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Ellen Hanak,
Jay Lund,
Brad Arnold,
Alvar Escriva-Bou,
Brian Gray,
Sarge Green,
Thomas Harter,
Richard Howitt,
Duncan MacEwan,
Josué Medellín-Azuara,
Peter Moyle,
Nathaniel Seavy
with research support from Jelena Jezdimirovic

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Water Stress and a Changing San Joaquin Valley

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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 and growing water stress. Agriculture is a leading economic driver and the predominant water user. The region's farms and related manufacturing businesses account for 25 percent of the valley's revenues and 16 percent of local jobs—and 89 percent of annual net water use.

The latest drought underscored valley agriculture's vulnerability to water scarcity and long-term declines in groundwater reserves. The region has a greater abundance of productive farmland than local water supplies for irrigation. In most years since the mid-1980s, groundwater has been used faster than it is being replenished ("groundwater overdraft"). Over the past three decades, overdraft has averaged nearly 2 million acre-feet per year, or 13 percent of net water use. This has contributed to increased pumping costs, dry wells, sinking lands, and declining reliability of this vital drought reserve.

The Sustainable Groundwater Management Act of 2014 (SGMA) requires valley farms and communities to bring their groundwater basins into balance by 2040. Farms must also respond to a variety of related resource and environmental challenges. Notable issues include nitrate contamination of groundwater—a special challenge in poor, rural communities—as well as accumulating salinity in soils, local air pollution, and the broad decline in aquatic, wetland, and terrestrial ecosystems.

With so many changes underway, major questions loom about the future of the valley's agriculture and the wider consequences for the region's economy, society, and environment. Several broad strategies can help address the valley's water imbalance and related problems:

- **Manage groundwater reserves:** Groundwater sustainability agencies being formed under SGMA will need solid water accounting tools to understand how much water is available and how much is being withdrawn. They will also need the ability to incentivize both recharge and reductions in pumping to attain long-term groundwater balance.
- **Expand usable supplies:** Capturing and storing more local runoff in groundwater basins and reusing water would help reduce the current deficit in the near term. Longer term, larger infrastructure investments such as improved water conveyance from the Delta could help.
- **Reduce demand:** Although farmers can save some water through crop choice and management, idling some farmland is also likely in basins that cannot close the groundwater deficit with new supplies. Water trading—both within and across basins—can lessen the costs of shortages.

- **Explore multi-benefit strategies:** Opportunities exist to manage groundwater recharge in ways that improve water supply and quality—for example, by tailoring irrigation systems and crop choices to maximize clean recharge in prime areas. Similarly, with the right incentives and regulatory assurances, idled lands can be managed to reduce impacts on air quality while improving wildlife habitat.

Valley farmers and residents have a history of creatively adapting to changing conditions. In meeting today's challenges, there are numerous opportunities to tackle problems cooperatively. But the valley also has a complex mix of entities and institutions managing water and land. Perhaps one of the region's greatest challenges is developing new cooperative approaches to seize these opportunities. 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 environmental conditions.

Introduction

The San Joaquin Valley—a region stretching from the confluence of the Sacramento and San Joaquin Rivers in the north to the Tehachapi Mountains in the south—is a global agricultural powerhouse. Valley farms produce half of California's total farm output—including most fruits, nuts, dairy, vegetables for processing, and livestock feed—and they are major suppliers to national and international markets. Farming and related businesses are an important economic driver of this growing region, which is now home to more than 4 million people.

Like many agriculturally dependent regions, the valley faces significant socioeconomic challenges, including a high rate of unemployment and pockets of extreme rural poverty that worsen when the farm economy suffers. The region also faces difficult public health challenges in which farming plays a role, including unsafe drinking water in many small rural communities and some of the nation's worst air quality. Water and land development for farming and urbanization have also transformed the natural environment—drying up rivers and wetlands, and converting diverse native landscapes into farmland.

The valley's growing conditions are favorable as long as water is available to irrigate crops during the long, dry summers. Yet local water supplies are limited in much of the region—and particularly the southern half—by the relatively low precipitation in winters and springs. In recent decades, many farms have depended on water imported from wetter Northern California through the Sacramento–San Joaquin Delta to augment local supplies. In many places, water imports have not stemmed the long-term reliance on pumping groundwater in excess of the rate at which it is replenished. Groundwater overdraft can also cause land to sink ("subsidence") as well as impair groundwater quality.

Water stress in the valley has been on the rise. Delta imports to valley farming have been limited over the past two decades—and especially since 2007—because of drought and regulatory actions to protect threatened and endangered salmon, smelt, and other native fishes. Growing demand for Delta imports within Southern California has also decreased valley supplies. The latest drought greatly reduced surface water deliveries to irrigators, and heightened conflicts over regulations that constrain Delta imports. Many farmers have made up for reduced water deliveries by pumping additional groundwater, accelerating problems of land subsidence and dry wells—including drinking water wells in small rural communities. Concerns have also grown about the long-term depletion of the region's aquifers.

These problems spurred the enactment in fall 2014 of the Sustainable Groundwater Management Act (SGMA), which requires valley communities to bring their groundwater basins into balance by 2040.[1] Achieving this goal will protect the region's long-term groundwater reserves, and enable its residents and economy to weather future droughts. But attaining balance will require difficult decisions, because water use will need to drop—as will irrigated acreage—in basins that are unable to close the groundwater deficit.

As valley growers and other residents begin the hard job of developing and implementing groundwater sustainability plans, they must consider other changing conditions related to water and farmland. This includes possible increases in environmental flows in some local rivers and the Delta that could further reduce surface water for irrigation. It also includes possible declines in surface water availability as the climate continues to warm and the Sierra Nevada snowpack diminishes, as well as increased competition with urban areas for water

[1] In this report, we use the term groundwater basin to refer to basins and sub-basins as defined by the California Department of Water Resources (2016a). A sub-basin is created by dividing a groundwater basin into smaller units using geologic and hydrologic barriers or, more commonly, institutional boundaries. SGMA implementation in many parts of the state, including the San Joaquin Valley, will occur at the sub-basin level. Bringing groundwater basins into balance refers to ending long-term overdraft, such that groundwater withdrawals and groundwater levels are stabilized on average.

and land. Water and land use decisions on farms will also be affected by efforts to address water and air quality concerns.

With so many changes underway, major questions loom about the future of the valley's agriculture and the broader consequences for the region's economy, society, and environment. We start from the premise that managing water and land sustainably is important to achieve three broadly shared goals for the valley: (1) a prosperous regional economy, (2) clean water and air for valley residents, and (3) a reinvigorated natural environment that supports diverse plant and animal life and provides improved outdoor recreational opportunities for valley residents and others.

One recurring theme in our analysis is that while the region has many common challenges, conditions also vary considerably—both within and across communities. This diversity—for instance, in the availability and suitability of water and land for different purposes—creates numerous opportunities to tackle problems cooperatively. But the valley also has a complex mix of entities and institutions managing water and land. As a result, perhaps one of the region's greatest challenges is developing new cooperative approaches to seize these opportunities.

The story of water and land use in the San Joaquin Valley—and its consequences for the region's economy, public health, and natural environment—is a story of continuing change and adaptation. Addressing the changes that lie ahead will not be easy, but the region's residents have a tradition of tackling problems creatively. Our hope is to help create a shared understanding of the valley's most pressing challenges and inform a conversation about how the valley's residents and others—including the rest of California and the federal government—can support a more promising future for this region. The stakes are high. So are the costs of inaction.

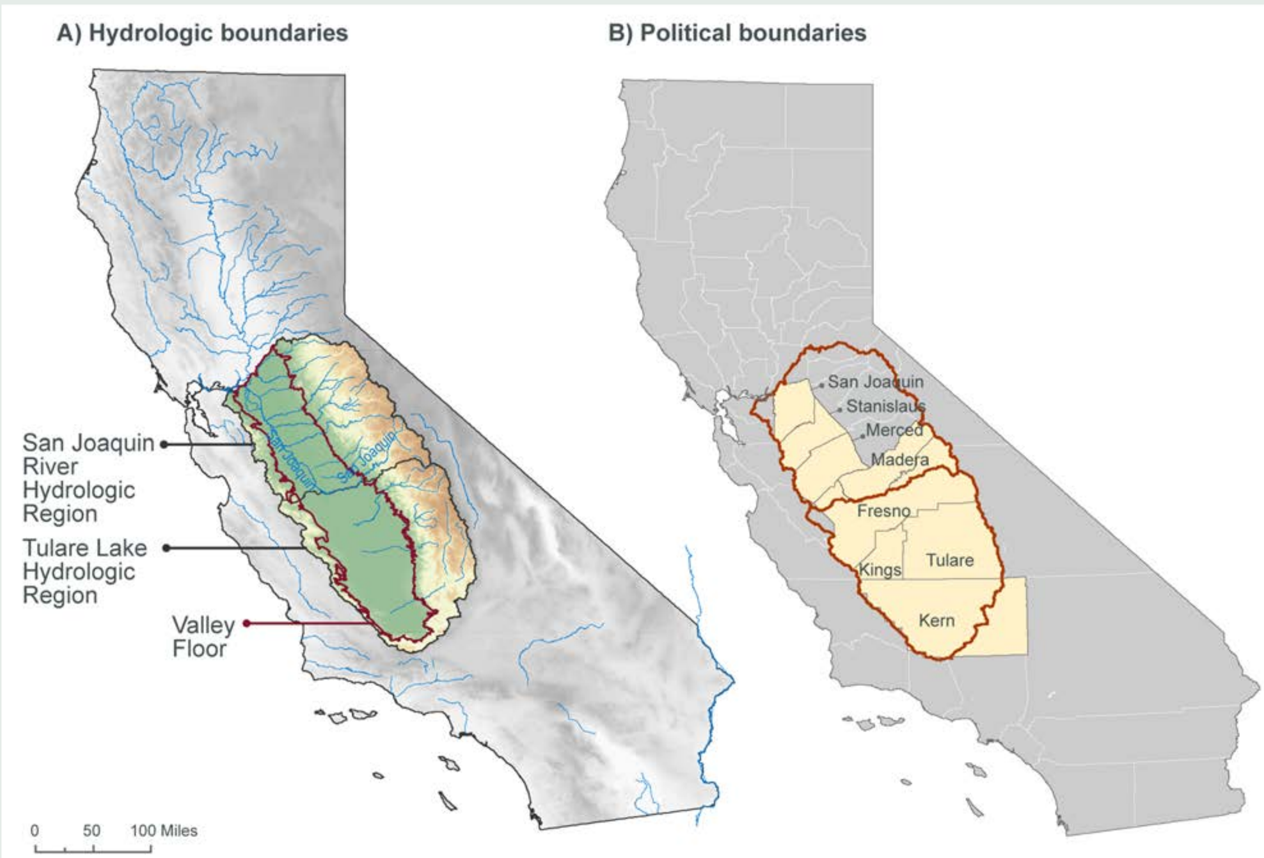
This report begins with an overview of the evolution of irrigated agriculture in the valley, including its role in the regional economy and its history of adapting to evolving technological and market opportunities. We next review some major resource challenges to which valley agriculture must continue to adapt. Foremost among these is water scarcity, and the need to bring groundwater basins into balance under SGMA. We then sketch out approaches to balance water supply and demand, improve water and air quality, and reinvigorate the natural environment.

Finally, we briefly explore the complex institutional context—and key roles for farmers, urban residents, as well as local, regional, state, and federal entities in initiating and supporting solutions to the region's challenges. (Note: This report is a prelude to a larger study, to be published in 2018, that aims to inform an ongoing regional and statewide discussion about the valley's future, and explore opportunities for cooperative solutions in greater depth.)

