where desert species once thrived may have been larger than the area shown as saltbrush (desert scrub) in the 1850 map; it likely included some of the area shown as grassland/oak woodland area (Germano 2011). Based on crop statistics (see Chapter 2) and 2014 land use maps from DWR, irrigated acreage was likely slightly lower than shown in 2004—and grassland slightly higher.

These transitions resulted in major habitat losses for native plants, fish, and wildlife. Consequently, 18 vertebrate species native to the valley are now regulated under the state and federal endangered species acts; an additional 27 species are identified as at risk (Hanak et al. 2017).

Conservation efforts have largely focused on creating or preserving small pockets of habitat to recover endangered species and support some at-risk species. This has been a challenging endeavor; land use changes, water management, and introductions of non-native species have resulted in ecosystems with species and conditions that are entirely novel compared to historical conditions.

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[101] The valley's urban footprint grew from about 40,000 acres in 1945 to over 500,000 acres in the present day.

The valley now supports a mix of native and non-native species. In many areas, ecosystems that support native species now rely on continuous management to maintain desired conditions. River flows on the San Joaquin and its tributaries are regulated to support salmon and other fishes. Water levels and food resources in managed wetlands are carefully regulated to provide habitat for migratory birds. Remaining patches of desert habitat are grazed with livestock to reduce the cover of non-native annual grasses, both to limit the risk of wildfire and to maintain habitat quality for native desert wildlife. In the absence of these ongoing management activities, the species and habitat diversity of the valley would be radically different.

Three Major Ecosystems

Despite these dramatic changes, the valley is still rich in plant and wildlife diversity. Three major ecosystems illustrate the challenging interplay of biodiversity, water, and farming: rivers and riparian corridors, wetlands, and the San Joaquin desert.

Rivers and Riparian Corridors

The San Joaquin River and its tributaries once supported salmon runs nearly as large as those of the Sacramento River system. The river also had a diversity of other native fishes, from sturgeon to Sacramento perch. With the construction of Friant Dam in the 1940s, almost the entire flow of the main stem San Joaquin River was captured for irrigation water supply. The dewatering of the river destroyed its salmon runs and hastened the decline of most other native fishes. The low-flowing, polluted waters of the lower San Joaquin River became suitable only for warm-water alien species. Populations of salmon were dramatically reduced and confined to cooler reaches of the lower Merced, Tuolumne, and Stanislaus rivers (Moyle 2002).

These changes in river management have also affected riparian corridors and floodplains. Much of this land was converted to agricultural fields, as the natural pattern of flooding became controlled by dams and levees. Once-dense floodplain forests of cottonwood, oak, and sycamore have been reduced to remnants or replaced with thickets of weedy, non-native plants. Numerous wildlife species dependent on floodplain forests—including the riparian brush rabbit, riparian woodrat, and Least-Bell's vireo (a small bird)—have been listed as threatened or endangered.

A major project to restore native fish populations in the lower San Joaquin River is currently underway; it is explored in detail in the next section. In the past two decades, there have also been some successful floodplain restoration efforts, including nearly 5,000 acres along the San Joaquin River (Rentner 2018). Despite these accomplishments, however, restoring functional floodplain ecosystems will require the restoration of thousands of additional acres (Dybala et al. 2017).

Wetlands

The valley once had a vast network of wetlands that provided habitat for millions of waterbirds on their journey along the Pacific Flyway (Garone 2011). Spring runoff fed a chain of lakes, sloughs, and marshlands that extended from San Francisco Bay to the Tehachapi Mountains (Figure 4.1). Perennial lakes, all lost to farming and flood control by the early 20th century, included Tulare, Kern, Goose, and Buena Vista. Although very shallow, Tulare Lake had a surface area about four times that of Lake Tahoe (Austin 2012).

Today, less than 5 percent of the region's historical wetlands remain. Most are part of a Central Valley-wide wildlife refuge system owned and managed by federal, state, and private parties. These wetlands and surrounding farmlands support waterbird populations, including migratory waterfowl and shorebirds. The streams and ditches that flow through the wetlands also support a diverse mix of native and non-native wildlife. Most wetlands are carefully managed with surface water from California's reservoirs.

The San Joaquin Desert and Upland Habitat

Historically—outside of its rivers and wetlands—the San Joaquin Valley floor's upland areas would have been characterized as a desert ecosystem (Germano et al. 2011).[102] The historical vegetation is not well documented, but today this area is covered by a mix of desert scrub and annual grasslands. Much of it was converted to irrigated agriculture, which caused an entire suite of desert plants and animals to decline dramatically. Many of these species—including the blunt-nosed leopard lizard, Fresno kangaroo rat, and San Joaquin kit fox—are now listed as threatened or endangered (Germano et al. 2011). The concentration of endangered species in the valley's upland habitat is particularly high. When the *Recovery Plan for Upland Species of the San Joaquin Valley, California* was drafted in 1998, it addressed 11 species of plants and animals that were already listed, and 23 additional species were recognized as being at risk of future listing (Williams et al. 1998).

Today, they rely on a handful of small protected areas that are intensively managed to support listed species, and a larger area of rangelands, which also provide valuable habitat but with much less intensive management. There are only a few areas, described below, where lands that were once irrigated agriculture have been restored to desert vegetation to provide wildlife habitat.

Management of this novel ecosystem is further complicated because the native plant community has been dramatically altered by exotic annual grasses and other plants. These grasses grow more densely than the native desert plants, which reduces habitat quality for desert wildlife and increases risk of wildfire. It is practically impossible to eradicate the exotic grasses, so these areas require vegetation management (including livestock grazing) to reduce fire risk and maintain quality habitat for desert wildlife (Germano et al. 2001 and 2012).

Opportunities and Challenges Ahead

Today's ecosystems in the San Joaquin Valley are novel and complex. Human actions have irreversibly altered historical conditions. Native and non-native species occur side-by-side. The three major historical ecosystems exist in small fragments on the valley floor and rely on continuous management to maintain desired ecological conditions. The region as a whole has one of the highest concentration of endangered species in the nation (Kelsey et al. 2018).

Climate change is likely to cause further shifts in the distribution of species, favoring those that are tolerant of high temperatures and threatening those that depend on wetlands and cool water temperatures (Gardali et al. 2012, Moyle et al. 2013). Native species will be threatened by these changes, and non-native species are likely to continue to arrive and spread. In the absence of the people and resources to manage them, these ecosystems could become dominated by a few invasive non-native species—severely reducing the habitat value for native species.

Forging a new path for the natural environment requires contending with these difficult realities. Beyond the ongoing ecological health concerns described above, the implementation of the Sustainable Groundwater Management Act (SGMA) brings a new set of challenges and opportunities. The farmland that will come out of production to help balance groundwater basins could allow for expansion of riparian, wetland, and upland habitat. But without a larger planning effort, it is unlikely that land retirement will happen in a strategic and coordinated way to capitalize on this opportunity. SGMA could also help stem the conversion of rangeland that supports species to irrigated cropland. But this, too, will require concerted action. Additionally, water resources will be scarce, as will funding required for habitat management.

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[102] The San Joaquin Valley desert has been defined by Germano et al. (2011) as an ecosystem characterized by low annual rainfall, alkaline soils on the valley floor, and desert-adapted plants and animals. The original extent of habitat where desert species once thrived was larger than the area shown as saltbrush (desert scrub) in the 1850 map in Figure 4.1; it likely included some of the area shown as grassland/oak woodland area (Germano 2011).

The Value of a Reconciliation Ecology Approach

Historically, many conservation efforts have been driven by attempts to recover listed species by focusing on the protection and management of natural areas. This approach typically considers people and their land uses to be independent of species conservation. Reconciliation ecology is a resource management strategy that looks for opportunities to support biodiversity and healthy ecosystems not only in natural areas, but also in areas where people are an important part of the landscape. The concepts of ecosystem-based management and multiple-benefit management are both important tools in the context of shifting toward reconciliation ecology.

Ecosystem-based management. Traditional species-focused conservation has been successful at preventing extinctions. But it has met limited success in recovering populations of listed species, expanding habitat, and improving ecosystem health more broadly to prevent listing of new species. One key problem is that the regulatory drivers for conservation—the federal and state endangered species acts—are invoked when species are already in severe decline. Once a point of crisis is reached, recovery can be difficult and costly. Going forward, the long-standing focus on protecting individual species should be complemented by a broader, ecosystem-based management approach. This requires setting conservation objectives based not only on the status of individual species, but on overall ecosystem health. The end goal is supporting abundance and diversity of desirable native and non-native plants, fish, and wildlife on a large scale.

Multiple-benefit management. With limits on available water and funding constraining habitat restoration, another facet of reconciliation ecology can help guide restoration decisions in the valley. Multiple-benefit management seeks to meet the needs of societies in ways that also enhance ecological function and habitat quality for species and ecosystems. These needs are many and diverse—flood protection, water supply, air and water quality, food production, and recreation. Projects that bring multiple benefits offer opportunities to share costs and leverage more sources of funding. For example, in some locations, groundwater recharge and banking facilities can also be used to create intermittent wetlands. Similarly, pooling funds for flood protection infrastructure with riparian and floodplain habitat improvements can result in larger projects that are more effective at meeting both objectives (Opperman et al. 2017).

The restoration of Putah Creek in the Sacramento Valley offers a model of both ecosystem-based management and managing for multiple benefits—including using scarce water for ecosystems very efficiently (Box 4.1).

Box 4.1: Reconciling Putah Creek

Putah Creek is emerging as a model of reconciliation ecology. In less than 20 years it has gone from an eyesore to a major attraction for fish, wildlife, and people. Local stewardship of the creek could serve as a model for restoration programs in the San Joaquin Valley.

Putah Creek flows east from the Coast Range into the lower Sacramento Valley. Historically, the lower reaches meandered through a vast floodplain into a sea of tules. The native Patwin people made use of the tules and the abundant fish and wildlife in the lower watershed. In the 19th century, farmers settled on the rich floodplain and confined the creek between levees. The channel was largely kept free of trees and shrubs. Monticello Dam (1957) was built to further prevent flooding and provide water. Water was diverted at the Putah Creek Diversion Dam, depriving the creek below the dam of most of its flow. The creek became something of a dumping ground.

Over time, awareness of the creek's potential for recreation and biodiversity led to efforts to restore it. UC Davis, for example, stopped mining gravel from the creek and created a riparian reserve along its banks. When drought stripped the creek of most of its remaining water, a group of local citizens, UC Davis, and the City of Davis filed a lawsuit to require releases from the diversion dam to maintain native fishes. In 1996, the court ruled in favor of the plaintiffs. The parties subsequently agreed to a flow regime that mimicked historic conditions, though at much lower levels.

Native fish populations recovered rapidly in the upper half of the rewatered section, while conditions in the lower reach favored non-native species, supporting a recreational fishery. A run of Chinook salmon was reestablished (Kiernan et al. 2012). The lack of endangered species allows the creek to be managed as an ecosystem, meaning the requirements of single species do not drive management decisions.

More natural flows also brought significant recovery in riparian vegetation and native birds (Dybala et al. 2018a). The community removed trash and placed bird nesting boxes along the creek. The cities of Davis and Winters built new creek-oriented parks, and UC Davis expanded its riparian reserve. Through all these changes, Putah Creek remains a highly altered novel ecosystem, with native and non-native species living together in a highly managed landscape (Moyle 2014).

Depending on the year, about 10 percent of water released from Monticello Dam supplies downstream natural flows and riparian water right-holders. The Solano County Water Agency pays for a full-time stream keeper, who works with diverse parties to manage the creek and to raise funds for restoration projects. The water agency also funds a monitoring program for fish, wildlife, and plants.

Managing Water and Land to Benefit People and Nature

Aspects of reconciliation ecology are already practiced in the San Joaquin Valley, and SGMA offers opportunities to implement this approach more broadly. Here we examine ways to effectively manage water for the environment, and the options for lands likely to come out of production as part of sustainable groundwater management. We then provide some examples from ongoing conservation efforts that illustrate how water and land can be stewarded to benefit people and nature. Scaling up these types of approaches could help the San Joaquin Valley emerge as a national leader in multiple-benefit, ecosystem-based management.

Making Environmental Water Use Efficient and Effective

The valley's rivers and wetlands need water to thrive. But with the many competing demands for scarce water supplies in this region, it is essential to manage it both efficiently and effectively. This requires being prepared to weather droughts—when freshwater ecosystems are most vulnerable—and taking advantage of wetter years to boost ecosystem health. An extensive review of how California's freshwater ecosystems fared during the 2012–16 drought found that several key elements can improve chances of success: watershed-level plans, dedicated ecosystem water budgets, and strong water accounting systems (Mount et al. 2017a). The most successful cases also involved strong partnerships between environmental managers and other local water users.