Box 1. What We Mean by the San Joaquin Valley

We draw on two ways of defining the San Joaquin Valley. The first is by natural watersheds in the valley, including the San Joaquin River and Tulare Lake hydrologic regions (Figure 1A). 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. For tracking the economy, we use a second definition—the political San Joaquin Valley, which includes the eight counties that cover the valley floor: Fresno, Kern, Kings, Madera, Merced, San Joaquin, Stanislaus, and Tulare (Figure 1B). For some purposes, we also present more detailed information by sub-regions within the valley floor, defined by agricultural and hydrologic conditions.

FIGURE 1
The San Joaquin Valley



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

The Evolution of San Joaquin Valley Agriculture

Agriculture has been the leading sector of the San Joaquin Valley economy since the late 19th century, when the region's farmers raised cattle, wheat, and other field crops. During the 20th century, the regional economy evolved to include an array of agricultural commodities, including fruits and vegetables, cotton, alfalfa, dairy, and orchard crops. Today, the valley produces roughly half of California's agricultural output. Its diverse range of crops and animal products serve state, national, and international markets. Farming and related food and beverage manufacturing are far more important in the regional economy—in terms of revenues, employment, and gross domestic product (GDP)—than in the state as a whole (Figure 2). The foundation that agriculture provides for the valley's economy is even larger if one considers the related economic activities in transportation, farm inputs, and finance, along with spillover (or "multiplier") effects on the overall economy.[2]

FIGURE 2
Agriculture is much more important to the San Joaquin Valley's economy than to California's economy

SOURCE: Author calculations using IMPLAN data for 2012. For details, see Technical Appendix B.

NOTES: Estimates shown are for direct economic effects of farm-related GDP, defined here as crop and animal production (including support services to agriculture) and food and beverage processing. Employment includes full-time, part-time, and seasonal jobs. The data are for 2012, prior to the onset of drought-related acreage reductions and a boom in prices for many commodities, including almonds. Technical Appendix B, Figure B2 provides data for 2014, when strong commodity prices raised farm-related GDP to 21 percent. For comparable information for each of the eight valley counties, see Technical Appendix B, Figure B3.

Valley agriculture has a long history of adapting to changing agricultural markets, technology, and water availability. Here we look at some factors influencing adaptations in recent decades.

A Rise in Perennials and Dairies

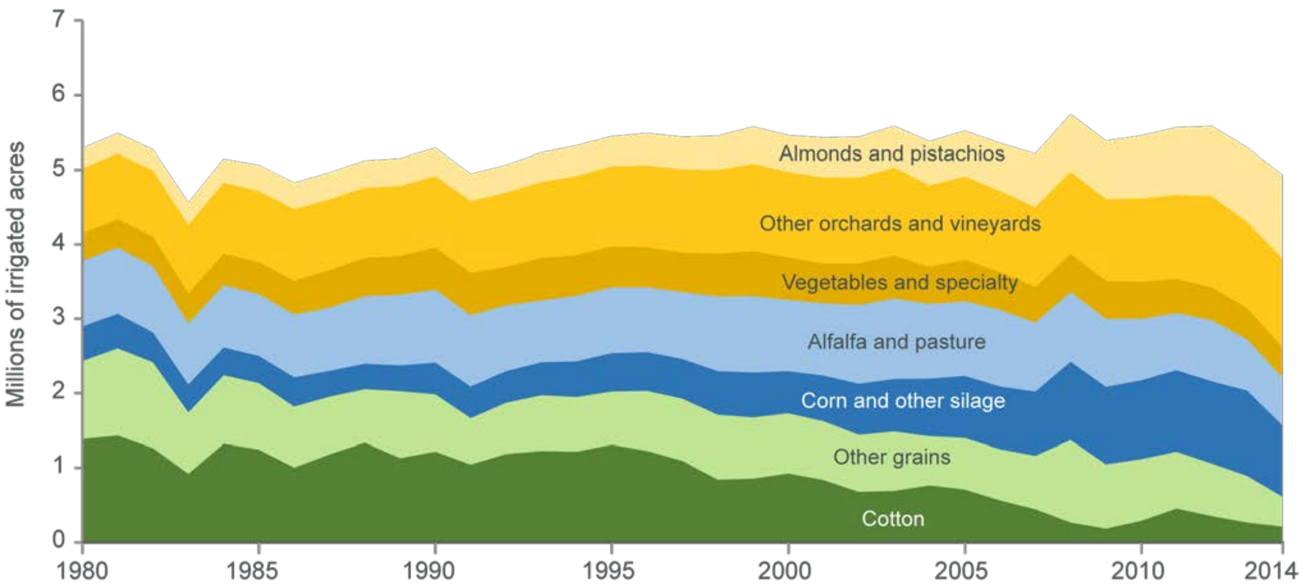
Since the early 1980s, growers have responded to a variety of changes—including rising agricultural commodity prices, continued technological innovation, low interest rates, and rising costs of land and water—with shifts toward perennial vineyards and orchards (especially nuts), high-revenue annual specialty crops such as tomatoes

[2] These spillovers include both "indirect" effects of economic activity from related sectors, like input sales, transportation, and agricultural finance, as well as "induced" effects of additional economic activity generated by the spending of farm-related incomes and taxes.

and melons, and fodder crops to support a growing dairy industry (Figure 3). From 1980 to 2012, irrigated acreage was relatively stable, averaging 5.2 million acres. Over this period, orchards and vineyards grew from 21 to 36 percent of total acreage, and vegetables and other specialty crops from 8 to 11 percent. Corn and other silage—used primarily by dairies—grew from 9 to 20 percent, and alfalfa and irrigated pasture—also used as feed—hovered near 16 percent. The flip side of this growth was sharp declines in less profitable field crops, including cotton—once a major commodity in the region—and some other grains.

FIGURE 3

The San Joaquin Valley's farmland has been shifting toward perennial crops and fodder for its dairies



SOURCE: USDA's National Agricultural Statistics Service (NASS), adjusted by ERA Economics.

NOTES: The figure reports acreage planted to irrigated crops and pasture for the eight-county San Joaquin Valley region. "Corn and other silage" includes corn silage and limited miscellaneous winter silage that cannot be identified within the NASS data. The figures are adjusted from NASS total crop acreage to account for irrigation. For example, some winter silage crops that are not irrigated are excluded, as is other (limited) dry-farmed hay.

Since 2012 and the onset of drought-related acreage reductions, almond acreage continued to expand in response to strong prices, and farmers cut back selectively on lower-revenue field crops. By 2014, irrigated acreage had declined to 4.9 million acres—the lowest since a severe drought in the early 1990s. Perennial crops were 43 percent of the total, and vegetables and other specialty crops were 12 percent.

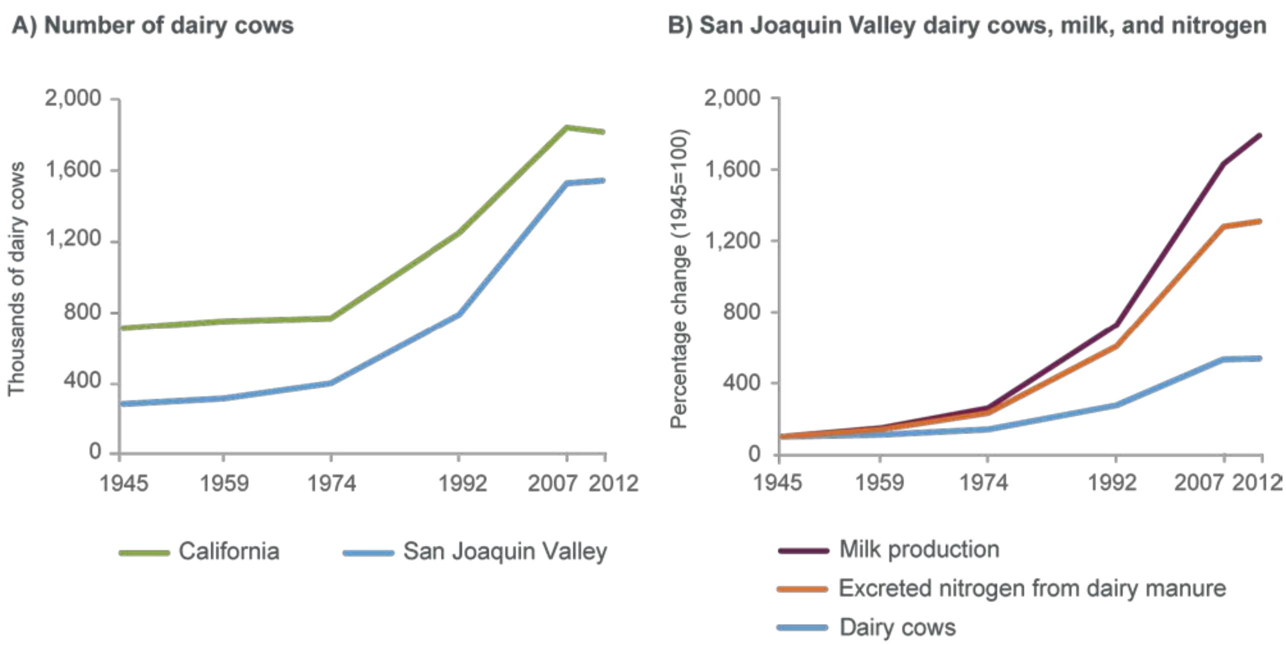
Farmers have continued to increase crop quality and yields through continued innovations in crop varieties and farm management. These improvements occurred despite some shifts in irrigated acreage toward former rangelands with lower quality soils, as urbanization on the valley floor displaced some prime farmland (Unger and Thompson 2013, Cameron et al. 2014). The adoption of drip and micro-sprinkler irrigation technology has facilitated such shifts. These technologies reduce the yield differences across soil types, and make it possible to irrigate hilly terrain that is unsuitable for traditional flood irrigation.[3]

[3] In particular, pressure-compensating drip and micro-sprinkler irrigation technology, which delivers a precise amount of water regardless of changes in pressure due to long rows or changes in terrain, has been instrumental.

Although dairy production in the valley began in the early 20th century, it has significantly expanded since the 1970s, propelling California to become the nation's leading dairy state (Figure 4A).[4] Today, 85 percent of California's 1.8 million dairy cows live in the valley. The valley's herd—which nearly quadrupled from the mid-1970s to the mid-2000s—is kept mainly in large, intensive "concentrated animal feeding operations" (CAFOs). Innovations in dairy management have enabled milk production to expand much faster than the herd (Figure 4B). So too has the production of nitrogen from cow manure—a growing environmental challenge. Milk (and nitrogen) production have continued to grow even as the number of cows has stabilized over the past decade.

FIGURE 4

The San Joaquin Valley is California's main dairy region



SOURCE: USDA agricultural census for cows (accessed from Haines et al. 2016). Author estimates of milk and nitrate excretion using estimates developed in Viers et al. (2012).

NOTE: The ratios of milk and excreted nitrogen to dairy cows are statewide averages. For county-level estimates of dairy cows, see Technical Appendix B, Table B1.

Persistent Diversity in Farm Sizes

Although the valley has some of California's largest farms, it also has many small and medium-sized farms. In 2012, valley counties registered nearly 20,000 irrigated farms, with a wide range of sizes (Figure 5). Relatively small farms and ranches still predominate in some eastern parts of the valley, while large operations managing thousands of acres occupy much of the southern and western farmland. Although consolidation has been occurring for several decades, farms with less than 500 acres of irrigated cropland still account for a quarter of irrigated acreage.[5] Half of all of these farms irrigate 10 to 100 acres, and even smaller farms are important

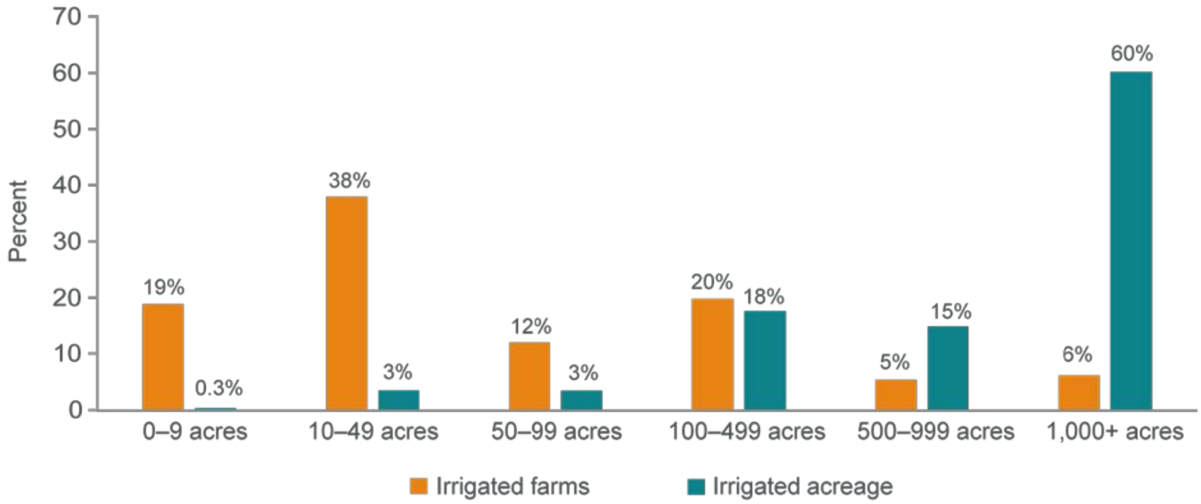
[4] California has had the most dairy cows in the United States since 1998, and has produced about 20 percent of all US milk since 2001 (USDA Economic Research Service 2016).

[5] For trends since the late 1960s, see Technical Appendix B, Figure B6.

revenue sources for some communities.[6] Solutions to the region's resource management challenges must recognize this diversity.

FIGURE 5

Large farms account for most irrigated acreage, but the San Joaquin Valley still has many smaller farms



SOURCE: US Department of Agriculture Census, accessed from Haines et al. (2016).
NOTES: The figure reports the share of irrigated farms for the eight San Joaquin Valley counties, and the share of irrigated acreage by farm size reported to the 2012 agricultural census. The total number of farms was 19,954 and the total irrigated acres reported was 4.2 million—about 20 percent below the estimates from the National Agricultural Statistics Service annual crop production surveys shown in Figure 3. For county-level estimates, see Technical Appendix B, Table B2.

Sustained Economic Growth…

Agricultural prices—and resulting farm incomes and profits—can vary considerably from year to year. Over time, however, commodity shifts have generally increased farm revenues, even in years with lower land (and water) use (Figure 6). Real farm revenues increased by 60 percent from 1980 (a year of historically high prices) to 2012. The even stronger showing in 2014 reflected a boom in prices for almonds and dairy that has since subsided.[7] These strong market conditions helped offset drought-related water shortages and higher production costs (Howitt et al. 2014 and 2015).

Despite continued innovations in labor-saving technologies, these production shifts have also supported moderate long-term job growth on farms and in related food and beverage processing industries.[8] And overall, 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 been experiencing rapid urban growth.[9]

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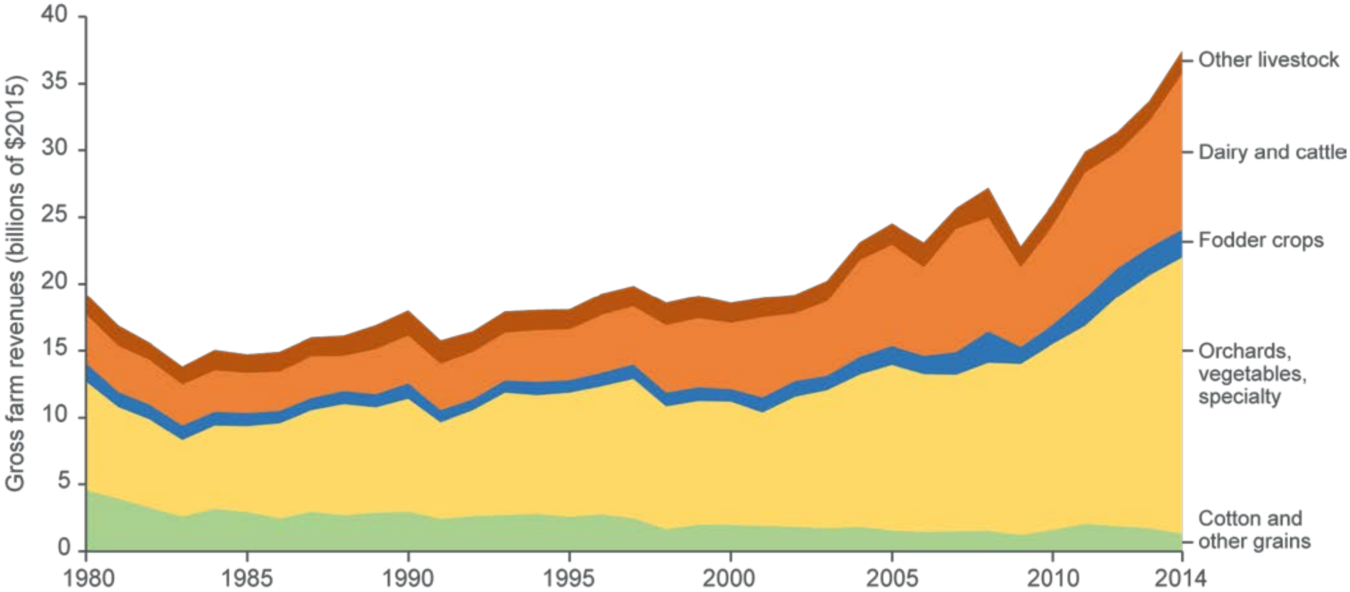
[6] For instance, the Hmong and other Asian communities with small produce farms rely on local farmers' markets for revenues. However, it is also likely that many farms reporting less than 10 acres of irrigated cropland are not as actively engaged in market-oriented production as larger farms (Koerth-Baker 2016).

[7] Statewide, real farm revenues declined by about 15 percent in 2014 and 2015, largely from price declines (especially for almonds and dairy). County-level data for 2015 was not available at the time of writing, but the San Joaquin Valley likely experienced the brunt of this drop, given the prevalence of these commodities in the region.

[8] Farm-related employment rose from an average of roughly 215,000 in the mid-1970s to more than 290,000 in 2015. Although it has declined over time as a share of total employment, its share has remained relatively stable for the past decade. For details, see Technical Appendix B, Figure B5 and related discussion.

[9] Because long-term regional GDP estimates are not available, we use regional income (including proprietor and wage income) as a proxy. From 2011-15, farm-related income averaged 18 percent of regional income, comparable to the average in the late 1980s to early 1990s. It dipped to an average of 14 percent in the early 2000s. For details, see Technical Appendix B, Figure B4 and related discussion.

FIGURE 6
Real farm revenues have risen over time in the San Joaquin Valley



SOURCE: National Agricultural Statistics Service, USDA, adjusted by ERA Economics
NOTES: The figure shows gross farm revenues, adjusted to 2015 dollars with the GDP implicit price deflator series. Information on net revenues (gross farm revenues minus costs) is not available at the county or regional level. The data are adjusted for missing price and yield information and other miscellaneous inconsistencies. Fodder crops include alfalfa, irrigated pasture, corn, and other silage. Other grains (included along with cotton in the green area) include non-silage grains.

…and New Management Challenges

These production shifts have also had some less favorable consequences. The strong investment in perennial crops and dairies has increased vulnerability to water scarcity. When irrigation water supplies are constrained, one management response is to fallow the least productive, lowest revenue acreage. Fallowing is much more costly and difficult for vineyards and orchards than for field crops, as trees cannot go without irrigation during dry years. During the latest drought, for instance, some farmers without ready access to groundwater leased water at record-high prices to keep their trees alive, and some uprooted trees.

Dairies are another long-term investment with greater drought vulnerability. When water is scarce, farmers can replace some local feed with imported grain. But many dairies rely on corn silage for a part of their milk cows' diets, and this must be grown near the dairies because it is so costly to transport. The growth in intensive dairies has also brought new environmental challenges, including how to safely dispose of nitrogen in manure.[10] To address these issues, valley farmers must continue to adapt.

[10] Dairies also face new regulations to reduce methane emissions from manure—a major source of greenhouse gases (California Air Resources Board 2016a and 2016b, Lee 2016).

Water Scarcity: A Major Challenge

Of the many natural resource challenges facing valley agriculture, perhaps the most critical issue is adapting to water scarcity.[11] The region has a dry and highly variable climate—with large swings in precipitation across years—and a generally greater abundance of productive farmland than local water supplies for irrigation. Historically, these conditions have spurred successive phases of water infrastructure development to augment both local and imported supplies. But these efforts have not durably resolved the region's water imbalance—and the related problem of groundwater overdraft.

Here we briefly review the evolution of water supply development for the valley. We then examine the region's water balance over the past three decades—comparing sources and uses—to assess the extent of the groundwater overdraft that farmers and other residents must now address as they implement the Sustainable Groundwater Management Act (Box 2).

The Development of Local and Imported Water Supplies

Irrigation using local surface water began in the late 1800s, with rudimentary systems to capture seasonal flooding. Local districts on the valley's east side then developed more extensive systems to capture water from the San Joaquin River and other rivers to the south. In the early 1900s, the region also began to export some water to the San Francisco Bay Area, as both the City of San Francisco and the East Bay Municipal Utilities District built reservoirs and aqueducts to tap San Joaquin River tributaries. In the 1930s, improvements in pumping technology facilitated the expansion of groundwater use in the valley, beginning long-term depletion of the region's aquifers (Hundley 2001, Moore and Howitt 1988).

The expansion of irrigated agriculture and declining groundwater levels spurred an era of reservoir and aqueduct construction, which captured more local surface water and made imports from Northern California available to the region. From the 1930s to the 1950s, the federal Central Valley Project (CVP) built dams and canals to supply valley farms. On the east side, the CVP's Friant Division began diverting San Joaquin River water to farms in the drier south. On the west side, the CVP started importing water from the Sacramento River through the Delta. In the southeast, the US Army Corps of Engineers followed with reservoir projects to capture flood flows for irrigation. In the 1960s, the CVP extended the delivery of Delta imports farther south on the west side. So did California's State Water Project (SWP), which also serves coastal urban areas. And in the mid-1970s, local water users built the Cross Valley Canal to connect SWP and Friant facilities in Kern County.

These successive investments resulted in an amalgam of local, state, and federal infrastructure to store and transport water (Figure 8), managed by a diverse set of agencies. These projects deliver water under a variety of water rights and contracts, with different levels of reliability when supplies are constrained. So while water scarcity is a regional problem, it is not experienced equally. Some farms and communities have very senior rights to surface water, established more than a century ago, and rarely experience shortages. In contrast, the CVP and SWP have relatively junior surface water rights, and many of their contractors are more susceptible to cutbacks. Still others—including many towns and rural communities—rely entirely on groundwater for drinking water and irrigation supplies. This makes them particularly susceptible to groundwater quality problems and falling water tables, and vulnerable to pumping restrictions with the implementation of SGMA.