Here are the key elements of this approach:

- **Watershed-level plans** consider how to use water for freshwater ecosystems most effectively in different types of water years, and how to make complementary investments in habitat and other actions to reduce stress on key species.
- **Ecosystem water budgets (EWBs)** are dedicated amounts of water that environmental managers can use to improve ecosystem function and benefit species. As with water rights and contracts, these amounts vary with hydrologic conditions—with more water available in wetter years than in dry years. EWBs should also function like water rights in other respects—giving managers the ability to trade and store environmental water to improve flexibility. This also encourages collaboration with other water managers, making the environment a partner, rather than a constraint.
- **Robust water accounting** is essential to keep track of scarce supplies and ensure that all parties are using their fair shares. It also helps incentivize flexible tools such as water trading and joint investments with other stakeholders in projects to boost supplies.

Negotiated settlements—involving multiple stakeholders—can be a good way to develop and implement the approach, because they harness the potential for creative local solutions that go beyond what regulatory agencies might require.[103] The resulting legal agreements among the parties also reduce uncertainty in water management. Although most elements of this package can be accomplished under existing law, some legal changes may be needed to enable EWBs to function more flexibly.

Models of Effective Management

Going into the 2012–16 drought, most of California's freshwater ecosystems did not have water management plans, and rather than having an ecosystem water budget they relied on minimum instream flows with limited flexibility for real-time management. Water accounting was often limited as well. But there were also some bright spots, where collaborative planning and a well-defined volume of water for the environment made effective management possible. In the Sacramento Valley, this includes Putah Creek (described in Box 4.1) and the Lower Yuba River—both places where parties had come together before the drought to develop and implement plans for improving ecosystem health.[104]

In the San Joaquin Valley, the best example of effective environmental water management is the network of managed wetlands in the wildlife refuge system. Since the early 1990s the wetlands have had a type of ecosystem water budget, established under the Central Valley Project Improvement Act. The project also funds management and the acquisition of additional water with income from a surcharge on CVP water use. During the drought, water allocations to the refuges were very low; like senior agricultural water users, they received just 48 percent of contract deliveries in 2014. But wetlands managers were able to make the most of this water by coordinating actions across the different refuges, and relying on real-time tracking of the location of migrating birds.

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[103] Local watershed groups can also play valuable roles in planning and on-the-ground stewardship (Grant and Langpap 2017).

[104] Mount et al. (2017b) provides eight detailed case studies of ecosystem management during the drought, including those mentioned here.

Supplemental water purchases were also used to expand bird habitat by temporarily flooding Sacramento Valley rice fields at key times. These efforts helped protect waterbird populations despite record dry, hot conditions. In the San Joaquin Valley, new infrastructure partnerships between wetland managers and agricultural water districts are also making it possible to capture and harness more local supplies.[105]

There is still room for improving refuge water management. Managers do not have flexibility to share water across different sites. Infrastructure investments are still needed to enable water deliveries to some refuges—something state bonds will help address.[106] And although the reliability of water supplies has increased with the CVPIA's water budget, deliveries generally fall short of program goals.[107] Audits have also noted the need for more transparent accounting of water deliveries to the refuges.[108] Yet progress continues to be made, and the refuges provide a positive model for reinvigorating the valley's natural environment through effective, collaborative water management.

As we discuss below, restoration of the lower San Joaquin River also has elements of reconciliation ecology, with potential to use the approach effectively on the San Joaquin River tributaries.

Managing Idled Cropland

The range of potential uses for the irrigated lands that will come out of production to help end groundwater overdraft is broad—and reconciliation ecology approaches can point valley stakeholders in the most promising directions.

By design, these lands will have little or no dedicated, ongoing water use. Potential uses envisaged under the current planning process include solar energy and multi-benefit restoration of some of the valley's historic riparian, wetland, and desert ecosystems (Kelsey et al. 2018). But even if these relatively ambitious targets are met over the next two decades, it would at best account for one-third of all land likely to be idled (Figure 4.2). Managing this transition successfully will require expanding the planning effort, to identify strategies that can yield the greatest benefits from *all* idled lands.

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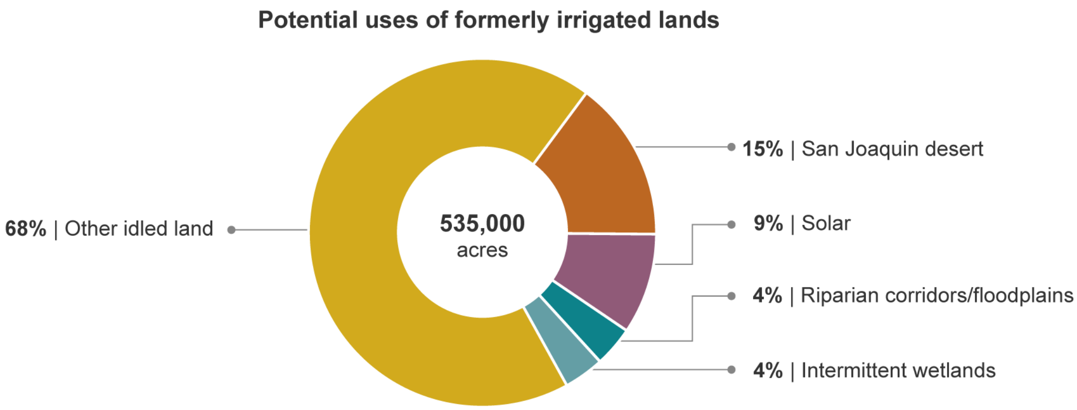
[105] See the panel discussion on "Advancing Partnerships for Healthy Ecosystems" with Ric Ortega, general manager of Grasslands Water District at an October 2017 PPIC conference. Pottinger (2018b) features an interview with Ortega about refuge water management challenges and opportunities.
[106] Proposition 1 (passed in 2014) includes $89 million to help build infrastructure so that all refuges can receive their water allocation from the CVP (Pottinger 2018b). That bond will likely also support some storage projects that could increase water supply reliability for the refuges, such as the expansion of Los Vaqueros reservoir.
[107] Central Valley Project Improvement Act Refuge Water Supply Program (2009) estimated that average water deliveries to the refuges increased by about 21,000 acre-feet (up from 422,000 acre-feet) after the enactment of the CVPIA, and that reliability of these deliveries improved (p. 29). The program has been more effective at providing "Level 2" refuge water—deemed a minimum—and less effective at attaining the full "Level 4" deliveries—a higher volume that is not guaranteed.
[108] For water accounting challenges, see Central Valley Project Improvement Act Refuge Water Supply Program (2009).

FIGURE 4.2

Land coming out of production will greatly exceed the footprint of current planning processes



SOURCE: Author estimates. For details on sources and assumptions, see technical appendix Table E2.

NOTES: This figure assumes that 535,000 acres of irrigated cropland will be idled by 2040 under SGMA. This is the estimated land retirement if roughly one-quarter of the valley's historical groundwater deficit is filled by augmenting supplies (Chapter 2). If land idling needs to be larger—either because of a higher future water deficit or limited success in augmenting supplies—the area in "other idled land" would likely expand more than the other categories.

Here are our rough estimates of potential uses of idled lands (for details, see Technical Appendix E):

- **Expanding solar energy.** Perhaps as much as 50,000 acres in the San Joaquin Valley could be used for solar development, given the state's new commitment to provide all electricity from carbon-free sources by 2045 under legislation enacted in 2018 (Senate Bill 100). However, not all new solar development will occur on retired cropland; some will likely use non-irrigated rangeland.[109] Solar energy represents one of the few options for generating significant non-farm revenues on lands retired to save water. Recent efforts also show that it is possible to manage these lands in wildlife-friendly ways.[110]
- **Reducing flood risk and expanding riparian corridors and floodplains.** Some retired land—perhaps 20,000 acres—may be suitable for multiple-benefit projects that reduce flood risk, increase groundwater recharge, and expand riparian corridors and floodplains. These lands would be intensively managed to restore habitat for fish and wildlife, similar to the existing restored floodplains along the San Joaquin River.
- **Creating intermittent wetlands.** Efforts are under way to improve the reliability of water supply for the valley's managed wetlands, but it is unlikely that their surface area will significantly increase. However, there are opportunities to expand dedicated recharge areas that can also serve as intermittent wetlands—perhaps 20,000 acres. This type of multi-benefit management—which takes advantage of opportunities to store high-flow water to create habitat—occurs at the Kern Water Bank, described below. Unlike recharge on active cropland, dedicated recharge areas reduce farm water use on an ongoing basis.[111]
- **Recovering the San Joaquin desert.** The recovery plan for this unique ecosystem envisages up to 80,000 acres for intensively managed habitat. This amount would allow for persistence, if not recovery, of listed desert species. The plan is ambitious; to date only small patches of this habitat have been restored. Below we provide examples where this type of management is now occurring.

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[109] Current restrictions on the development of solar energy on prime farmland, described below, are one reason why.

[110] Although solar development has often been considered to be detrimental to wildlife habitat, new installation techniques such as wildlife-friendly fencing and greater space below and between panels offer the potential to maintain wildlife habitat within the perimeter of solar installations (Phillips and Cypher 2015).

[111] There is also some interest in seasonal flooding of suitable annual cropland in very wet years, with the land being fallowed for that year's growing season. This strategy could provide important recharge and flood mitigation benefits, but it would only reduce crop water use in years when the land is fallowed. If that is once in 10 years, 1,000 acres of such land would provide water savings equivalent to just 100 acres of long-term crop idling.

- **Managing other idled land.** Most remaining land to be idled (365,000 acres or more) exceeds the scope of these energy and habitat restoration plans. Some of this acreage could accommodate new housing or industrial developments—*if* they rely on urban conservation to meet their water needs.[112] But without proactive planning, much could be fallowed with little consideration of the potential benefits or impacts for the valley, creating issues with dust, weeds, and pests. Coordinated approaches, combined with incentives, could minimize the negative impacts and provide benefits for soil health and carbon storage, as well as habitat if lands are managed as a system of wildlife corridors.

This mix of future land uses is not a foregone conclusion. The shape of the landscape—and the benefits from idled land—will depend on how and where fallowing occurs. It could occur piecemeal, with little investment in planning or management, or in a more coordinated manner. There will also be choices to make between permanently retiring cropland or fallowing it in rotation for shorter periods. Either way, achieving multiple benefits from idled lands will depend on the level of stewardship and coordination.

To illustrate the essential role of stewardship, Table 4.1 displays the spectrum of management options and benefit streams for areas already targeted for multi-benefit restoration and most other idled lands.[113] The "no action" alternative—where the land is not managed at all—may be the least beneficial overall. Especially in wetter years, significant weed growth is likely. This elevates the risk of invasive weeds that can infest adjacent cropland and cause fires—threatening neighboring properties as well as air quality. To avoid some of these problems, farmers commonly engage in two basic maintenance practices on fallowed fields: disking or spraying.

TABLE 4.1

A spectrum of management approaches is available for lands coming out of production, with varying benefits

	No action	Basic maintenance		Conservation-oriented management		
Benefits	No management	Disking	Spraying	Land stewardship (e.g., cover crops, compost, grazing)	Coordinated land management (stewardship + connectivity)	Species-focused coordinated land restoration (permanent retirement)
Weeds/pests/fire suppression	✗	✓	✓	✓	✓	✓
Air quality (dust, other)	✗	✗	✗	✓	✓	✓
Soil health (including carbon storage)	✗	✗	✗	✓	✓	✓
Native species habitat	✗	✗	✗	?	✓	✓✓

SOURCE: Developed by the authors, based on the literature and expert interviews.

NOTES: "✗" denotes a lack of listed benefits with the management option, and "✓" denotes the potential for realizing these benefits. Most options would be available for temporarily fallowed land and permanently retired land. To provide some types of habitat benefits, however, the lands would need to be permanently retired (see text). Areas suitable for intermittent flooding could also provide groundwater storage and flood mitigation benefits.

Disking is popular because it also makes the land inhospitable for threatened and endangered species. Although unmanaged lands provide poor habitat because of weed growth, there is still a risk that such species will come

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[112] For historic displacement of prime farmland due to urban development, see Unger and Thompson (2013) and Cameron et al. (2014). As we show in Chapter 2, these shifts did not reduce total irrigated acreage (or farm water use).