[11] This report focuses on challenges related to natural resource aspects of farming, including water and land. The sector will also need to continue responding to broader economic conditions, including national and international markets for its products, as well as changing interest rates and markets for labor and other inputs. Although water and land are essential inputs for crop production, these other market factors can make a bigger difference to the sector's bottom line.

Box 2. The Sustainable Groundwater Management Act

In 2014, Governor Brown signed into law a set of bills commonly known as the Sustainable Groundwater Management Act (SGMA). The legislation directs local agencies and stakeholders to develop institutions, plans, and implementation strategies to sustainably manage their groundwater resources for the long run (Kiparsky et al. 2016). If local agencies fail to act, SGMA directs the state to intervene.

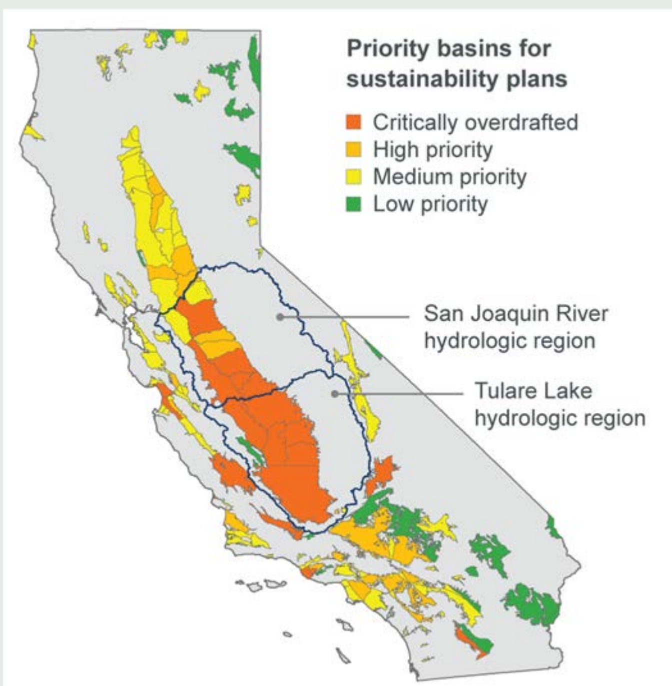
The law defines sustainable management as the avoidance of six effects: (1) drawing down water levels too far, (2) depleting storage in the aquifer, (3) degrading water quality, (4) allowing seawater intrusion, (5) causing land to subside, or (6) using groundwater in ways that reduce other people's surface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

Local stakeholders are in charge of carrying out the key provisions of SGMA. New or existing agencies overlying the most stressed groundwater basins (those designated by the Department of Water Resources as medium- and high-priority, and critically overdrafted) are tasked with establishing Groundwater Sustainability Agencies (GSAs), and formulating Groundwater Sustainability Plans (GSPs). Any local agency in a basin can form a GSA, but GSAs may not have overlapping boundaries. To avoid state intervention, GSAs must be formed by June 2017.

GSAs in critically overdrafted basins are required to develop plans by January 2020, while 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 sustainability.

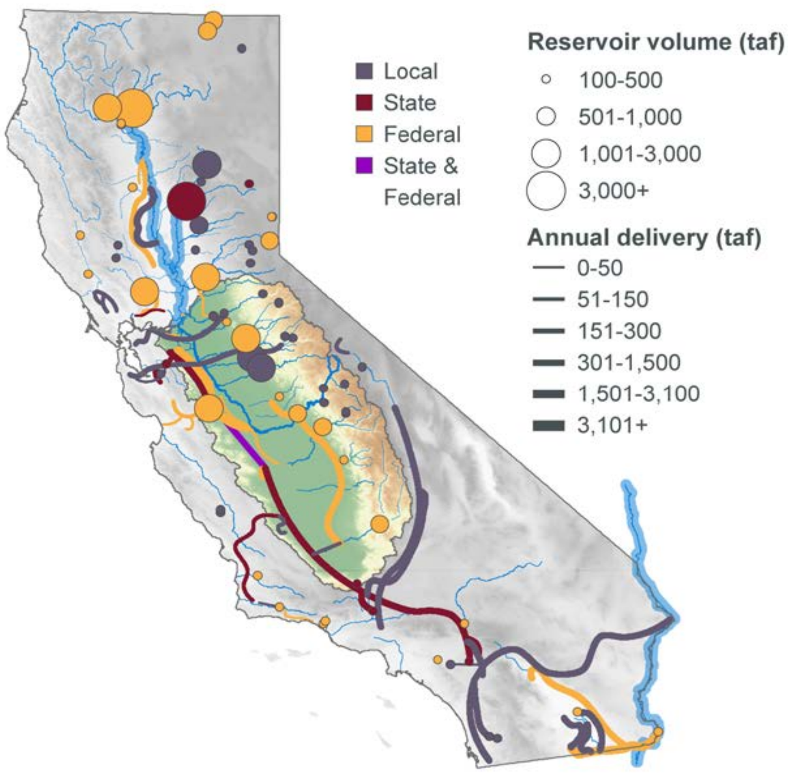
SGMA is especially significant in the San Joaquin Valley. Of the valley's 16 groundwater basins, 11 are considered critically overdrafted, subject to the 2020 timeline (Figure 7). Four medium- and high-priority basins in the northern Valley will have until 2022 to start implementing their plans. Only one—a relatively saline basin on the Valley's west side—is not required to prepare a sustainability plan.

FIGURE 7
Most San Joaquin Valley basins are critically overdrafted



SOURCE: California Department of Water Resources.

FIGURE 8
The San Joaquin Valley receives local and imported surface water from a diverse array of projects



SOURCE: Adapted from Figure 2.6 in Hanak et al. (2011), 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 thousand acre-feet (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.

The Valley's Water Balance Today

To manage water resources effectively for the long-term, it is essential to understand the valley's water balance: how much water is available from different sources, how much is used in different activities within the region, and how much leaves the region for use elsewhere. Developing an accurate picture of this balance is difficult, because many key components—including groundwater withdrawals (a key source) and farm water use (the largest use)—are not systematically measured or reported. Understanding the water balance also requires accounting for the difference between gross and net water use—the water that returns to rivers, streams, or aquifers after use and is available for reuse ("return flow") (Box 3).

Box 3. Gross and Net Water Use and Return Flows

Gross water use is the total amount of water applied to farm fields, urban landscapes, and managed wetlands, as well as water used indoors. Net water use is the portion of gross use that is consumed by people, animals, or plants, embodied in manufactured goods, evaporated into the air, or discharged into saline water bodies and made unusable without significant treatment. Net water use excludes "return flows"—the portion of gross water use that returns to rivers, streams, or aquifers after use and is available for reuse.

Return flows mainly come from irrigation water not consumed by crops and urban wastewater discharges. Irrigation return flows are a major source of aquifer recharge in the San Joaquin Valley. Because they are available for reuse, return flows are not considered a use in a region's water balance. For this reason, the water balance presented in this report focuses on net—rather than gross —water use. Water users in different parts of the valley will also need to account for return flows as they bring their water sources and uses into balance under SGMA.

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.[12] From 1986 to 2015, annual net water use averaged 13.3 million acre-feet (maf), with 89 percent for farming and the remainder consumed by cities (4%), managed wetlands (2%), and natural landscapes (5%).[13]

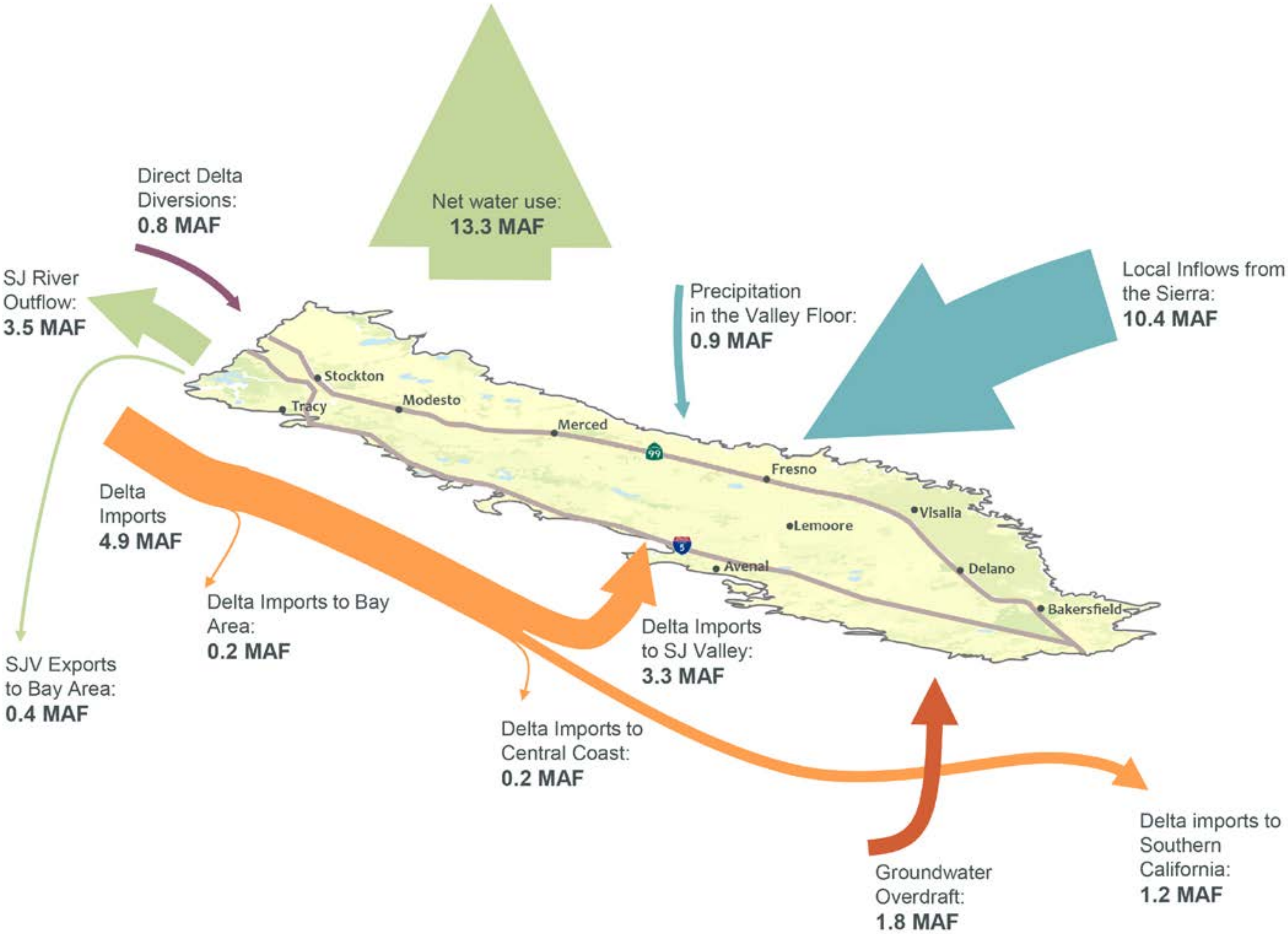
This water comes from four sources (Figure 9):

1. **Local supplies (56%).** This includes water flowing in from the local rivers and streams originating in the Sierra Nevada (10.4 maf), plus precipitation falling on the valley floor (0.9 maf), minus exports from local rivers to the Bay Area (0.4 maf) and outflows to the Delta (3.5 maf), for a net total of 7.4 maf.
2. **Delta imports (25%).** On average, 4.9 maf of Delta imports enter the valley through the CVP and SWP pumps in the south Delta near Tracy, and 3.3 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.
3. **Direct Delta diversions (6%).** In the northernmost part of the valley, most water users divert water directly from the Delta (0.8 maf). Depending on location and timing, this water originates from the Sacramento River or local rivers.
4. **Groundwater overdraft (13%).** Because they recharge the valley's aquifers either directly or through return flow, a portion of all three of the sources listed above is consumed through groundwater pumping. This pumping can be considered sustainable groundwater use because it comes from recharge. On average, valley water users also pumped 1.8 maf per year of additional groundwater. This is the long-term level of overdraft, or diminishing groundwater reserves.

[12] Figure 1A depicts the valley floor, and Technical Appendix A describes sources and methods for the water balance estimates.
[13] Gross water use—which includes water returned to rivers and aquifers—was approximately 18.8 maf, and return flows were 5.5 maf. (29% of gross water use). The share of return flows in gross water use varied across sectors: 28 percent for agriculture, 63 percent for urban, and 57 percent for wetlands (estimates from the California Department of Water Resources for 1998-2010).

FIGURE 9

The San Joaquin Valley's water balance: sources and uses (1986–2015)



SOURCE: Author estimates using data from several sources (for details, see Technical Appendix A).

NOTES: For a breakdown of the water sources available for use in the valley, see the discussion in the text (p. 16). San Joaquin River outflow includes flows from the San Joaquin River at Vernalis (averaging 2.6 maf/year) and flows from the Mokelumne and Cosumnes Rivers and other east-side streams (0.9 maf/year). Direct Delta diversions correspond to net water use by San Joaquin Valley water users located within the Delta.

Some decline in groundwater reserves is expected during droughts, when less surface water is available. The problem occurs when aquifers are not recharged in wetter years. The long-term declines in the valley's groundwater reserves reflect surface-water scarcity and a lack of formal groundwater management. There has been some progress in managing recharge since the 1990s, particularly in Kern County.[14] But in contrast to some overdrafted basins in Southern California and the Bay Area, valley water users have not yet placed effective overall limits on the volume of pumping. In the absence of limits, individual users have incentives to pump more than is collectively sustainable.

[14] This includes groundwater banks that also store water for other parties—including cities in the Bay Area and Southern California (Hanak and Stryjewski 2012).

Overdraft is a longstanding problem, particularly in the drier southern part of the valley, and an important goal of the water infrastructure projects described above was to help close this gap.[15] But for a variety of reasons, these projects have not met this expectation. Indeed, regional overdraft has been accelerating since the early 2000s, in part due to the following factors:

- **Southern California imports.** In the early decades of the State Water Project, coastal urban water agencies often did not take all the water they were entitled to, and valley farmers were able to pick up the surplus at low cost.[16] Southern California now uses this water, and it has also bought some SWP contracts from irrigation districts in the valley. On average, this translates to a decline of 0.5 million acre-feet of Delta imports going to the valley since 2001.[17]
- **Changing environmental regulations.** Delta imports have also been smaller than originally anticipated because of a suite of environmental flow regulations introduced since the early 1990s, intended principally to protect vulnerable fish species. The cumulative effect of these changes on total imports has not been well documented—and is likely smaller than sometimes thought.[18] But there is little doubt that imports have been more restricted, particularly over the past decade.
- **Drought.** Recurrent drought has reduced both local supplies and imports. The period 2001–15 was the driest since the prolonged dry period of the late 1920s and '30s.[19]

Figure 10 shows how groundwater overdraft has accelerated as drought and reductions in Delta imports have limited surface water inflows to the region. Local supplies and imports are much more variable than water use, and they have declined in recent years (Panel A). Surface reservoirs supplement annual supplies in the early years of droughts, but they run out of water when droughts wear on (Panel B). Meanwhile, net recharge of groundwater basins valley-wide has occurred in just a few years in the past three decades (Panel C). In most years, groundwater is being used faster than it is being replenished. From 1986-2000, groundwater overdraft contributed 10 percent of net water used in the valley. From 2001–15, its share rose to 17 percent.[20]

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[15] Imports were intended to support expansion of agriculture in some parts of the valley—such as the west side areas of Fresno and Kings County—and reduce groundwater overdraft in other places, such as Kern County. For a chart showing groundwater depletion in the region since the early 1920s, see Mount et al. 2016b.

[16] The SWP was never built out to its planned capacity, so average project deliveries have been generally lower than planned. This was less noticeable for valley growers in the early years because of the ability to access unused urban supplies.

[17] As described in Technical Appendix A, Figure A18, Southern California increased its share of total Delta imports from an average of 19 percent in 1986–2000 to 29 percent in 2001–15, for an average annual increase of roughly 500,000 acre-feet. This resulted in a commensurate decline in the valley's share of imports, from 72 to 61 percent. The growth in Southern California's share reflects increased ability to take delivery of SWP contract water and store it in local surface and groundwater storage, sales of SWP contracts to Southern California agencies by San Joaquin Valley irrigation districts, and net withdrawals of Southern California water stored in Kern County groundwater banks during recent droughts.

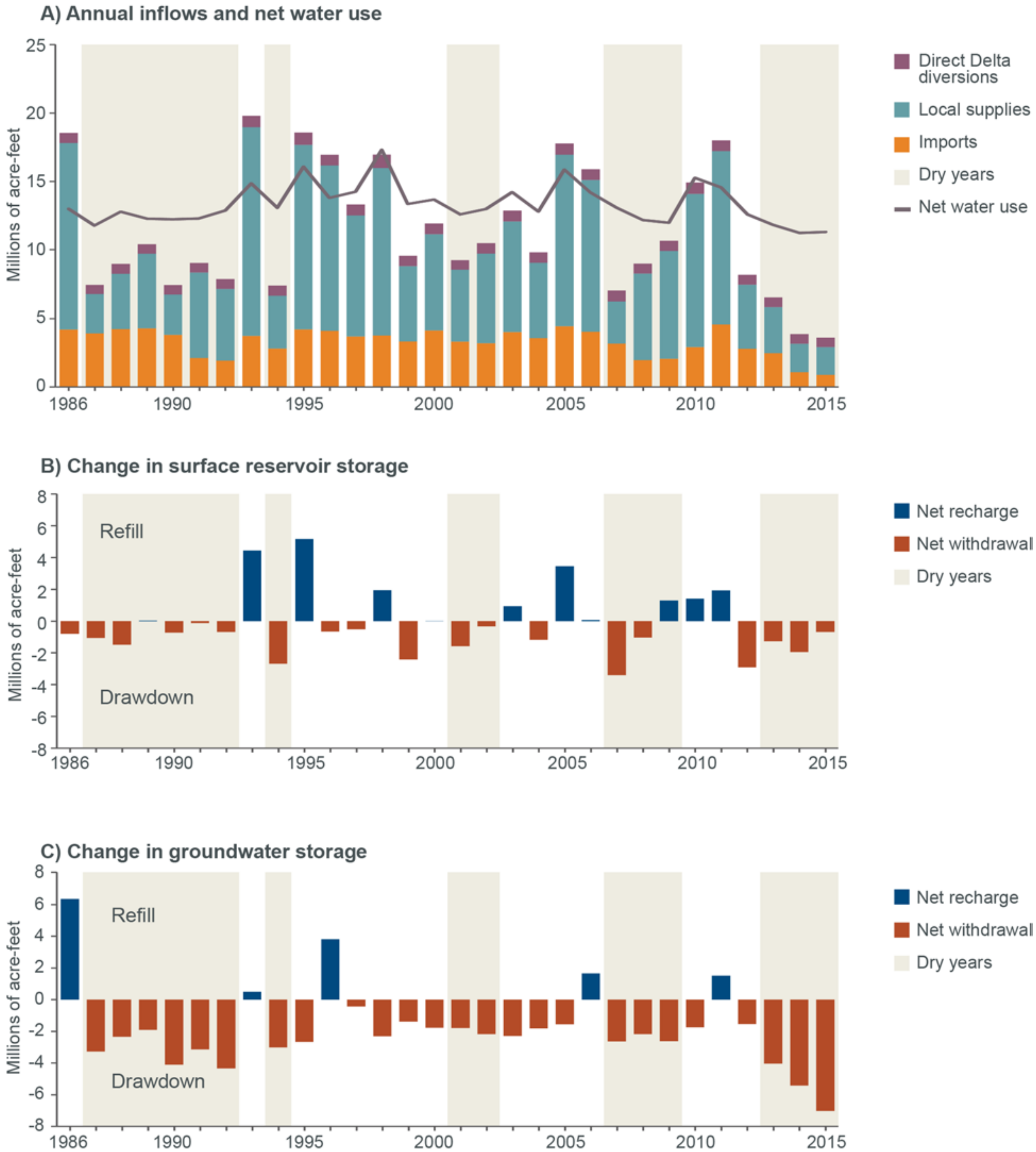
[18] Discussions of the impact of various environmental regulations on Delta imports sometimes suggest they have resulted in cuts of as much as 2 million acre-feet per year. As described further below, these assessments may assume that individual regulatory programs are additive—always resulting in additional water supply cutbacks, when in some cases they can be met using the same water. Also, they may not adequately consider import reductions related to hydrologic factors (such as drought) since the late 2000s. Overall, Delta imports were higher in many years following the adoption of more stringent environmental regulations in the early to mid-1990s (Cody, Folger, and Brown 2015).

[19] This calculation uses summary precipitation data for the region from the National Oceanic and Atmospheric Administration (NOAA). In this 15-year period, only four years had precipitation above the 1901–2000 average.

[20] The corresponding shares for imports were 27 percent and 23 percent, and for local supplies 58 percent and 54 percent, respectively. Delta diversions remained constant at 6 percent.

FIGURE 10

Drought and reduced Delta imports have accelerated overdraft in recent years in the San Joaquin Valley



SOURCE: Author estimates using data from several sources (for details, see Technical Appendix A).

NOTES: To facilitate comparisons, bar heights in all three panels have the same scale. The components of annual inflows (Panel A) are described in the text. "Dry years" are those classified as dry or critically dry for the Sacramento Valley based on the California Cooperative Snow Survey. This basin is the main source of Delta imports, and dry conditions there are highly correlated with conditions in San Joaquin Valley rivers. The dry year classification considers precipitation in that year and water available in surface storage from the prior year.

Conditions have become acute since the onset of the latest drought, when surface water deliveries were especially low. Farmers reduced irrigated acreage and total water use in 2014 and 2015, but they also drilled record numbers of new irrigation wells and pumped record volumes of groundwater to keep crops alive.[21] This accelerated groundwater overdraft has raised numerous concerns, ranging from irreversible land subsidence, to higher pumping costs, to dry wells. Subsidence rates—with lands sinking by nearly a foot per year in some places—are approaching records reached earlier in the 20th century, before Delta imports began. This is damaging infrastructure, including the large aqueducts of the CVP and the SWP, flood channel capacity in portions of the San Joaquin River, and local water delivery systems.[22] And since 2014, the drying up of more than 3,100 domestic and small community drinking water wells within the region has raised immediate public health concerns.[23]

In fall 2014, these conditions spurred the enactment of SGMA, which will require local water users to manage groundwater sustainably. The groundwater deficit can be closed by augmenting supplies, reducing demands, or some combination of these two approaches. In the near-term, this will likely increase costs for valley farming and the regional economy. But if successful, it can improve long-term water supply reliability for the most profitable farm activities and lower water management costs for many farms and other local users. As described below, numerous tools and approaches are available to reduce the costs of these adjustments.

Related Challenges for Water and Land Management

Beyond water scarcity, agricultural production in the valley faces a number of related challenges. Farm practices have contributed to a variety of environmental and public health problems—reflecting tradeoffs that are common in many farming regions. Notable issues include nitrate contamination of groundwater, salinity accumulation in soils, local air pollution, and the broad decline in aquatic, wetland, and terrestrial ecosystems, which affect vulnerable species. Farmers must respond to these concerns and adapt to new laws and regulations intended to address these issues.