[113] Management considerations will be somewhat different for lands that will convert to energy, residential, or industrial uses. However, some of the conservation-oriented approaches might also be relevant on lands being outfitted with solar panels. Acreage converted to housing or industrial development using urban water savings would likely be required to mitigate dust and weeds, and might also be able to provide some species-focused conservation benefits.

onto the property when the land is no longer being farmed. Disking allays fears that the land's future uses could be restricted because of listed species' presence (Bean 1997). But disking has downsides. In addition to eliminating any habitat benefits, disking produces dust, which can degrade air quality and reduce water quality in local waterways (Baker et al. 2005). Some growers opt for spraying to manage vegetation, which can also have negative consequences for neighboring farms and the broader environment.

Conservation-oriented management includes a wide range of practices beyond basic maintenance. Land stewardship practices include using cover crops, composting, and/or grazing to manage vegetation and build soil health on individual fields. Additional conservation efforts seek to provide habitat benefits for native species. Coordinating the location of stewarded lands—to provide large enough areas for these species to thrive, or to provide connections between good habitat areas—is one such approach. More intensive species-focused management includes actions to foster the establishment of native species—such as recreating topography in leveled fields, planting native vegetation, and installing artificial burrows or dens to make them more hospitable for native wildlife.[114] Areas suitable for intermittent flooding could also provide groundwater storage and flood mitigation benefits. Some stewardship practices—including planting cover crops and reestablishing native vegetation—may initially require some irrigation water. And while some practices would be compatible with fallowing lands on a temporary basis, permanent retirement would likely be required to provide some types of habitat benefits.[115]

Minimizing management costs will be important, given the scale of this effort and the limited revenues available. The costs of land management are likely to increase with conservation-oriented approaches—with efforts focused on restoring native species potentially the most costly. But as discussed below, by providing an array of benefits, conservation-oriented approaches also can raise revenues for managing retired lands, and create new employment opportunities for rural residents.

Lessons from Ongoing Conservation Efforts

Ongoing conservation work in each of the three major ecosystem types offers lessons on how a reconciliation ecology approach can be used more broadly to improve ecosystem health for a wide array of species and to achieve multiple benefits for people and nature.

Multi-benefit River Restoration: San Joaquin River Restoration Program

Projects to restore the ecological function of the San Joaquin Valley's rivers and floodplains have primarily focused on improving instream conditions for salmon and other native fishes, and restoring floodplain vegetation to support migratory songbirds and terrestrial wildlife.

The largest of these efforts is the San Joaquin River Restoration Program, created by the 2006 settlement of litigation to restore flows to the main stem of the river below Friant Dam. The program is funded by state and federal contributions and a surcharge on water use. Although the effort focuses on restoring spring-run Chinook salmon, it benefits many other native fishes, birds, and mammals. The program seeks to manage restoration flows flexibly—with an ecosystem water budget, of sorts—to improve habitat. Once they are used, water contractors are

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[114] As an example, in the San Joaquin River National Wildlife Refuge, managers have built earthen mounds to accommodate the endangered riparian brush rabbit when the lowlands are flooded (Kelly 2018). Contouring terrain or installing artificial structures to mimic natural burrowing areas could help restore San Joaquin desert species (Cypher et al. 2005). Stewart et al. (2019) also note the value of actions such as introducing native shrubs, grading lands, and weed control through targeted grazing and burning to re-establishing the endangered blunt-nosed leopard lizard and other desert species. However, they also observe that in some places, given enough time, simply retiring land may be sufficient for some aspects of habitat recovery.

[115] For example, reestablishing endangered kangaroo rats in new habitat areas requires substantial effort before and after their translocation (Tennant et al. 2013). Such investments would likely be more worthwhile in areas that are permanently retired.

allowed to recapture, reuse, or transfer most of these flows; in wetter years, they can also buy back water lost to the restoration effort at a reduced price.[116]

Reestablishing spring-run Chinook salmon in this altered river system will be challenging. The run will always be small and dependent on hatcheries, because cold-water habitat below Friant Dam is very limited. Juvenile salmon will also need to find their way down the highly altered river channel and through inhospitable habitat in the Delta before reaching the ocean. But if the program succeeds, it will show that it is possible to restore a species that was once a dominant feature of the ecosystem. And there are many other benefits of having a living river, which is likely to become a recreational magnet as fish and wildlife populations develop again.

The program can be enhanced to achieve broader benefits. In particular, it could be better integrated with the Central Valley Flood Protection Plan. The flood plan recognizes that flood system improvements could also benefit habitat for fish and wildlife, but there is no official mechanism to coordinate with the river restoration. Restoring floodplain forests could also contribute to California's carbon sequestration goals (D'Elia et al. 2017, Dybala et al. 2018b). Restoring some irrigated farmland along the river can also help address the valley's groundwater deficit.

The program could also serve as a model (or at least a starting point) for other river restoration efforts in the region. It has many elements of effective environmental water management outlined above: planning for water use and complementary habitat investments, designation of an ecosystem water budget, good accounting, and the ability to manage water flexibly in conjunction with other water users. This approach would be valuable on the Tuolumne, Stanislaus, and Merced rivers—three tributaries to the San Joaquin River where the State Water Board has required water users to augment environmental flows. The board recently adopted mandated flow levels, but also left open the possibility of approving a negotiated settlement as an alternative, as part of a comprehensive agreement on flow management in the Sacramento–San Joaquin Delta watersheds in 2019.[117] This agreement could include collaborative investments to manage water for the environment (Mount et al. 2016). For instance, groundwater recharge projects could boost environmental flows in dry years. This approach, used effectively on the lower Yuba River, could also reduce the costs of the program to water users (Hanak 2018).

The cost of the San Joaquin River Restoration Program is high: state and federal agencies are expected to spend up to $890 million to implement the program. However, in addition to improving ecological condition, these expenditures are expected to generate jobs directly through the restoration construction and indirectly through enhanced recreational opportunities in the region (Kantor 2012).

Recharging Groundwater and Providing Habitat: The Kern Water Bank

Groundwater recharge projects may be especially well suited to the multiple benefit approach. One particularly effective example is the Kern Water Bank.[118] This recharge project—a joint powers authority owned and operated by a group of SWP contractors and water users—lies west of Bakersfield on 20,000 acres of the Kern River's alluvial fan. It is one of the state's largest recharge projects, with storage capacity of up to 1.5 million acre-feet (Water Association of Kern County 2017). Its facilities include approximately 7,000 acres of recharge ponds, 85 recovery wells, and a canal that connects the recharge and recovery facilities with the California Aqueduct. Bank members purchase surface water for recharge when available and make withdrawals from the bank when needed.

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[116] See San Joaquin River Litigation Settlement (Friant Water Users Authority n.d. and Final Q&A n.d.), and San Joaquin River Restoration Program (2018). The average projected reduction in irrigation water supplies to Friant project contractors is 170,000 acre-feet, or 15 percent, but measures such as recapture and recirculation of flows and groundwater storage are intended to minimize these impacts.

[117] State Water Resources Control Board (2018a) describes the details of the mandated flows, and State Water Resources Control Board (2018b) is the press release describing the board's recent decision and statement regarding negotiated settlements.

[118] The details of this case study are from the website of the Kern Water Bank Authority (last consulted on October 4, 2018) and Kern Water Bank Authority (2017).

In 1997, the Kern Water Bank Authority entered into a Habitat Conservation Plan under the federal Endangered Species Act and a Natural Community Conservation Plan under California law to provide significant co-benefits for wildlife from the management of its groundwater recharge facility. Under these agreements, the authority has restored 17,000 acres of cropland to upland and intermittent wetland habitat. The agreements also designate over 3,000 acres as a conservation bank—one of nine administered by the state Department of Fish and Wildlife in the valley. By allowing landowners to purchase credits as mitigation for their own projects, these banks help consolidate habitat, which is especially valuable for many San Joaquin desert species (Bailey and Germano 2015).

The conservation agreements were centered on the site's potential for managing vegetation to improve upland habitat for San Joaquin desert species—including some endangered species already on the property. This work has been successful—with an abundance of desert species now found on site. And an added benefit is that the recharge ponds have become habitat that functions as intermittent wetlands. In wet years, these areas host dozens of species of waterbirds, including some sensitive species. Bank managers hypothesize that the recharge lands' topography makes them particularly suitable as wetland habitat. Whereas recharge basins are typically highly engineered structures with evenly contoured sides and depths, the Kern Water Bank's basins have more natural, sloping contours and varying water depths, which provide more diverse habitat.

At least a quarter of the valley's 202 agricultural and urban water suppliers had one or more recharge basins on their lands in 2017, and managers we surveyed reported considerable interest in expanding this tool on suitable lands (Hanak et al. 2018). Although few of these projects will be on the scale of the Kern Water Bank, many will present opportunities to achieve the multiple benefits of water supply, water storage, and intermittent wetland habitat enhancement for birds.

Stewarding Retired Lands and Restoring the Desert Ecosystem

The Kern Water Bank also provides a good example of how vegetation management can steward retired cropland in upland areas for multiple benefits. In this case, the conservation work mainly focused on keeping the exotic grasses under control, primarily with grazing.[119] This has helped prevent air quality and pest problems, while creating habitat for San Joaquin desert species. Grazing is also a preferred strategy in some other upland restoration efforts.[120]

A US Department of Interior initiative has also sought to use retired farmland for more comprehensive desert ecosystem restoration, including reintroduction of native vegetation. As described in Chapter 3, poor drainage and shallow groundwater are a major problem on the valley's west side, leading to salt accumulation in the soil that makes it unsuitable for agriculture. The Central Valley Project Improvement Act authorized the purchase and retirement of compromised agricultural lands. An interagency Land Retirement Program was tasked with developing tools for retiring these lands in a way that would improve habitat for desert wildlife. This effort has been ecologically successful for some species, but it also highlights the challenges of fully restoring the desert ecosystem.[121]

The program uses two actively farmed sites in the valley. The Tranquillity site (roughly 2,000 acres in Fresno County) was retired and 800 acres were restored in 1999. Restoration began at the 8,000–acre Atwell Island site (Kings and Tulare counties) in 2001 and continues today, with small areas being restored each year.

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[119] Other permitted approaches in the vegetation management plan—used as needed—include mowing, burning, and spraying (Kern Water Bank Authority 2017).

[120] This includes the Carrizo Plains, to the west of Kern County, an area within the historic range of the San Joaquin desert. On the valley floor, the Maricopa Sun Solar Energy Project near Taft (Kern County) includes a Habitat Conservation Plan for upland habitat. This project is initially converting small areas to habitat, and will eventually convert the roughly 4,000–acre solar park at the end of the solar panels' useful life. Sequoia Riverlands Trust is managing habitat in both areas.

[121] This case study draws primarily on US Department of the Interior (2005, 2010).

Several restoration techniques have been tested: seeding with native plants, installing topographic contours, a combination of seeding and contouring, and control with minimal intervention. These experiments have demonstrated that native shrubs could be established on retired land, but there was less success at recovering a full suite of native plant species. Several non-native grasses became extremely abundant, reducing habitat quality for desert wildlife and increasing fire risk. And although the habitat created was colonized by numerous desert wildlife species, the recruitment of threatened and endangered species was limited.

This program demonstrates that the restoration of San Joaquin desert vegetation is possible on marginally productive, salinity-impacted lands. Maintaining the habitat value for native desert wildlife will require ongoing management such as prescribed grazing to control non-native grasses (Germano et al. 2001, 2012). A critical next step is to understand how lessons learned can be applied to larger efforts at reasonable cost (Lortie et al. 2019). This may require developing restoration techniques based on large-scale farming practices (e.g., producing native seeds, growing seedlings in nurseries, extensive preparation of fields prior to planting, and irrigation and weed management for several years after planting), as used in the restoration of San Joaquin floodplain forests.

The Stewardship Toolkit

Stewarding the valley's water and land resources to benefit people and nature will require new approaches to planning and a focus on practical, cost-effective solutions. Here we discuss pathways and tools that can help facilitate this transition: broad-based planning, regulatory flexibility, financial incentives, and technical support. This effort will not need to start from scratch. But making it work well will require new ways of thinking, creative application of existing tools, and some regulatory changes.

Broad-based Planning

Above we described the importance of launching watershed-level planning—involving multiple stakeholders—to manage water effectively for the valley's freshwater ecosystems. For a variety of reasons, valley stakeholders will also need to engage in much broader and more comprehensive planning for the management of the region's lands than ever before. Making the most of groundwater recharge potential requires protecting highly suitable lands from development, and considering which lands to favor to protect groundwater quality.[122] Planning is also essential to effectively manage land transitions with the implementation of SGMA—both to help keep the most valuable cropland active, and to reap the most benefits from lands coming out of production.