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[21] For trends in well drilling, see Technical Appendix B, Figure B7. For an analysis of the economic impacts of drought, including estimates of land idling, see the studies by Howitt et al. (2014, 2015) for the California Department of Food and Agriculture. Table A5 in Hanak et al. (2015) provides a multi-year summary of these impacts for the state as a whole.

[22] For a general overview of subsidence, see California Department of Water Resources (2014). During the drought of the late 2000s, the US Geological Survey found subsidence rates of 1 to 21 inches over a three-year period (Sneed et al. 2013, Faunt et al. 2015). A NASA study of subsidence rates from 2015-16 shows the valley's main areas of subsidence growing wider and deeper, with growing damage to water project infrastructure such as the California aqueduct and the Delta-Mendota Canal (Farr et al. 2017). Subsidence-related cost estimates for the CVP and SWP aqueducts are not available, but some local infrastructure costs have been estimated. For a discussion of impacts to Sack Dam, where continued subsidence will cost local farmers $10 million to move water that can no longer flow by gravity because the land has shifted, see Richtel (2015). Subsidence-related damage to a bridge over a canal in Fresno County will cost $2.5 million to repair (KSFN 2015).

[23] This is the estimate of wells reported dry as of December 2016. See technical appendix Table B3 for a breakdown by county. Hanak et al. (2015) Table A6 provides data on small water systems with compromised water supplies.

Persistent Water Quality Challenges

Nitrate Contamination of Drinking Water

One pervasive problem is the accumulation of nitrate in groundwater, due to decades of intensive use of nitrogen fertilizer and dairy manure on fields (Figure 11).[24] Much of the nitrogen not consumed by crops moves slowly downward into groundwater supplies, eventually threatening drinking water sources. A detailed study for the Tulare Lake hydrologic region, where the problem is widespread, found that roughly 250,000 residents—11 percent of the region's population—are already highly susceptible to nitrate contamination.[25] Nitrate ingestion is particularly harmful for infants—causing "blue baby" disease (reduced oxygen in the blood).[26] Water treatment can remove it, but this can be costly.

The nitrate problem is most acute for small community and domestic wells that are relatively shallow, where nitrate concentration is often higher. Small communities also face higher costs in addressing contamination, because they lack the economies of scale in water treatment available to larger water systems. In addition, these communities are often poor, and lack the technical, financial, and managerial resources needed to operate upgraded systems.

This crisis has spurred multi-pronged efforts to find near-term safe drinking water solutions for communities affected by nitrate and other groundwater contaminants, such as naturally occurring arsenic and hexavalent chromium. It has also prompted a policy to reduce the amount of nitrogen entering the environment from farms ("nitrogen loading"), which can reduce groundwater contamination over the long term. In 2007, the Central Valley Regional Water Quality Control Board ("regional water board") began requiring dairies to obtain permits to discharge nitrogen and salts into surface and groundwater through the Central Valley Dairy Order. And in 2010, the regional water board's Irrigated Lands Regulatory Program (ILRP) expanded its earlier focus on protecting surface waters from a range of pollutants originating on farms (e.g., pesticides, pathogens, and sediment) with a new requirement that growers shift to farming practices that also reduce the release of excess nitrogen into soils and aquifers (Harter 2015).[27]

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[24] Lagoons used to store manure at dairies also contribute to spikes in groundwater contamination.

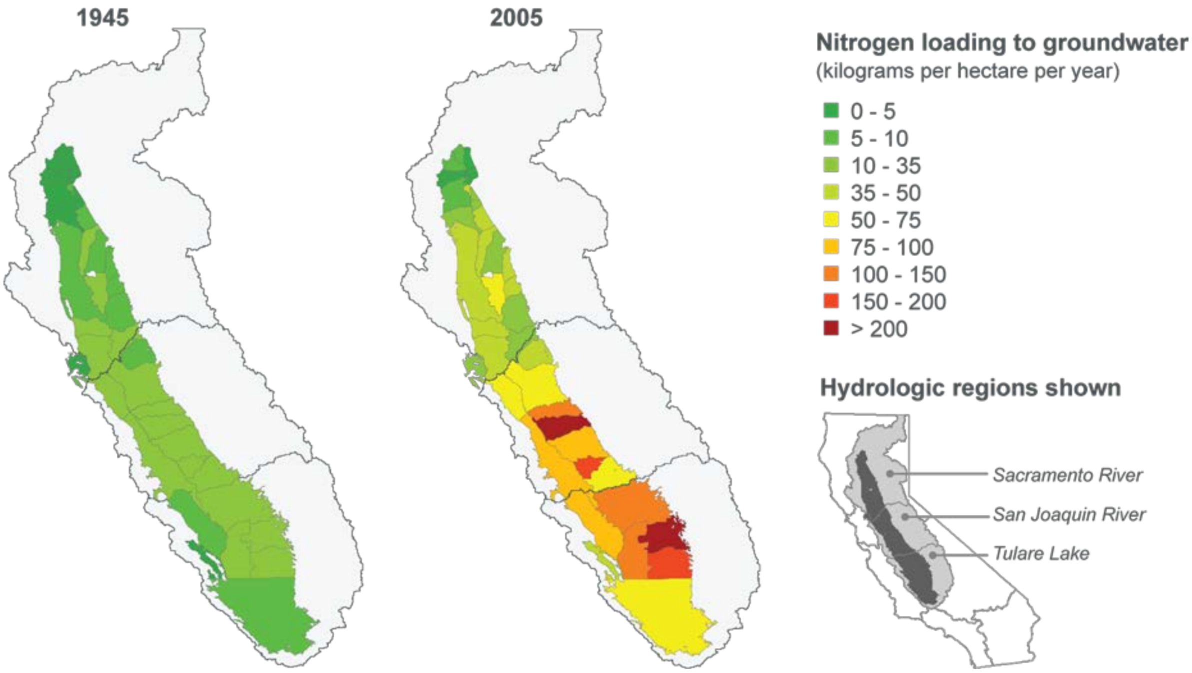
[25] See Honeycutt et al. 2012. This includes nearly 33,000 residents served by domestic wells or very small local water systems, with fewer than five connections. This estimate excludes the City of Fresno, which has some wells susceptible to nitrate but benefits from significant economies of scale in managing the problem through blending with surface water and treatment. For a map of small water systems in economically disadvantaged communities that are vulnerable, see Technical Appendix B, Figure B8.

[26] For more background on nitrate see Addressing Nitrate in California's Drinking Water: Questions and Answers.

[27] The ILRP's surface water program launched in 2003, and the Central Valley regional water board began issuing waste discharge requirements addressing both surface and groundwater in late 2012 (State Water Resources Control Board 2016a).

FIGURE 11

Nitrate contamination of groundwater is a widespread problem in the San Joaquin Valley



SOURCE: Harter et al. (2016).

NOTES: Thirty-five kilograms of N per hectare per year (about 31 pounds per acre) is a benchmark to separate "low-intensity" from "high-intensity" loading (Viers et al. 2012). All areas shaded in yellow, orange, and red are experiencing high-intensity loading.

Salt Accumulation and Reduced Farmland Productivity

Salt accumulation in soils and groundwater is also a longstanding problem for agriculture in parts of the valley, particularly on the west side of the Tulare Lake hydrologic region (Figure 12). High levels of salt in irrigation water reduce yields and limit the types of crops that can be grown. And when salts accumulate in the soil, this reduces its productivity, ultimately making it unsuitable for farming. These problems cost valley farmers around $370 million per year in lost revenue (MacEwan et al. 2016). High salt content also raises costs for drinking water, potentially requiring costly desalting.

There are several main sources of salts in the valley:

- it occurs naturally in some groundwater;
- irrigation mobilizes naturally occurring salts in local soils;
- crops use irrigation water, but leave most minerals—including salts—in their root zone;
- poor drainage of irrigation water keeps salty groundwater close to the root zone; and
- water imported from the Delta has a relatively high salt content.

The problems caused by salts are more pronounced in areas with overdrafted groundwater basins, such as those in the central and southern valley.[28]

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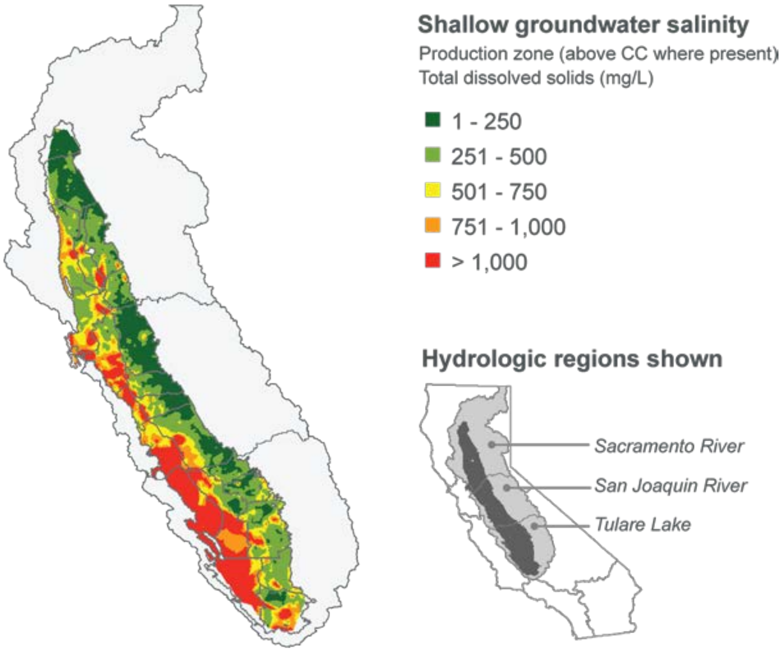
[28] In these basins, salts flushed from the root zone to groundwater are trapped and concentrated in a closed loop: groundwater is pumped for irrigation, crops remove water as they grow, salts are left in the root zone and flushed back to groundwater. Each pumping and recharge cycle increases salinity, causing long-term degradation of the aquifer. 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, thus exporting accumulated salt out of the region to the Delta.

FIGURE 12
Salinity is a growing problem for crop productivity on the San Joaquin Valley's west side



SOURCE: CV-SALTS, "High Resolution Ambient Water Quality Mapping." Draft, May 2016.

NOTES: The figure shows shallow groundwater salinity on the valley floor. Levels above 1,000 milligrams per liter of total dissolved solids (TDS, a measure of salinity) increasingly limit crop yields and crop choices. CC is Corcoran clay.

Although there is a long history of efforts to mitigate salt accumulation, the state has only recently proposed a regulatory approach.[29] Building on the Dairy Order and the ILRP, the Central Valley SALTS program is a stakeholder-led effort to comply with the state's overarching "anti-degradation" policy, which seeks to maintain water quality at levels that protect existing uses. In this case, the goal is to avoid further salinization of the Central Valley aquifer system.[30] CV-SALTS was launched in 2009 and involves municipal and industrial dischargers in addition to farmers. In 2016 the coalition presented its final plan for salt and nutrient management to the regional water board (CV-SALTS 2016b). As discussed in the section on management approaches below, proposed strategies will likely increase water costs for valley farming.

Air Quality

Despite considerable improvements in recent years, the San Joaquin Valley still has some of the nation's worst air quality, with dangerously high levels of smog-forming ozone and particulate matter that increase respiratory and cardiovascular health risks. In part, this results from the valley's natural features: the bowl-shaped topography, bordered by mountain ranges, hinders air renewal. A variety of pollution sources contribute to the problem—notably heavy and growing vehicular traffic. Farm operations and practices such as agricultural waste burning are

[29] For a discussion of earlier efforts, see Orlob (1991) and San Joaquin Valley Drainage Program (1990).