Today, land use planning in the valley tends to be locally driven, with only limited consideration of water resources. City planning departments focus on land use decisions within their boundaries and their spheres of influence—adjacent unincorporated areas where they are likely to expand. County planners focus on unincorporated areas—home to most farming and open space, as well as most small rural communities. City and county general plans typically devote little attention to water. And water agencies have not traditionally been involved in land use planning, except to certify that water is available to support new development projects in urban or urbanizing areas (Hanak 2010).

With SGMA, greater coordination will be necessary at the basin scale, involving groundwater sustainability agencies and their many stakeholders—farmers, business and community groups, environmental nonprofits—along with city and county land use planners and others. Some county planners have begun working with these groups to help envisage beneficial transitions. In particular, Kern County's planning department is considering the likelihood that considerable cropland may come out of production as it updates the county general plan.

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[122] Much of the land surrounding the valley's cities is suitable for recharge, and vulnerable to being paved over without careful planning (technical appendix Figure E3, Jezdimirovic 2018).

Basin-scale planning is also critical to protecting lands suitable for recharge and considering which lands can best protect groundwater quality.

For many key land use decisions, a broader regional planning effort—involving local planning departments, groundwater sustainability agencies, stakeholders, and regulators—will be needed. Regional planning is particularly important for maximizing habitat benefits, because many ecological patterns are regional in nature (Huber et al. 2010). This is also an appropriate scale for mapping the most suitable lands for solar development (e.g., near existing transmission systems), and for considering some groundwater recharge investments (e.g., expanded conveyance) and the potential retirement of salinity-impacted lands.[123] It can also help assess the land-use implications of valley-wide surface water trading, which could improve the value of fallowed land by expanding opportunities to convert it to productive new uses.[124] Regional planning could also facilitate beneficial economic transitions more broadly. Although there have been some forums to consider regional resource management issues, a mechanism does not yet exist for coordinating land use decisions at this scale.[125]

Habitat-focused Regional Planning

The Central Valley Ecoregional Conservation Network proposed by Huber et al. (2010) is an illustration of how regional planning might guide land fallowing to generate the greatest ecological value. This analysis used information about existing wildlife habitat and patterns to identify core conservation areas and corridors connecting them (Figure 4.3A). These areas could incorporate a range of land uses compatible with wildlife conservation, including highly managed conservation areas, private rangelands with livestock grazing, and even specific types of wildlife-friendly agriculture (e.g., corn or alfalfa).[126] Corridors are frequently identified in both regional and state-wide conservation strategies because they facilitate movement across fragmented landscapes and help species move to adjust to a changing climate.[127]

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[123] See Figure 3.2 for a map showing lands with high concentrations of salinity in shallow groundwater, which are concentrated on the valley's west side.

[124] Without valley-wide surface water trading, there would be very little fallowed land in its wetter, northern half. By shifting some fallowing from south to north, this trading creates more possibilities to repurpose cropland, such as floodplain restoration and habitat corridors. Figure 2.5 shows the projected geographic shift in fallowing when overdraft is addressed entirely through demand management; fallowing levels would be lower with new supply investments.

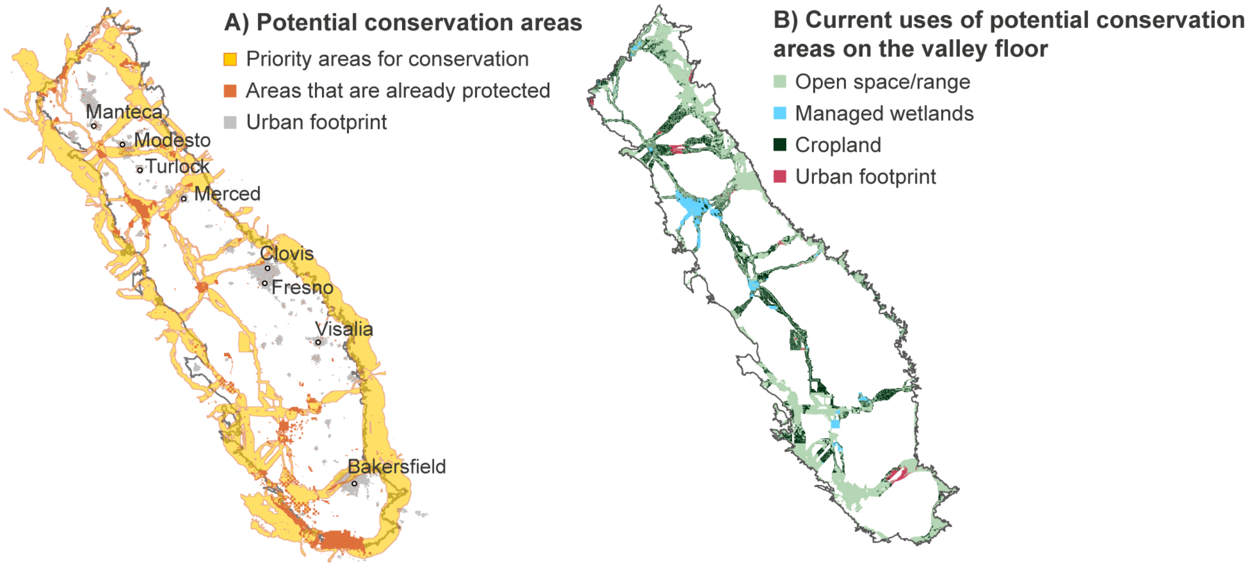
[125] For instance, the California Partnership for the San Joaquin Valley, a public-private organization established in 2006, convenes local government, business leaders, and state officials on these issues. Another example is the San Joaquin Valley Regional Policy Council, which provides a forum for communication on regional planning issues. Its initiatives include the San Joaquin Valley Greenprint, an effort to support land-use and resource-management planning in the valley's non-urban areas with maps and other tools.

[126] These fields provide habitat for a variety of birds within the valley, including the threatened Swainson's Hawk, Lesser Sandhill Crane, and Long-billed Curlew (Shuford et al. 2013, Ivey et al. 2014, Fleishman et al. 2016).

[127] For a regional example see Southern Sierra Partnership (2010); for a statewide example see Keeley et al. (2018).

FIGURE 4.3

A linked network of regional habitats could be created with strategic farmland conversion



SOURCES: Potential conservation areas: Huber et al. (2010) (data link). Current (2014) land use: California Department of Water Resources (2017a).

In this scenario, the core and corridor areas cover 2.2 million acres on the San Joaquin Valley floor (Figure 4.3B). Approximately 7 percent of these areas are already managed as state or federal conservation areas (e.g., the wildlife refuges). Another 60 percent are currently open space or rangelands used for livestock grazing, which is generally compatible with providing wildlife habitat if managed appropriately. Approximately 30 percent (663,000 acres) is irrigated cropland—an area on par with the lands that may come out of production under SGMA.[128] Aggregating areas of permanent land retirement and temporary fallowing in these areas could greatly increase the ecosystem value of these lands.

Ownership and Management

Planning would need to consider not only how to incentivize landowners to make these decisions, but also who would own and manage lands. Many farmers are unlikely to want to continue owning and managing them, because the required skillset is quite different from farming, as are the legal risks. One option is to convert permanently retired lands into public lands, owned and managed by federal or state agencies with existing land assets and expertise, including the federal Fish and Wildlife Service and Bureau of Land Management, and the state Department of Fish and Wildlife and Wildlife Conservation Board. This approach would be most feasible in areas contiguous to existing public lands. Another possibility being explored is for water districts or GSAs to take on this role for their growers as part of local demand management efforts; the district would purchase the land, and the water tied to the land could be available for use elsewhere within the district.[129] Alternatively, the retired

[128] Of this total, approximately 300,000 acres of land were in permanent crops in 2014. Taking these crops out of production is more costly. But since this is a long-term process, even lands currently in permanent crops might eventually become available, when the orchards come to the end of their useful economic life.

[129] As described below, districts or GSAs can assess their growers and use the funds to buy land and take it out of production. Some districts in the Kern Basin are considering this as part of SGMA implementation. Where districts and GSAs do not have the capacity to do this, another option might be for local land trusts to work with groups of farmers to create water cooperatives. The farmers would contribute funds to buy land for fallowing, and receive the surface and pumping rights tied to the fallowed land (minus an allocation for habitat, if needed). The local land trust would manage and restore the land. Shares in the cooperative would be tradeable, so farmers could sell their shares (and the water tied to those shares). This arrangement would probably work best within a single district, where the water can easily be moved between properties.

land might remain with the current landowner, but with a conservation easement that restricts the land use on the property. Local land trusts or government agencies such as resource conservation districts (described below) could be responsible for habitat stewardship. Temporarily fallowed lands would not change hands, but farmers could receive technical and financial support to manage them for wildlife and other benefits, such as soil health.

A large regional effort, on the scale of the network Huber proposed, will be able to draw on existing planning mechanisms and expertise, but it will require scaling up the coordination among various parties, including local governments, regulators, water managers, farmers, GSAs, and others. It will also need to look beyond wildlife habitat to include other societal values, such as water supply and flood management, water and air quality, and outdoor recreation. Importantly, landowners must be treated as true partners and given both voice and choice in the process. Generating such a process will require a significant upfront investment to build trust in coordinated land idling programs. Other challenges include regulatory hurdles and the need for funding and technical support. The following sections describe tools for addressing these issues.

Regulatory Flexibility

Environmental regulations are designed to protect public health and the natural environment. But they can sometimes be applied in ways that prevent meeting those goals and reaching the best overall outcomes. Regulations can also increase the time and cost of environmental permitting without improving decision making. Different regulations can also be in conflict, putting regulated parties in a bind. To manage the land and water transitions in the valley in a beneficial way, these concerns will need to be addressed. Some existing regulatory tools can facilitate creative solutions, by giving more flexibility to project design and implementation. Some changes may also be needed. Here we review three key areas where flexibility is essential: implementing large, multi-benefit projects, simplifying the environmental permitting process, and protecting landowners seeking to steward fallowed lands from regulatory risk.

Facilitating Large, Multi-benefit Projects

Implementing reconciliation ecology principles on a large scale requires a framework for managing lands and water for the benefit of multiple species, while allowing for other economic uses. Although administration of state and federal endangered species acts has traditionally focused on conservation and recovery of single species, both state and federal law allow for a broader perspective on species protection and habitat management.

Several broader approaches would be worth expanding in the valley. The most noteworthy are Habitat Conservation Plans (HCPs), created under the authority of the federal Endangered Species Act; and Natural Community Conservation Plans (NCCPs), which contribute to the implementation of the California Endangered Species Act and related state laws. Both HCPs and NCCPs allow economic uses of land and water resources while also managing for the benefit of multiple species, and are typically approved for at least several decades. A key provision is the authorization of localized negative impacts ("take") to listed species, as long as the overall project is meeting requirements to protect these species (and in the case of NCCPs, improving their condition).

The Kern Water Bank is a good example of the HCP/NCCP approach.[130] This agreement authorizes the impacts the recharge project's operations (e.g., flooding, groundwater withdrawals, vegetation management, infrastructure construction) may have on listed species in recharge basins, given the protections put in place on other lands designated as sensitive habitat and conservation banks. Thus, the threat of regulation over listed species was addressed proactively, rather than becoming an ongoing risk. This proactive approach makes it easier to manage flexibly to enhance wildlife benefits, rather than managing to avoid attracting listed species into the area.

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[130] As of early 2017, there were a total of 24 HCP and/or NCCP projects within the eight San Joaquin Valley counties (Hanak et al. 2017, Table B4).

The Kern Water Bank HCP/NCCP may serve as a useful guide for other large-scale habitat programs—especially where land conversion may affect one or more endangered species. The HCP/NCCP process is expensive and protracted, however, making it less suitable for small projects. This highlights the advantage of countywide or even regional HCP/NCCPs in which individual landowners can participate—taking advantage of broader ecosystem planning and economies of scale in permitting costs.

Another tool to facilitate integrated regional management is the state Department of Fish and Wildlife's Regional Conservation Investment Strategy (RCIS). This pilot program authorizes investment strategies for terrestrial and aquatic species, as well as the creation of mitigation credits such as those used in the Kern Water Bank's conservation bank.[131] The program is intended to be a speedier alternative to the NCCP process, though without the regulatory assurances for specific activities. It is untested in the San Joaquin Valley, but is under exploration in Kern County as a way to help strategically manage future land conversions.

Simplifying Permitting of Restoration Projects

Restoration project proponents must currently go to multiple agencies to get permits, resulting in a lengthy and costly process.[132] In recognition of this problem, several state and federal agencies have established expedited permitting processes for some actions (Sustainable Conservation 2018). In some cases, it is also possible to reduce time and cost through programmatic permitting—issued on a regional basis for activities that are substantially similar in nature. Yet even with these options, there are many limitations: each agency has its own set of requirements about the size, place, and specific activities for covered projects. A broader, more inclusive approach is needed to simplify the permitting process.

The Habitat Restoration and Enhancement Act was a step in the right direction. This 2014 law limits the Department of Fish and Wildlife's evaluation and permitting timeline to 60 days for small-scale projects that improve fish and wildlife habitat. In the first two years, the department approved more than 24 restoration projects around the state with these expedited procedures (Sustainable Conservation 2016).[133]

Several environmental organizations, led by Sustainable Conservation, have also gained approval for expedited review of small-scale habitat restoration and improvement projects from a variety of state and federal agencies and large-scale projects with the National Marine Fisheries Service (NMFS) and the California Coastal Commission. These projects include salmon habitat and related uplands restoration, streambed and bank stabilization, invasive plant removal, and migratory bird habitat and wetlands improvements (Sustainable Conservation 2018).

Sustainable Conservation is seeking to broaden this effort through collaboration with the Army Corps of Engineers, the US Fish and Wildlife Service, and the State Water Board using the NMFS programmatic authorizations as a model. The objective is to expedite implementation of commonly proposed aquatic habitat restoration, water quality improvements, and related multi-benefit projects statewide. A similar effort would be invaluable for facilitating permitting for upland habitat projects in San Joaquin Valley.

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[131] Examples of potential conservation and habitat enhancement actions include: "land acquisition and protection, habitat creation and restoration, restoration of creeks and rivers, restoration of habitat on public land, installation of wildlife crossings and fish passage barrier removal" (California Department of Fish and Wildlife 2017).
[132] Examples include analysis of land use changes under the California Environmental Quality Act, permitting of activities that may affect waters and wetlands under the Department of Fish and Wildlife's lake and streambed alteration program, the US Fish and Wildlife Service and National Marine Fisheries Service reviews of habitat alterations that could affect listed species, and the Army Corps of Engineers' review of activities affecting wetlands under Section 401 of the Clean Water Act.
[133] The department must submit a report to the legislature on its use of the Habitat Restoration and Enhancement by December 31, 2020, and the statute will terminate on January 1, 2022, unless the legislation extends it (Fish & Game Code §§ 1656 & 1657).

Protecting Landowners from Regulatory Risk

It will also be necessary to better protect landowners from regulatory risk when stewarding fallowed cropland. One issue concerns the risk of listed species establishing themselves on these lands, which can lead to restrictions on how the land is used. This could be addressed with more active use of "safe harbor" agreements. Another issue is that costly mitigation could be required if landowners retire what is currently considered prime farmland. This will require removing inconsistencies between SGMA and the application of state and local farmland protections.[134]

Safe harbor agreements. Conversion of fallowed land into temporary habitat can bring regulatory risks for landowners if these lands attract listed species. Protecting farmers from these risks facilitates positive outcomes for both landowners and the environment. Safe harbor agreements with the state Department of Fish and Wildlife and the US Fish and Wildlife Service can address this risk. These agreements seek to promote the conservation of threatened and endangered species while assuring landowners that no additional regulatory burdens will be imposed on them for habitat improvements that attract listed species (US Fish and Wildlife Service 2009). Activities can include planting and maintaining native vegetation, controlling floodwaters, and protecting nesting and foraging areas. Safe harbor agreements typically measure a baseline condition and allow the landowner to return to it without penalty (Wilcove and Lee 2004). Neighbors of land enrolled in the program may also protect themselves from liability for taking species that stray onto their property.

There are currently just three such agreements in the San Joaquin Valley—versus 10 in the Sacramento Valley, including several covering multiple counties (Hanak et al. 2017, US Fish and Wildlife Service 2018). Expanding the use of safe harbor is essential for achieving multi-benefit stewardship on fallowed lands; without it, incentives remain strong for farmers to disk or spray these lands to make them less attractive to listed species—an approach that not only limits habitat and soil health benefits, but also increases risk of air quality problems (Table 4.1). One promising initiative, now in early stages, is the development of a programmatic safe harbor agreement to cover multiple species in the southern San Joaquin Valley. The Environmental Defense Fund is leading this effort.

Relaxing restrictions on the retirement of prime farmland. State and local laws that protect prime farmland could be in conflict with the need to convert large amounts of land to other uses. Most notably, the California Environmental Quality Act guidelines—as well as some local ordinances—require protecting farmland that has been used for irrigated agriculture in the recent past, and that meets certain soil quality standards.[135] Those wishing to convert such lands to other uses must fund the acquisition or protection of other prime farmland.

As described below, mitigation fees for land development can be a useful way to raise funds for acquiring and managing fallowed lands for multiple benefits. But mitigation requirements on prime farmland that is being transitioned to uses such as carbon storage or habitat stewardship—which generate less revenue—could have the opposite effect, by increasing the costs of managing these lands. Prime farmland protections may also be in direct conflict with SGMA's requirement to phase out groundwater overdraft. When cropland can no longer be irrigated because of a long-term water deficit within the basin, it should no longer be defined as prime farmland.

SGMA's implications for rural communities may make it necessary to reconsider or adjust other policies designed to protect agricultural communities. For example, it may be desirable to relax the requirements of the Solar Use Easement Act, which prohibits cities and counties from acquiring easements for solar installations on prime

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[134] Food safety is another area where regulations can pose challenges for restoring or preserving habitat in agricultural areas. The presence of wildlife can pose a real risk to neighboring farms' ability to comply with these regulations or related practices required by buyers. In a study focusing on the Salinas Valley, Gennet et al. (2013) show that the conversion of riparian habitat may be accelerating because of on-farm practices meant to promote food safety. As the authors note, produce buyers are pressuring growers to engage in land-use practices that are not conducive to wildlife and habitat conservation, in a scientifically questionable attempt to reduce risk of food-borne illness. They recommend an evidence-based, adaptive approach to manage farms for both food safety and ecological health.

[135] For a definition of prime farmland, see the Department of Conservation website.

farmland. In basins facing the prospect of significant cropland retirement, solar energy is one of the best opportunities for revenue generation, and prime farmland may at times be better located than other lands.

Financial Incentives

Stewarding water and land for multiple benefits will require funding. A variety of sources contribute to the restoration efforts examined above—surcharges on water use, mitigation fees paid by land developers, grazing fees from livestock owners, and state and federal grants. An even wider range of programs can be tapped to support this work going forward (Table 4.2). Some sources can provide long-term support (e.g., to acquire land or water rights or pay for ongoing management); others can help implement specific practices over a shorter period (e.g., temporary acquisition of water supplies, or installation of fences to manage grazing). And whereas some sources will only be available for the highest quality habitat—such as lands that host endangered species—many can support a much broader range of uses, including simple stewardship of fallowed lands with cover crops.

At this point it is difficult to estimate how much funding will be needed, or how much can be made available from each source. What is clear is that creative use of these funds can produce many stewardship opportunities. This includes tapping a variety of use fees—on water, land, and energy—as well as state and federal grants.

Water, Land, and Energy Use Fees

Water. The CVPIA restoration fee on water use—now about $10 per acre-foot for agricultural customers and $20 for urban and energy sector customers—supports a variety of stewardship efforts in the valley, from the wetlands refuges to San Joaquin River restoration, to restoration of dryland ecosystems. Surcharges on other surface water projects could make similar contributions elsewhere, for instance as part of negotiated settlements to improve river health on the San Joaquin River tributaries.[136] A new type of fee on groundwater use is likely as part of basin balancing: GSAs are authorized to charge users to cover the costs of supply and demand management programs. As noted above, one innovative idea being explored by a Kern County water district is to use these funds to acquire land, and retire the associated groundwater allocation (Pottinger 2018a). This approach gives farmers flexibility to pump more than their allocations, and lets the district find the most suitable lands to retire, ideally where it can get multiple benefits such as recharge or habitat.

Land. Livestock grazing on idled lands is an important tool for vegetation management; grazing fees can also bring in modest revenues to support land management. Mitigation requirements for various types of land development (including solar installations) are already used in the valley to acquire habitat, and may be particularly useful for managing lands to support endangered species.

Energy. The market for carbon credits—where energy users pay others who can reduce greenhouse gas emissions or store carbon more cheaply—has potential to fund numerous land stewardship practices under discussion here. Riparian forest restoration, rangeland management, and planting cover crops on idled lands can all store carbon.[137] Today, credits for these nature-based carbon storage activities are mainly limited to private, voluntary markets. But the approach could expand significantly if California authorized these activities as a way to offset emissions under its cap and trade program for large emitters required to reduce emissions.[138]

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[136] As a local agency example, the Sonoma County Water Agency uses a surcharge on water sales to support stewardship of the Russian River (Hanak et al. 2014).
[137] Matzek et al. (2015) show that even at today's low carbon prices, the carbon value of floodplain forests is high enough to offset restoration costs. Dass et al. (2018) show that grasslands and rangelands may be even more effective than forests at carbon storage.
[138] The state currently authorizes forestry projects to offset emissions, but not land management (California Air Resources Control Board 2015).

TABLE 4.2

Funding sources for land and water conservation in the San Joaquin Valley

Source	Description	Current or potential stewardship uses
Water, land, and energy use fees		
Surface water diversion fees	Fees assessed on water use (e.g., Central Valley Project Improvement Act restoration fee, some local agency fees)	▪ Acquisition of water for environmental flows ▪ Land restoration in riparian corridors (e.g., San Joaquin River restoration) and upland areas
Groundwater pumping fees	Fees assessed by groundwater sustainability agencies to fund supply and demand management projects (e.g., Orange County Water District)	▪ Acquisition of land to retire the associated groundwater allocation
Grazing fees	Rental payments from livestock owners to graze their animals on range, retired land	▪ Vegetation management on retired land, plus (limited) income to cover other management costs
Development mitigation requirements and fees	Requirements to offset loss of open space from land development (e.g., new housing, solar, transportation projects) under federal, state, and local ordinances—sometimes administered through assessment of fees	▪ Acquisition of land in areas with high habitat value (e.g., presence of listed species) ▪ Can be used to consolidate habitat, e.g., with conservation banks, Central Valley Habitat Exchange
Carbon credits	Program that allows energy users to offset greenhouse gas emissions (GHG) by purchasing credits that fund other parties to reduce emissions or store carbon	▪ Support for land conservation investments that store carbon (e.g., grasslands, riparian forests); state authorization required for credit under state GHG regulations
State and federal grants and credits		
State habitat conservation grants	Wildlife Conservation Board (WCB) and Department of Fish and Wildlife grants to local agencies, non-profits, and individual farmers, principally funded by state general obligation bonds	▪ Acquisition of land and water for fish and wildlife habitat (WCB) ▪ Long-term (25 year) support for various habitat conservation investments on land (Ecosystem Restoration on Agricultural Lands program of WCB) ▪ Support for various land and water habitat conservation investments (Department of Fish and Wildlife)
State and federal habitat conservation tax credits	Reduced property tax assessments for land donations for ecological or open space uses (e.g., Natural Heritage Preservation Tax Credit Program, Open Space Easement Act), funded by reductions in state general fund; federal income tax credits for similar purposes	▪ Permanent land acquisition or dedication (through easements) for habitat ▪ More limited use to date for water rights acquisition
State farm stewardship grants	Department of Food and Agriculture grants to farmers for practices that will reduce greenhouse gas emissions (water efficiency, healthy soils, manure management), funded by state revenues from cap and trade program	▪ Short-term support for land conservation investments (healthy soils, habitat restoration that stores carbon, e.g., grasslands, riparian forests)
US Department of Agriculture (USDA) resource conservation grants	Natural Resources Conservation Service and Farm Services Agency grants to individual farmers and in some cases local agencies and other groups for resource stewardship (e.g., air quality, soil health, water conservation, wildlife habitat, etc.), funded by federal Farm Bill	▪ Permanent land dedication (through easements) to restore wetlands or to protect agricultural recharge areas from development (Ag. Conservation Easement Program) ▪ Medium-term (10–15 year) rental payments and conservation investments for land stewardship (Conservation Reserve Program, Conservation Reserve Enhancement Program) ▪ Short-term (1–3 year) support for various conservation investments on fallowed land (Environmental Quality Improvement Program)
State groundwater sustainability grants	Department of Water Resources grants to GSAs and other local entities to support sustainability, funded by state bonds	▪ Support for land acquisitions and ongoing stewardship as part of groundwater demand management programs

SOURCES: Compiled by the authors from various sources.

NOTES: Some programs are not yet used for the purposes shown (see text). Technical Appendix F provides information on USDA grants.