[30] The program's full name is Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS). For a description, see Harter (2015).

also important sources.[31] Several recent programs have sought to reduce farm-related emissions, by controlling agricultural waste burning, retrofitting diesel irrigation pumps and old tractors, and replacing heavy-duty trucks with newer, cleaner models.[32]

Current air regulations require farmers to limit dust when driving farm equipment on dirt roads and fields, but they do not address dust-related emissions from fields that are left fallow during the growing season. As discussed below, the implementation of SGMA—with its requirement to reduce long-term groundwater overdraft—raises the prospect of a significant increase in idled lands in the decades to come, and the need to consider ways to limit air pollution from these lands.

A Transformed Natural Environment

Similar to other agricultural regions in the US, the establishment of commercial farming in the valley brought many changes in water and land management which over time thoroughly transformed its natural environment. In recent decades, policies to restore some water in rivers and wetlands to support fish, birds, and other species have increased competition—and the potential for conflict—with other water uses. There are also challenges in managing land for vulnerable terrestrial wildlife.

Land Use Change and the Transformation of Valley Ecosystems

The region was once one of California's most productive areas for fish and wildlife (Garone 2011, Gronberg et al. 1998). The valley floor had a vast chain of lakes and wetlands that supported fish, frogs, elk, bear, and waterfowl. Lake Tulare was the largest freshwater lake (in surface area) west of the Mississippi. The San Joaquin River basin supported runs of up to a million salmon a year.

Agricultural expansion converted much of the wetlands and floodplain areas to grazing and farmland. In the early to mid-20th century, dams for irrigation and flood control were built on all valley rivers. These efforts transformed the land and changed the distribution and seasonality of water within the region. Today, most of the valley floor is a vast agroecosystem, managed intensively for crop production. The remaining areas—which include wildlife refuges, strips of riparian forest, regulated rivers, and small restoration projects—are novel ecosystems that contain a mixture of native and non-native species. Such areas require intensive management to maintain their vulnerable native wildlife and fish populations.

The passage of the Endangered Species Act (ESA) in 1973 led to numerous listings of valley animal species as threatened or endangered, including spring-run Chinook salmon and steelhead trout (US Fish and Wildlife Service 2016a). Because of irreparable changes in their habitat, some of these species are unlikely to return to the valley in significant numbers. But for some 18 vertebrate species listed under federal or state ESAs—including birds, mammals, fishes, amphibians, and reptiles—protection and recovery remain important drivers of land and water management (Figure 13). The need for water and habitat on private land to protect these species has fostered a culture of conflict between landowners, farmers, and other water users and the regulatory agencies charged with species protection.

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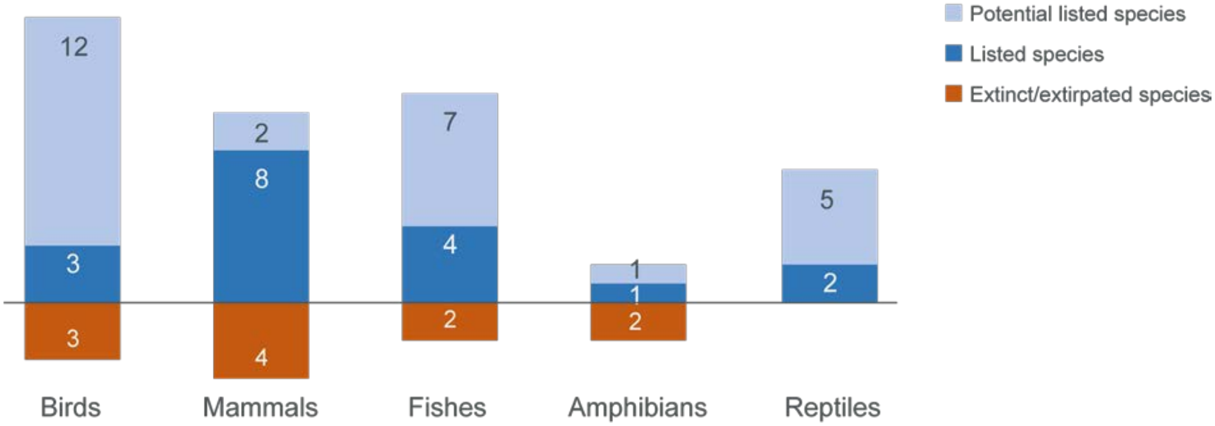
[31] In its 2015–16 annual report, the San Joaquin Valley Air Pollution Control District identified farm operations as responsible for 22 percent of particulate matter (PM) 2.5 emissions, and agricultural waste burning and forest management for another 5 percent. Farm equipment accounted for 17 percent of annual emissions of oxide of nitrogen (NOx), and farm operations (including confined animal feeding operations) and pesticides and fertilizers accounted for 30 percent and 5 percent, respectively, of volatile organic compound (VOC) emissions. Ozone is created by photochemical reactions of NOx and VOC in sunlight. (San Joaquin Valley Air Pollution Control District 2016).

[32] On the agricultural waste management program, see California Air Resources Control Board (2016a), p. 46. On the other programs, see San Joaquin Valley Air Pollution Control District (2016). The recent closure of many bioenergy facilities, unable to procure long-term power purchase agreements at current energy prices, is limiting the ability to convert agricultural waste to biofuel, and prompting the regional air district to consider allowing increased agricultural burning of some crops.

FIGURE 13

Native species decline is driving water and land use regulation in the San Joaquin Valley



SOURCE: Developed by the authors using information from the California Department of Fish and Wildlife (see Technical Appendix C for details).

NOTES: This exercise only considers vertebrate species. "Extinct/extirpated" refers to species that once were present in the San Joaquin Valley, but are either extinct, extirpated, or occur at very low densities (e.g., red-legged frog, willow flycatcher, and pronghorn). Most of the extirpated species are listed under the federal or state ESAs, but the region does not figure prominently in their critical habitat designations or recovery plans. "Listed species" are species listed under the federal or state ESAs that are still present in the valley, and a focus of local recovery efforts. "Potential listed species" are those recognized as "species of special concern" by the California Department of Fish and Wildlife and could become listed in the future. Such listings have the potential for significant additional impacts on management and regulation in the San Joaquin Valley.

The complexity of the conflict is exemplified by current practices around the idling of farmland. Even in wet years, some idling of fields is a common part of farm management, including to improve crop yields.[33] In discussions with farmers around the valley, they explained that farmers often till—or "disk"— these fields to ensure they don't grow vegetation, which can harbor wildlife. The concern is that these lands may be colonized by listed species and restrict their future use for farming. While regulatory incentive programs exist to address this type of situation, it appears that many private landowners in the San Joaquin Valley do not have sufficient trust in the regulatory agencies for these solutions to be effective.[34]

Recent Ecological Restoration: A Focus on Flows

Some of the most heated conflicts have occurred over the allocation of water to improve environmental conditions in the valley's rivers and wetlands, as well as the Sacramento River watershed—the source of most Delta imports. The combined effect of these allocations on water supply has not been well documented, but they have reduced water deliveries for irrigation, particularly for some farmers dependent on Delta imports.[35] Here we summarize some key changes to water allocations:

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[33] For instance, in 2011 (a wet year), the NASA Ames Research Center used satellite imagery to estimate that there were 1.2 million of acres of idled farmland in the Central Valley floor (including the Sacramento and San Joaquin Valleys); see Howitt et al. (2015), appendix C. Howitt et al. (2015) estimated additional land idling of 540,000 acres from drought-related water shortages in 2015.

[34] One example is a program known as "safe harbor" agreements, which protect landowners who agree to provide habitat on their lands from regulatory sanctions related to such actions. As shown in Table 1 below, there have been only three safe harbor agreements in the San Joaquin Valley. In the Sacramento Valley, there have been 10, including several agreements covering multiple counties (US Fish and Wildlife Service 2016b).

[35] See Cody, Folger, and Brown (2015) for a review of regulatory programs and other factors affecting Delta imports. Using state and federal data, including information provided by agency managers, the authors provide ranges of estimates of regulatory effects on exports for some years, but also note the difficulty of determining the role of regulatory versus hydrologic factors in Delta imports during the latest drought. They also describe the overlapping nature of some environmental regulations affecting Delta imports.

- **ESA-related actions for salmon, Delta smelt, and other listed fish.** Since the early 1990s, the listing of several fish species as threatened or endangered under the federal ESA—including two runs of salmon, Central Valley steelhead, and Delta smelt—have altered operations for the CVP and SWP and reduced Delta imports. This has been especially true since 2008, when the "biological opinions" governing these projects' operations were revised following a federal court decision that the existing levels of pumping were harming protected species.[36]
- **Support for wetlands and salmon under the Central Valley Project Improvement Act (CVPIA).** This law, passed by Congress in 1992, mandated changes to the CVP to benefit fish and wildlife throughout the Sacramento–San Joaquin watershed. One focus is allocating flows for wetlands that support ducks, shorebirds, and other aquatic species—including numerous wetlands in the San Joaquin Valley.[37] The CVPIA also dedicates flows to support salmon recovery, deducted from deliveries to CVP contractors on the west side. While water deliveries to these irrigation districts have fallen—by 600,000 to 800,000 acre-feet per year—total environmental flows have not increased by a commensurate amount. This is because these flows also help fulfill other environmental water regulations in the Delta—including ESA requirements and obligations to maintain Delta water quality for multiple purposes (cities, farms, and fish) under state and federal water quality laws.[38] Thus the CVPIA reduces the amount of water that other water users—including those receiving SWP water within the valley—need to contribute to meet regulatory standards.
- **Support for San Joaquin River restoration.** In 2009, after an 18-year lawsuit, Congress authorized the San Joaquin River Restoration Program, which initiated a massive effort to return year-round flows to sections of the San Joaquin River that had gone dry as a result of the Friant Dam operations. This program was designed to minimize water reductions for irrigators by allowing the recapture and reuse of most of these flows downstream.[39]

Additional policies in the offing could change environmental flows—and water supplies for other users—in different ways. In September 2016, the State Water Board proposed increasing environmental flows to support salmon and steelhead on three San Joaquin River tributaries—the Merced, Stanislaus, and Tuolumne—a move that would reduce flows to water-right holders on the east side and the San Francisco Bay Area communities that draw from the Tuolumne River (State Water Resources Control Board 2016b). The board is also considering increased Delta outflow requirements from the Sacramento River to support salmon, steelhead, and smelt within the larger watershed (State Water Resources Control Board 2016c)—potentially lowering Delta imports.[40]

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[36] See US Court of Appeals (2014a and 2014b) and Lund (2016). Biological opinions are developed by the fisheries agencies, and indicate how the projects must operate to minimize harm to ESA-listed species. Prior to the 2008 changes, the projects had more flexibility to meet the environmental flow requirements and minimize losses in their water deliveries, including by shifting the seasonality of pumping, which lessened overall water supply impacts on water deliveries. This flexibility was reduced with the updated biological opinions. For long-term trends in Delta imports, see Mount et al. (2016a) and Cody, Folger, and Brown (2015). Delta imports were higher in many years during the 2000s than in earlier periods.

[37] For some estimates of water deliveries to Central Valley wetlands, see Central Valley Project Improvement Act Refuge Water Supply Program (2009). That study 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). Some of the water delivered to wetlands is purchased from irrigation districts with relatively senior water rights, using funds collected from CVP contractors (Hanak and Stryjewski 2012). Within the San Joaquin and Tulare Lake regions, there are 90,000 acres of wetlands, of which 65 percent is privately owned, mainly managed for duck hunting. The Central Valley as a whole has more than 200,000 acres of managed wetlands (Central Valley Joint Venture 2006).