State and Federal Grants and Tax Credits

Habitat conservation. In recent years, voter-approved state general obligation bonds have made hundreds of millions of dollars available for ecological stewardship grants to local agencies, non-profit organizations, and farmers. These programs—generally administered through the Wildlife Conservation Board and the state Department of Fish and Wildlife—can fund the acquisition of land and water rights, as well as investments in habitat restoration. Some awards are competitive statewide; others are specifically earmarked for use in the valley.[139] Several state programs also provide landowners with property tax credits for dedicating land to habitat, and federal income tax deductions are available for donations of land and, in some limited cases, water rights.[140] Private individuals and businesses can also make tax deductible donations to support land acquisitions and ongoing stewardship activities of local agencies and nonprofits.

Farmland and rangeland conservation. State and federal programs also support farmers—and sometimes local agencies and nonprofits—to steward their lands. The state programs—administered by the Department of Food and Agriculture—are relatively recent, and funded by the cap and trade program and bonds. The fiscal 2019 budget includes $20 million statewide (Shobe and Merrill 2018). Federal programs have been in place for decades under the Farm Bill; from 2012–17 they provided an annual average of nearly $155 million statewide, and $50 million within the San Joaquin Valley.[141] They are administered by two services within the US Department of Agriculture: the Natural Resources Conservation Service (NRCS) and the Farm Service Agency (FSA).

State and federal programs both emphasize investments on active cropland, including the installation of low-water irrigation systems. As described in Chapter 2, such investments help improve crop productivity and water quality, but they do little to address groundwater deficits because they mainly reduce the water applied to fields, not the amount consumed by crops. To reduce greenhouse gas emissions, the state has begun supporting biodigesters to convert dairy methane to energy, and USDA has issued many grants to replace old diesel engines to improve air quality.

These programs could also support the management of fallowed lands to provide wildlife habitat and minimize undesirable consequences, such as the loss of soil health or the proliferation of invasive weeds. For example, state programs to reduce greenhouse gas emissions could support fallowing practices designed to build healthy soils and restore vegetation that stores carbon and provides habitat value, such as grasslands and riparian forests (Dybala et al. 2018b).

USDA programs could also be used for a wider range of purposes, from permanent easements to restore wetlands or to protect agricultural recharge areas from development, to extended rental payments on fallowed lands, to short-term support for various conservation investments on these lands.[142] Changes introduced with the 2018 Farm Bill will increase USDA's capacity to provide this help.[143] Additional changes in program rules could be helpful. In particular, designating groundwater depletion as a resource concern would give NRCS more flexibility to craft suitable support packages. Assistance to some growers would also be restricted by income limits under

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[139] For instance, Proposition 68, approved in June 2018, set aside $200 million for restoration of Central Valley rivers, including the San Joaquin River tributaries.

[140] For federal programs on land donations, see Land Trust Alliance (n.d.). For water rights, see Hicks (2011), who notes that tax deductions for water rights have been one-off transactions.

[141] See Technical Appendix F for a detailed discussion of these USDA programs.

[142] Nation-wide, USDA conservation programs already support stewardship of lands that are temporarily retired or protected under longer term easements. Some western states—including Colorado, Idaho, Kansas, and Nebraska—have used the Conservation Reserve Enhancement Program (CREP), which involves joint federal and state funding, as a mechanism to idle land to reduce irrigation water use.

[143] Funding for the Environmental Quality Incentives Program (EQIP)—the largest conservation program in the valley—has been increased, and the program is now available to support projects by local water management agencies and associations as well as farmers. Funding has tripled for the innovative Regional Conservation Partnership Program, which leverages public and private dollars to tackle regional conservation challenges, and the application process has been simplified. And throughout the Farm Bill, conservation program descriptions have been updated to include soil health and carbon sequestration as targeted outcomes.

most programs. But the key action needed is a concerted request from the state and local stakeholders that USDA use its programs to help the region's farmers to make beneficial land transitions as it addresses scarcity.

Groundwater sustainability. State grants to help implement SGMA could also support the stewardship of lands coming out of production. Such grants could also be used for USDA programs that require a state match.[144]

Pooling Resources and Incentivizing Landowner Decisions

With so many potential funding sources, people will need to be strategic to make the dollars count. Pooling funds from several sources will often be necessary to cover both up-front investments and ongoing stewardship. Aligning funds with planning goals will also be important to encourage farmers to direct their land conversion decisions toward the best locations, with the most suitable array of stewardship practices. A voluntary, incentive-based approach will discourage piecemeal land fallowing, while leaving the ultimate decisions to farmers.

Another key consideration regarding grower incentives is the value of the water on fallowed lands. Some landowners may be willing to sell their properties outright—along with the groundwater allocations attached to them. This is the model being considered in Kern County and elsewhere as a way to implement demand management, described above. However, many growers are likely to be more interested in participating in stewardship programs if they can maintain their groundwater credits to use on other lands they farm, in addition to their surface water allocations.[145] For them, conservation easements to manage the fallowed lands would be more attractive options than outright sales.[146]

Technical Support

Landowners and other stakeholders will also need technical help to implement stewardship strategies. Because there is still much to learn about the best ways to manage water and land resources for multiple benefits in the valley, this support will need to include piloting and testing of different approaches—for example, cost-effective approaches to restore habitat for desert wildlife, grazing techniques that generate desired habitat conditions, and water efficient approaches to maintain soil health. Third-party "honest brokers"—entities and individuals who can provide scientific and engineering expertise and identify common ground among landowners, regulators, and local governments—can be especially valuable for this work.

Resource Conservation Districts (RCDs) are one such entity. RCDs are special districts that engage in on-the-ground conservation efforts with farmers and other stakeholders. They are primarily funded by grants and private contributions. RCDs have served as an important bridge between NRCS programs and private landowners (California Association of Resource Conservation Districts 2005). They could play a major role in supporting collaborative land transitions in the San Joaquin Valley. But this will require an infusion of resources; the annual budgets of the valley's RCDs are some of the lowest in the state, and many parts of valley counties are not currently covered by RCDs (Figure 4.4). Some of the sources identified above can help fill the funding gap, and planning can help organize the expansion of RCD coverage.

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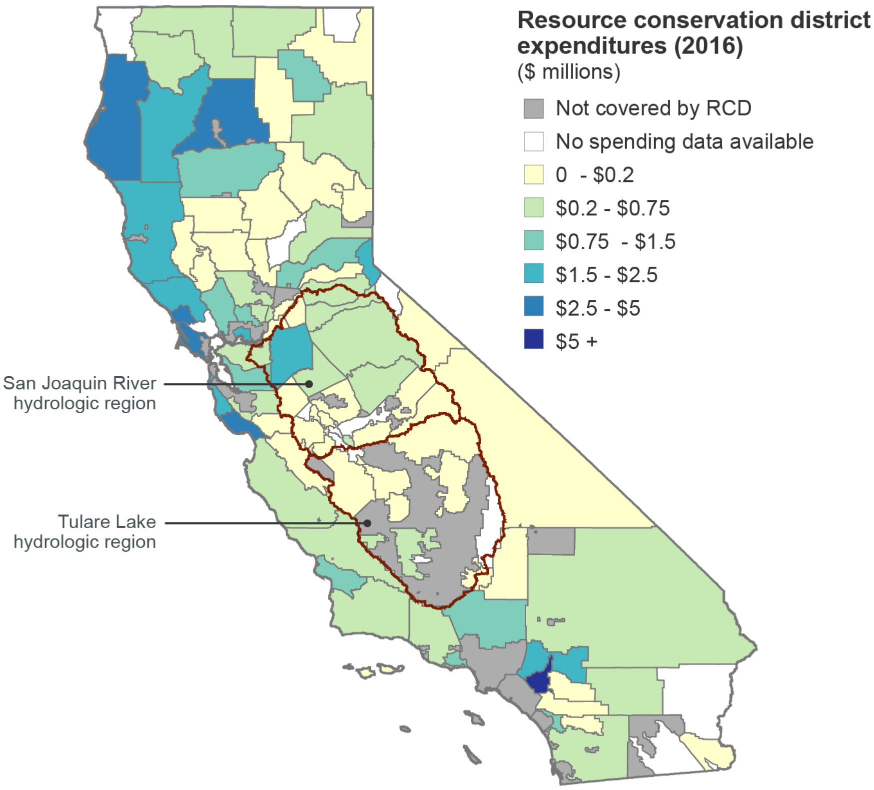
[144] The CREP program—which provides 15-year rental payments and management support to steward non-irrigated lands—requires state matching grants.
[145] In some water districts, growers have a similar concern regarding their right to maintain control of surface water allocations associated with fallowed land.
[146] The "water cooperative" idea, described in footnote 129, would also maintain these incentives while allowing outright land sales to the cooperative.

FIGURE 4.4
Resource conservation districts in the San Joaquin Valley have very little funding, and many uncovered areas



SOURCES: RCD maps: Cullinen (n.d.). Spending: State Controllers' Office accounts for fiscal year 2016.

Supplementary funding for other types of technical support will also be needed. This includes the NRCS and the UC Cooperative Extension and Farm Advisor system, which currently have too few environmental specialists in the San Joaquin Valley. Environmental non-profits are another important resource for technical analysis on habitat suitability and on-the ground support for specific restoration activities. State and federal wildlife agencies will need more experienced in-house professionals able to oversee conservation projects and coordinate with stakeholders.

Looking Forward

Effectively addressing water stress and land use changes in the San Joaquin Valley offers opportunities to put lands coming out of production to good use, use environmental water more efficiently and effectively, and ease the transitions that are coming as SGMA is implemented. Multiple benefit approaches can be targeted to yield enhanced groundwater recharge, improved air and water quality, healthier soils, new recreational opportunities, additional flood protection, improved habitat, and new revenue streams for private landowners engaging in conservation-oriented management. But adopting such approaches will require valley stakeholders to engage in much broader and more comprehensive planning for the management of the region's lands than ever before. Here are a few takeaways for approaching this effort:

- Decision making about how best to manage the changes coming to the valley will be done at many levels, ranging from individual farms and irrigation districts to GSAs and county planning bodies. Fragmentation is a challenge—especially in basins with many GSAs. Creating effective and practical pathways for improved communication and coordination at all levels will be essential.

- Achieving multiple benefits from retired lands—in terms of public health and the natural environment—will depend on the level of stewardship and coordination. Determining how best to achieve coordinated land retirement and bring multiple benefits will require a significant upfront investment in building trust in the process. A regional planning exercise to review the possibilities—along with the risks of inaction—and seek broad consensus on best practices for managing idled lands could be a useful early step. This regional perspective is also essential for coordinating programs that incentivize landowners and GSAs to target fallowing in prime habitat areas for targeted species.
- Creating targeted approaches to address key issues is one way to break down what might seem to be a daunting planning effort. For example, focusing on multiple benefit approaches for recharging groundwater and managing floods could offer a starting point for broader planning around supply augmentation under SGMA. Creating groups to work on issues such as regulatory flexibility could also help.
- Finding opportunities to build on early successes and make greater use of existing stewardship tools is another way to build confidence in these processes.

Finally, creating a cohesive "multiple benefits plan" for the valley is a lofty goal that brings big opportunities, but also major challenges. Various kinds of support—planning expertise, outreach, facilitation, financial, and more—will be needed to advance the necessary planning efforts, involving broad stakeholder engagement. Beyond financial help, state and federal support for regulatory flexibility will be needed to create the large-scale multi-benefit projects that arise.

Chapter 5. Roadmap to a Better Future

The San Joaquin Valley is at the epicenter of many of California's most difficult water management problems. The region has a large groundwater deficit. Groundwater quality continues to decline, affecting drinking water supplies and agricultural productivity. And the valley's riverine, wetland, and upland ecosystems are under severe stress, with a growing number of vulnerable species. Dealing with these difficult issues requires significant changes in water and land management. The entire region—and California as a whole—will benefit if solutions to the valley's problems support the economy while improving public health and the natural environment.

Implementation of the Sustainable Groundwater Management Act (SGMA) is the catalyst for this inevitable change. Reliance on long-term over-pumping of groundwater to fill the gap between water supplies and demands is no longer an option. The costly consequences of overdraft are on the rise: dry wells, land subsidence that damages infrastructure, increased energy use to pump water, and reduced water reserves to cope with future droughts. And although bringing basins into balance is now required by state law, the rising costs of overdraft make groundwater management necessary for the valley under any circumstances.

The water-related challenges facing the valley did not arise overnight. And some traditional management approaches have reached limits in what they can achieve in isolation. For example, traditional species conservation efforts have protected some species from extinction, but have failed to develop an array of habitats that support healthy populations of native plants and animals. Efforts to address groundwater pollution are still being developed, but it's already clear that there is a need for more urgent emphasis on treatment and mitigation, not just pollution prevention. Bringing groundwater supplies and demands into balance will require more integrated approaches to water and land management. This offers new opportunities to tackle water supply, quality, and environmental challenges jointly.

In this report we have identified approaches for coping with water scarcity in the valley while also tackling a range of related water quality and ecosystem issues. Our analysis explored how traditional resource management approaches can be enhanced or supplemented to address new challenges. We find that the best solutions increase flexibility, provide incentives, acknowledge linkages, and leverage the potential for achieving multiple benefits.

For instance, flexible approaches to groundwater basin management—allowing trading and banking of supplies for dry years and crediting those who invest in recharge—can lower the costs of reducing overdraft. Co-managing groundwater quantity and quality—with attention to the recharge capability of soils—can augment supplies while limiting nitrate contamination. Considering the habitat potential of idled lands can avoid air quality and weed problems while benefitting the natural environment. And fostering flexible, realistic, multi-benefit approaches to managing ecosystems can reduce conflict over environmental management while improving its effectiveness.

The issues facing the valley are complex and will require a comprehensive response, implemented over decades. A significant effort and investment in the success of SGMA is needed from all levels of government, farmers, local communities, and other stakeholders. Although the task at hand is a heavy lift, changes need not happen overnight. The key is to start building the elements that will put the valley on a path to sustainable management for the long run.

Priorities for Action

This report breaks down the water and land management challenges facing the valley into three solution-oriented categories: (1) balancing water supplies and demands, (2) addressing groundwater quality challenges, and (3) fostering water and land use transitions to benefit people and nature. Here we recap key findings and summarize priorities for local, regional, state, and federal entities.

Balancing Water Supplies and Demands

A central task for local entities under SGMA is to bring groundwater supplies and demands into balance. Chapter 2 analyzed strategies that could help close this gap, including investing in new surface and groundwater storage, incentivizing urban water conservation, reducing water use on farms, and increasing water trading. We find that a portfolio approach—combining cost-effective supply investments and water trading to help farmers manage demands—is most promising. Supply investments—particularly to increase capture and underground storage of local runoff from big storms—could fill roughly one-quarter of the historical groundwater deficit of 1.8 maf/year. Closing the remaining gap will require reducing net farm water use, with more than 500,000 acres of irrigated cropland coming out of production. Facilitating local surface and groundwater trading within basins is essential to avoid the costliest reductions of nut, fruit, and vegetable acreage. Expanding surface water trading within the valley to allow water to move across basins to more profitable uses could significantly further reduce the costs of using less water. Overall, the decline in regional GDP and employment from ending groundwater overdraft would be about 40 percent lower with this combined supply and demand portfolio than without it.

Here are the institutional and regulatory actions needed to implement this portfolio approach.

Priorities for Local and Regional Action

Strengthen basin accounting. Formal, standardized, and transparent accounting systems are foundational to many promising actions. For instance, Groundwater Sustainability Agencies (GSAs) will need to set up incentives to avoid overpumping. An effective way to do this is to allocate shares of groundwater that each user can pump—similar to the practice in adjudicated basins. Such a system can facilitate local groundwater trading, and be employed to charge water users who pump more, with the revenues supporting projects that increase supply or reduce demand. Strong accounting—with standardized methods for tracking recharge as well as withdrawals—is also needed to incentivize recharge projects, including private sector investments in water banking and on-farm recharge. GSAs have the frontline responsibility for groundwater accounting, but DWR can promote good accounting standards.

Assess infrastructure needs. Expanding local and regional infrastructure for water conveyance and surface storage may be necessary to facilitate recharge and take full advantage of water trading opportunities. Land subsidence from excess groundwater pumping has reduced the capacity of two of the valley's critical conveyance arteries: the Friant-Kern Canal and the California Aqueduct. These reductions limit the ability to move water from the wetter northern part of the valley to the drier south, where demand for new supplies is highest and conditions for recharge are most suitable. Investments in new east-west conveyance may also be warranted, along the lines of Kern County's Cross-Valley Canal. State and federal agencies will be essential partners in these efforts, but regional and local entities that own and operate storage and conveyance infrastructure can play a critical role in helping to assess system capacity issues and potential. Local managers will also need to evaluate which augmentations of their own capacity—including recharge basins, surface reservoirs, conveyance, and other tools—are warranted.

Incentivize on-farm recharge. One of the least costly ways to expand recharge is by spreading water on suitable fields when excess flood flows are available. This strategy has great potential, but it is still in early stages of adoption. Farmers could be incentivized to recharge on their lands in exchange for a "SGMA credit"—for example, the ability to pump some of this water in the future. GSAs should develop crediting systems in water or cash. This will require more formal, standardized water accounting systems and groundwater budgets.

Develop local trading rules. Water trading is already common in the valley, both at very local scales and across wider distances. Expanding valley-wide trading of surface water is one of the best ways to lower the costs of managing demand. SGMA also presents a new opportunity to trade groundwater locally, another way to help water users manage scarcity in overdrafted basins. To reap these benefits, local water districts and GSAs will need to develop a healthy trading culture, with rules that ensure transparency and fairness. Farmers and water managers who have participated in water trading can play a key role in talking to others about how this can work. For groundwater trading, formal accounting—including allocations for individual users—will also be essential.

Coordinate to maximize benefits. Implementing a portfolio approach is the most cost-effective way to balance supplies and demands. But to reap the most benefits from recharge, trading, and other tools, local entities will need to collaborate both within and across basins. This will require overcoming fragmentation: the valley now has more than 120 GSAs for its 15 groundwater basins. Collaborative efforts to bank groundwater with other parties will enable recharge to occur in the most suitable areas and can help districts with poor local recharge conditions balance their groundwater accounts. The process generally requires the parties to have a physical connection through a shared aquifer or conveyance.

Priorities for State and Federal Action

Clarify how much water is available for recharge. The State Water Board should develop a straightforward, expeditious process to enable water users to capture high-flow surface water when it is available. Beyond the legal aspects of establishing new rights, an essential part of this process is technical: developing a simple, rapid way to determine when flows on local rivers exceed water required for the environment and downstream users. Having the ability to make these decisions quickly is critical, given the flashy nature of these river systems: high flows occur infrequently and tend to be concentrated in a few weeks or months. An expeditious, transparent process is necessary to support recharge investments.

Facilitate approvals for trading and banking projects. Limitations in conveyance infrastructure are compounded by difficulties in securing state and federal permits for surface water trades and groundwater banking. Although it is important to ensure that trading and banking do not harm other water users or the environment, it is difficult to receive approvals for these activities in a timely manner. New administrative approaches are needed to simplify the approval process—such as through programmatic environmental reviews and preapprovals of some types of trades.

State and federal agencies should also work with local water agencies to facilitate the consolidation of places of use assigned to different water rights to provide blanket permitting for regional water sharing. A useful model is the temporary consolidation of place of use for the CVP and the SWP within the San Joaquin Valley during the past two droughts, which enabled farmers to trade more freely. These agencies can also facilitate the development of off-site groundwater banks, which face many of the same constraints as water trades, including timely approvals to use conveyance infrastructure and authorization to store and use water in the most suitable locations.

Modernize infrastructure operations. In addition to addressing infrastructure gaps, there is a need to rethink how infrastructure is operated, to manage groundwater and surface storage together to increase their joint potential to store more water. This includes reducing the water held in surface reservoirs in the fall—and getting this water into the ground—to increase reservoir storage capacity during the wet season. It also includes updating dam operations to work with advanced weather forecasting technology. These approaches will be increasingly important with a warming, more variable climate, which is likely to concentrate winter and spring runoff in shorter periods. Analysis of new surface storage opportunities should also be considered in this light. State agencies—especially DWR and the State Water Board—should lead the modernization of reservoir operations. Various federal agencies, including the Army Corps of Engineers, the US Bureau of Reclamation, and the Federal Energy Regulatory Commission, will be essential partners in reoperating the system.

Addressing Groundwater Quality Challenges

In addition to water shortages, the valley also faces complex groundwater quality challenges that are intricately linked to agricultural land and water use. Chapter 3 considered ways to tackle these challenges, with a focus on providing safe drinking water—the most pressing issue—and managing long-term salt and nitrate loading on farmland. Nitrate in drinking water is a major public health concern. And agricultural productivity is threatened by the accumulation of salts in groundwater and soils. A balance must be found between protecting water and land resources for the long run and maintaining the viability of agriculture in the present, while also ensuring safe drinking water solutions. Finally, expanding groundwater recharge will require attention to water quality, to manage potential trade-offs when recharge risks moving nitrate and other contaminants into the water table.

Here are the institutional and regulatory actions needed to address these challenges.

Priorities for Local and Regional Action

Support solutions to the safe drinking water crisis. The valley is home to roughly half of the public water systems that do not provide safe drinking water to their customers in California, and the water in many domestic wells is also unsafe. This issue—which primarily affects poor, rural residents—requires urgent solutions. Providing economies of scale to small water systems shows the most promise. This includes consolidation with larger systems—or making other institutional arrangements to aggregate smaller systems and promote sharing of technical, financial, and managerial expertise. New regulations will require agricultural and urban dischargers to provide safe drinking water solutions in areas most affected by nitrate. Counties, urban water systems, and local nonprofits will also need to collaborate with affected rural communities and contribute technical and managerial expertise.

Mitigate dry wells. Some rural residents are also at risk from shallow drinking water wells going dry as groundwater levels fall. During the last drought, three-quarters of all residents who lost water supplies were in the San Joaquin Valley. To ease the burdens on the regional economy, most GSAs are likely to implement SGMA by making gradual reductions in excess pumping until 2040. As a result, continued lowering of the water table is likely. Flexible rules that allow more pumping during droughts could also benefit the regional economy, but would cause groundwater levels to fall further. Rural communities with shallow supply wells and households with domestic wells will be the most affected. GSAs should develop plans that anticipate these problems, map wells most likely to be affected, and employ strategies to ensure that rural communities do not lose drinking water supplies. State and county agencies should support this planning effort. Some models for mitigation exist in Kern and Yuba counties.

Coordinate water quality and quantity management. Under SGMA, GSAs must manage groundwater in a way that avoids harming water quality. As GSAs develop and start implementing their plans, they should consult with various entities responsible for groundwater quality. In addition to individual agricultural, industrial, and municipal dischargers, key partners include the Irrigated Lands Regulatory Program coalitions, Dairy Cares, and the nitrate management zones that will be formed to implement the valley's new Salt and Nitrate Control Program. Early coordination could help GSAs develop recharge projects that minimize harm—and potentially improve water quality near vulnerable local communities. Over time, there is also potential to coordinate land retired to reduce water use and to manage salinity.

Implement new technologies to manage pollutants, especially for dairies. Valley agriculture will need continued improvements in technologies and practices to manage nitrogen and salts. Dairies—a large economic sector—face major challenges in managing manure, which causes air pollution and greenhouse gas emissions in addition to nitrate in groundwater. The valley's dairies produce enough manure to fertilize a significant share of the state's cropland, but manure is heavy to transport and difficult to apply precisely. Advances are needed to improve the efficiency of manure fertilization on dairy cropland, and to develop environmentally safe, cost-effective manure-based fertilizer products that can be marketed to other farms.

Priorities for State and Federal Action

Ensure funding for safe drinking water. Funds for capital investments are available from several state and federal programs. But a key challenge for communities without safe drinking water is the lack of funding to support ongoing operations and maintenance of their water systems, especially when they need new treatment plants. Several bills have been proposed in the California Legislature to fill this gap, but an enduring solution has remained elusive. State leadership is needed to establish a reliable funding source.

Provide regulatory flexibility. Groundwater recharge is one of the best options to increase usable water supplies in the valley. But some recharge practices have the potential to flush legacy pollutants present in the soils deeper into the aquifer, causing temporary spikes in groundwater contamination. Fertilizer management will also be needed to safely recharge groundwater on active cropland, a potentially cost-effective way to capture high winter and early spring flows. Managed properly, groundwater recharge could improve groundwater quality over time. To facilitate recharge and maintain the viability of valley agriculture, state and federal water quality regulators should allow for some continued nitrogen and salt loading as long as impacts on rural community drinking water supplies are mitigated. This approach is consistent with the new regional regulatory plan.

Fostering Water and Land Use Transitions to Benefit People and Nature

Effectively addressing water scarcity and the resulting land use changes in the San Joaquin Valley offers opportunities to put lands coming out of production to good use—and gain more "pop per drop" from limited land resources. Chapter 4 explored how to harness the impending changes to generate multiple benefits for people and the natural environment. Multiple-benefit approaches to water and land management can yield enhanced groundwater recharge and improved air and water quality. They can also promote healthier soils, and provide new recreational opportunities, additional flood protection, improved habitat, and new revenue streams for private landowners engaging in resource conservation.

An approach called "reconciliation ecology" offers opportunities to improve the natural environment while managing changes coming to the valley. Rather than focusing solely on protecting or restoring natural areas, reconciliation ecology emphasizes strategies that increase the habitat value for native plants and animals living outside of traditional protected areas. It also holds promise for reducing conflict over the use of water and land for ecosystems and species.

Stewarding the valley's water and land resources to benefit people and nature will not need to start from scratch. But making it work well will require new ways of thinking, creative application of existing tools, and some regulatory changes. Adopting this approach will also require valley stakeholders—together with their state and federal partners—to engage in much broader and more comprehensive planning than ever before.

Here are the actions needed to foster water and land management for the benefit of people and the environment.

Priorities for Local and Regional Action

Undertake comprehensive land use planning. Today most land use planning is in the hands of city and county governments. Counties can play an important role in planning for broader benefits, helping cities to map out their expansions carefully and reducing the costs to landowners of participating in conservation efforts. GSAs can also work with environmental nonprofits to plan for retirement of the most suitable lands.

But to make the most of the changes coming with SGMA, planning should be broadened to the entire region. Coordinated planning at the level of groundwater basins, counties, and the region will be critical to protecting lands suitable for recharge and determining which potential recharge lands might reduce groundwater quality. And since most ecological processes operate at the regional scale, restoration decisions are best made regionally. This is also an appropriate scale for mapping the most suitable lands for solar development (e.g., near existing transmission systems), and for considering some groundwater recharge investments (e.g., expanded conveyance) and the potential retirement of salinity-impacted lands. To do this level of planning, a new kind of organization is needed. We propose the establishment of a multi-county authority that covers the entire region and receives funding from both state and local sources for its activities.

Plan for and manage ecosystem water differently. Regional planning is also needed to better manage scarce water for the valley's river and wetland ecosystems. Valley water users and other stakeholders should work with regulators to develop watershed level plans that consider how to use ecosystem water most effectively in different types of water years, and how to make complementary investments in habitat and other actions to reduce stress on key species. Local parties should also participate in negotiated settlements with regulators to manage ecosystem water differently. We propose creating ecosystem water budgets for this purpose (see below). Multi-party settlements harness the potential for creative solutions that go beyond requirements from regulatory agencies.

Provide incentives and funding. A voluntary, incentive-based approach that targets the best lands to fallow will discourage piecemeal land fallowing, while leaving the ultimate decisions to farmers. Local fees on land and water use—including county mitigation fees for land development and new groundwater pumping assessments—can help fund the acquisition and management of fallowed lands in areas most suitable for providing multiple benefits. Irrigation district and GSA rules should be flexible regarding the use of water from fallowed lands. Rather than selling their land (and the associated groundwater credits), some growers may prefer to maintain ownership of fallowed lands and use the water credits on other lands they farm.

Priorities for State and Federal Action

Implement an ecosystem water budget approach. Current practices that rely on minimum instream flow and water quality standards do not provide enough flexibility to support freshwater ecosystems. Granting ecosystems a water budget that is managed like a water right is a promising approach. The water within this budget could be flexibly managed, stored, and traded. This approach allows environmental managers to prepare for drought and to have assets for response. It will create new opportunities for partnerships with other water users, and can help reduce conflict over scarce supplies. Although they could benefit from additional flexibility, the water allocations for Central Valley wildlife refuges and restoration efforts on the San Joaquin River illustrate the value of such an approach. The State Water Board, with legislative support, should set ecosystem water budgets as part of its water quality control plan for the Delta and its watershed.

Increase regulatory flexibility. To foster creative, beneficial management of water and land use transitions, parties need more flexibility for project design and implementation. State and federal agencies should encourage the adoption of broad planning processes, such as Habitat Conservation Plans; simplify the permitting of restoration projects; encourage the use of "safe harbor agreements" to protect farmers engaged in habitat management from regulatory sanctions if their fallowed lands attract listed species; and relax mitigation requirements on prime farmland that is being transitioned to uses such as carbon storage and habitat stewardship.

Expand technical assistance and research support. There are many open questions about restoration at the scale predicted under SGMA. Technical assistance from third-party honest brokers such as resource conservation districts, environmental nonprofits, and state and federal advisors can be invaluable—but is currently underfunded. State and federal governments should also support research on important questions to guide conservation and idled land management in the valley. Key issues that will benefit from greater research and technical assistance include finding cost-effective approaches to restore habitat for desert wildlife, water-efficient approaches to maintaining soil health (e.g., cover crops that require little or no irrigation), and grazing techniques (e.g., best livestock types and grazing regimes) that can generate desired habitat conditions and offset management costs.

Provide incentives and funding. An array of funding sources could be used to support land and water conservation efforts, including fees on water, land, and energy use, as well as state and federal grants and tax credits. State and federal governments should play a key role in incentivizing desirable land idling and conversion in the valley. Current farm and ranchland conservation programs provide considerable funding for resource stewardship activities. But the valley now requires more concerted approaches focused specifically on the new challenges posed by SGMA. In addition to some state programs, the new Federal Farm Bill has significant potential in this regard. We propose the development of a new state-federal partnership to fund land retirement and restoration.

Managing Change for a Prosperous, Healthy Valley

San Joaquin Valley farmers and residents have a history of creatively adapting to difficult and changing conditions. Today’s challenge is to find practical ways to manage unavoidable water scarcity and quality problems to protect public health, maintain economic prosperity, and improve the natural environment. The San Joaquin Valley’s economy has been deeply dependent on irrigated agriculture for more than a century. To continue on a prosperous path for the next century will require balancing groundwater accounts, tackling water quality challenges, and taking advantage of opportunities to get multiple benefits for people and nature from limited water resources and lands coming out of production.

Perhaps one of the region’s greatest challenges is developing new cooperative approaches to seize these opportunities. The solutions to the valley’s problems do not fall neatly into the traditional political and institutional boundaries. The issues are complex, and many players will need to be involved in the solutions. Addressing this suite of issues will require a well-planned, comprehensive response and an all-hands-on-deck level of cooperation and participation.

Although state and federal partners can help, the valley’s future is in the hands of its residents. A valley-wide conversation on the changes that lie ahead can help determine how to tackle the challenges outlined here and take the next steps for creating a better future. The stakes are high. So are the costs of inaction.

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ABOUT THE AUTHORS

Ellen Hanak is director of the PPIC Water Policy Center and a senior fellow at the Public Policy Institute of California, where she holds the Ellen Hanak Chair in Water Policy. Under her leadership, the center has become a critical source of information and guidance for natural resource management in California. She has authored dozens of reports, articles, and books on water policy, including *Managing California's Water*. Her research is frequently profiled in the national media, and she participates in briefings, conferences, and interviews throughout the nation and around the world. Her other areas of expertise include climate change and infrastructure finance. Previously, she served as research director at PPIC. Before joining PPIC, she held positions with the French agricultural research system, the President's Council of Economic Advisers, and the World Bank. She holds a PhD in economics from the University of Maryland.

Alvar Escriva-Bou is a research fellow at the PPIC Water Policy Center. His research explores integrated water, energy, and environmental resources management, including systems approaches, simulation and optimization of economic-engineering models, and climate change analysis. Previously, he worked as a civil engineer, managing and developing large infrastructure projects for local and regional governments and consulting firms in Spain. He holds a PhD and MS in water and environmental engineering and a BS in civil engineering from the Polytechnic University of Valencia in Spain, as well as an MS in agricultural and resource economics from the University of California, Davis.

Brian Gray is a senior fellow at the PPIC Water Policy Center and professor emeritus at the University of California, Hastings College of the Law in San Francisco. He has published numerous articles on environmental and water resources law and coauthored a variety of PPIC reports, including the 2011 interdisciplinary book on California water policy, Managing California's Water: From Conflict to Reconciliation. He has argued before the California Supreme Court and the US Court of Appeals in cases involving wild and scenic rivers, water pricing reform, takings, and water rights and environmental quality. He is a recipient of the William Rutter Award for Excellence in Teaching and the UC Hastings Outstanding Professor Award. He holds a JD from the University of California, Berkeley, and a BA in economics from Pomona College.

Sarge Green is currently the interim director of the Center for Irrigation Technology at Fresno State. He has been with the water programs at Fresno State since 2007. Prior to that, he was general manager of Tranquillity Irrigation District in western Fresno County for 18 years, and before that worked for 13 years at the California Regional Water Quality Control Board, Central Valley Region.

Thomas Harter is the Robert M. Hagan Endowed Chair for Water Management and Policy at the Department of Land, Air, and Water Resources at the University of California, Davis. Previously, he was an assistant cooperative extension specialist at the University of California Kearney Agricultural Research Center in Fresno County, where he established his research program in agricultural groundwater hydrology—a program he continues to develop at UC Davis. He also serves on the board of the Groundwater Resources Association and of the Water Education Foundation. His research group emphasizes the nexus between groundwater and agriculture, with a focus on nonpoint-source groundwater pollution, sustainable groundwater management, groundwater and vadose zone modeling, groundwater resources evaluation under uncertainty, groundwater-surface water interaction, and on contaminant transport. He received his BS and MS in Hydrology from the Universities of Freiburg and Stuttgart, Germany; and his PhD in Hydrology from the University of Arizona.

Jelena Jezdimirovic is a research associate at the PPIC Water Policy Center. Her research expertise includes groundwater management and safe drinking water. During her undergraduate studies she served as a research intern at the National Priorities Project and spent summers working for the Federal Reserve Bank of Chicago. She holds a BA from Mount Holyoke College, where she majored in economics and critical social thought.

Jay Lund is an adjunct fellow at the PPIC Water Policy Center and director of the Center for Watershed Sciences at the University of California, Davis. As a professor in the Civil and Environmental Engineering Department, he has conducted system optimization studies for California's water supply, as well as modeling studies of flood control, climate change adaptation, water marketing, water utility planning, and integrated water resources management. In addition to authoring or coauthoring more than 300 publications, he has served on the advisory committee for the 1998 and 2005 California Water Plan Updates, as president of the Universities Council on Water Resources, and on the Delta Independent Science Board. He holds a PhD in civil engineering from the University of Washington, Seattle.

Josué Medellín-Azuara is the Steyer-Taylor Fellow at the PPIC Water Policy Center, an associate professor of environmental engineering at UC Merced, and an affiliate of the UC Davis Center for Watershed Sciences. His professional experience includes project and environmental management positions for industry and consulting for nongovernmental organizations such as the Natural Heritage Institute, the Stockholm Environment Institute, El Colegio de México, The Nature Conservancy, and the World Bank. He has directed modeling and research projects on water supply, remote sensing of water use, salinity and nitrate problems, and adaptation to climate change in California. He holds a master's degree in agricultural and resource economics and a PhD in ecology from UC Davis.

Peter Moyle is distinguished professor emeritus in the Department of Wildlife, Fish and Conservation Biology and associate director of the Center for Watershed Sciences at the University of California, Davis. He has been researching the ecology of California's freshwater and estuarine fishes since 1969. He has coauthored numerous papers on the ecology, status, and trends of California's diverse and endemic fishes, including salmon and trout. His present research focuses on climate change, effects of drought on fishes, and strategies for ecological reconciliation. He is lead author of Suisun Marsh: Ecological History and Possible Futures (UC Press, 2014), which reflects his

40 years of study of fish and water issues in the San Francisco Estuary. He has also studied fish and water issues in Botswana, Sri Lanka, and the Iberian Peninsula. He holds a PhD in zoology from the University of Minnesota.

Nathaniel Seavy is an adjunct fellow at the PPIC Water Policy Center and research director of the Pacific Coast and Central Valley Group at Point Blue Conservation Science. His research is focused on the ecology and conservation of riparian ecosystems, bird migration, understanding and preparing for the ecological effects of climate change, and applying science to conservation decision making and public policy. He has published more than 45 peer-reviewed scientific papers and book chapters in journals such as Ecological Applications, Journal of Wildlife Management, Biological Conservation, Conservation Biology, and PLoS ONE. He holds an MS and PhD in zoology from the University of Florida.

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Public Policy Institute of California
500 Washington Street, Suite 600
San Francisco, CA 94111
T: 415.291.4400
F: 415.291.4401
PPIC.ORG/WATER

PPIC Sacramento Center
Senator Office Building
1121 L Street, Suite 801
Sacramento, CA 95814
T: 916.440.1120
F: 916.440.1121