[38] See Cody, Folger, and Brown (2015), pp. 26-27, for an example of CVPIA water allocations in 2014.

[39] The average 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 (The San Joaquin River Litigation Settlement, Final Q&A, n.d.).

[40] For information on Phase II of the board's Bay-Delta effort see San Francisco Bay/Sacramento – San Joaquin Delta Estuary (Bay-Delta) Program. State Water Resources Control Board (2016c) provides analysis of potential new environmental flow requirements within the watershed.

Meanwhile, federal legislation enacted in December 2016 could increase Delta imports by relaxing ESA-related pumping restrictions (Mount et al. 2017).

Other Potential Changes in Store

While most of the efforts described above have focused on improving habitat for species already listed under the federal or state ESAs, the valley also has at least 27 native species that could become candidates for listing if their conditions do not improve (Figure 13). Examples include fishes (Pacific lamprey, Sacramento hitch), amphibians (western spadefoot toad), reptiles (California glossy snake), birds (tricolored blackbird), and mammals (short-nosed kangaroo rat).

These species are currently considered in many conservation plans and voluntary conservation efforts in the valley. If they become listed under the ESA, this could reduce the flexibility of management approaches and increase conflict over land and water management. It would be preferable—both economically and ecologically—to develop pro-active approaches that avoid listings. As discussed in the section below, fostering multi-benefit approaches to managing the natural environment may help parties move beyond the current culture of conflict. Some of the voluntary conservation efforts now underway in the valley offer promise in this regard.

Management Strategies and Approaches

Valley agriculture needs solutions that can bring water supplies and demands into balance, while also addressing a range of farm-related water and air pollution problems and ecosystem decline. Tackling these related challenges effectively will benefit not only the region, but the state as a whole. Here we briefly explore a range of management strategies and approaches. We highlight some considerations for choosing strategies, and ways in which cooperative, integrated approaches—where various parties work together to address multiple goals simultaneously—may be especially promising. More in-depth analysis of these approaches will be a focus of a longer report to be published in 2018.

Although our focus is on valley agriculture—the sector most vulnerable to water stress—the region's growing urban and suburban communities also play important roles in managing water and land use in the valley, and they will be key partners in developing and implementing effective solutions to pressing problems (Box 4). More generally, coordination among a range of entities involved in water and land management and oversight will be increasingly important—as discussed in the following section.

Box 4. The Role of Urban Areas in Forging Solutions

In recent decades, the San Joaquin Valley has had one of California's fastest-growing populations, and this trend seems likely to continue. Between 1990 and 2015, population in the eight valley counties increased by 50 percent—or nearly 1.4 million residents—and the state projects nearly 1.8 million more residents by 2040. To date, much of this growth has expanded the urban and suburban footprint onto adjacent farmlands, rather than increasing the density of development on existing urbanized lands.

Although urbanization has converted some productive farmlands, it has not reduced total irrigated acreage (Figure 3). Farmers have been able to adapt by productively farming less-fertile soils, thanks in part to irrigation technology improvements. Also, cities use much less water than farms. From 1998–2010, cities used just 8 percent of the total gross water use of cities and farms. The urban share of net water use—the measure that matters most for the region's water balance—was much lower (4 %). This is because most urban water use in the Valley becomes available for reuse as return flows into rivers or aquifers.

Continued growth could mean additional competition for prime farmland, something that valley communities could consider in their land-use planning. In contrast, we do not expect that urbanization will significantly reduce water available for farmland irrigation. This is because the main net urban water use in the valley is landscape irrigation, and there are opportunities to significantly reduce outdoor watering over time. As an example, when the state called for mandatory reductions during the latest drought, gross urban water use in the valley fell from 226 to 169 gallons per person per day, and much of this decline was from reduced landscape irrigation. Urban water agencies are likely to continue promoting outdoor savings as part of the state's long-term conservation goals.

Cities and towns will be important partners with farms and rural communities in addressing the Valley's water management challenges. All parties need to be involved in implementing SGMA, and cooperative approaches can help bring basins into balance. Examples of partnerships already exist in recharging groundwater basins, supplying farms with treated wastewater, and upgrading local infrastructure to manage water more efficiently. And there is potential for more. Cooperation to protect and manage recharge areas can be valuable, because many of the lands with good recharge potential are on the urban fringe. Cities and towns can also help address problems of safe drinking water in small rural communities by connecting these communities to the larger, safer, and more cost-effective urban systems where feasible.

Continued urbanization is also likely to influence the local demand for environmental quality, including greater pressure to protect air quality. A growing population will also increase the demand for open space and natural amenities. These shifts will present challenges for valley agriculture, but also opportunities to seek solutions that provide multiple benefits.

Balancing Water Supplies and Demands

The water balance described in this report shows a large, long-term imbalance between the valley's local and imported water supplies and its water demands. To close the gap, water users have drawn down groundwater reserves in all but a few years since the mid-1980s, and overdraft has averaged roughly 1.8 million acre-feet per year. Valley farms and communities will need to end this practice as they implement the state's groundwater law. Here we consider several broad sets of tools that can help achieve this goal: managing groundwater reserves, expanding usable water supplies, reducing demand, and increasing the flexibility of the water system.

In weighing these approaches, it is important to recognize that the extent of overdraft—and the corresponding management challenges—vary considerably across the region.[41] For instance, the groundwater deficit is relatively

[41] This discussion draws on estimates of overdraft from the California Department of Water Resources California Central Valley Groundwater-Surface Water Simulation model (C2VSim).

low in the northeastern part of the valley (near Turlock and Modesto), where most farmers have senior rights to water from San Joaquin River tributaries. The deficit is also moderate in areas on the west side. Even though many farmers with low-reliability CVP contracts are under pressure to find other supplies, the groundwater can be too saline for irrigation. Overdraft is most severe in parts of the Tulare Lake hydrologic region—including Kern County.

If the 30-year gap shown above needs to be met entirely by reducing pumping, this could lead to irrigated acreage cutbacks of roughly 500,000 acres valley-wide. The gap could be smaller if strategies are implemented to expand local and imported water supplies. And it could be larger if these supplies are lower, reflecting a drier climate, increased urban demands, or increased environmental flow requirements—all factors contributing to higher overdraft since the early 2000s.

To minimize revenue losses from reduced pumping, growers would likely stretch available supplies somewhat by changing irrigation management and crop choices, and they would reduce their least profitable activities first when they need to idle land. As an example, in 2015, at the height of the recent drought, San Joaquin Valley farmers faced water shortages of around 10 percent compared to pre-drought conditions. They fallowed about 8 percent of cropland, and experienced crop revenue losses of about 3 percent.[42]

For the next phase of this project, we will examine the costs and benefits of bringing the valley's groundwater into balance under a range of water supply conditions and management approaches. The costs include investments to expand usable supplies and the economic losses from fallowing cropland to close the water gap. Stabilizing groundwater levels also brings long-term benefits. Growers benefit from reduced energy costs of pumping, reduced need to replace pumps or deepen wells, and improved reliability of water to irrigate their most profitable crops.[43] Other regional benefits can include reduced damage to infrastructure from land subsidence, fewer declines in water quality, and reduced energy use and well replacement costs for drinking water systems.[44]

We now briefly examine the range of approaches that can help the valley make the transition to sustainable groundwater management in ways that lessen the costs and increase the benefits. The next phase of this project will also examine these solutions in greater depth.

Managing Groundwater Reserves

By July 2017, groundwater users in 15 of the valley's 16 basins must have formed Groundwater Sustainability Agencies (GSAs)—the entities that will have local oversight responsibility for developing Groundwater Sustainability Plans (GSPs) and attaining water balance. GSAs in the 11 critically overdrafted basins must adopt and begin implementing GSPs by 2020, and the others must start by 2022 (Box 2).

The law gives local GSAs the authority to monitor and measure use and charge fees to cover the costs of basin management. At a minimum, GSAs need solid water accounting tools—including monitoring systems and models of how water moves within the basin—to understand how much water is available and how much is being withdrawn (Escriva-Bou et al. 2016). They also need the ability (and authority) to incentivize or require reductions in pumping when needed to attain long-term groundwater balance.

[42] These comparisons are relative to 2010, an above-normal water year. Farmers faced larger cuts in surface water deliveries, but they made up some of these cuts with extra groundwater pumping (Howitt et al. 2015).

[43] See RMC Water and Environment, M. Cubed, and ERA Economics (2015) for an economic analysis of some of the factors noted here for the Kings and Tulare basins.

[44] Within the San Joaquin Valley, there are few remaining cases where groundwater pumping depletes surface water flows, because sustained overdraft has broken the hydrologic connection with surface flows. For this reason, reducing overdraft in this region is unlikely to create significant benefits for surface water users and the environment. Such benefits are more likely in parts of the state where groundwater basins are less depleted, and still closely connected to river flows, such as the Sacramento Valley and some coastal areas.

To date, groundwater management discussions in the valley have tended to shy away from approaches that assign pumping rights to groundwater users, hoping instead that matters can be resolved through voluntary efforts to increase recharge or reduce demand. But assigning or managing pumping rights—commensurate with the amount of natural recharge from precipitation and runoff—could incentivize additional management tools to help bring basins into balance at lower cost.

For instance, once water users know how much they can safely pump—i.e., their sustainable share of natural recharge—they can implement robust groundwater banking and trading programs. With groundwater storage, water users can decide to carry over some of their annual pumping allotments and bank them until later years without fear that someone else will take the water in the meantime.[45] With trading, water users within the basin who could benefit most from using more than their share—for instance, to keep orchards thriving during droughts, when surface supplies are low—will be willing to compensate others who can use less.[46] Groundwater accounting systems can also incentivize recharge programs that benefit other groundwater users—for example, by crediting water users who incur costs to recharge the basin.[47]

At a minimum, GSAs will need to collect enough funds from local water users to cover the costs of monitoring and basin oversight. Ideally, they would also collect funds to cover the costs of recharge. This is already a common practice in managed basins in Southern California, the Bay Area, and the Central Coast, where water users pay for recharging the basin with Delta imports, recycled water, and stormwater.[48] To facilitate flexible basin management, GSAs could also have funds to cover the costs of mitigating negative external impacts from pumping. For instance, during droughts, there are likely to be substantial overall economic benefits from allowing extra pumping, even if this causes the water table to fall. Having a fund to cover related problems—such as dry domestic wells—can mitigate harm to vulnerable members of the community.[49]

Expanding Usable Water Supplies

Since the passage of SGMA, residents have become even more keenly aware of the importance of expanding water supplies. Every drop of water added makes it easier to meet SGMA mandates with fewer reductions in water use and irrigated acreage. No "silver bullet" can erase the valley's large water deficit, but a variety of options could help reduce it:

- **Capturing and storing more local runoff**. Options include increasing groundwater recharge by capturing and spreading more winter and spring flood flows onto fields and into recharge basins, and building new surface storage—such as the proposed Temperance Flat reservoir on the San Joaquin River. Most water originating in the valley is already used locally, however, and it can be costly to capture all runoff in wet

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[45] Under Kansas' Multi-year Flex Account Program, groundwater users are allowed to bank or exceed their annual groundwater allotments in any year, with total pumping restricted on a rolling five-year basis. See the Kansas case study in the technical appendix to Escriva-Bou et al. (2016).

[46] A good example of this practice is in Southern California's Mojave Basin—an adjudicated basin where pumping shares are regularly traded (Hanak and Stryjewski 2012). In contrast to most adjudicated basins in that region, Mojave has many agricultural pumpers, in addition to urban agencies.

[47] A pilot program to incentivize recharge in this way is occurring in the Pajaro Valley (Fisher 2016).

[48] In the Santa Clara Valley Water District and Orange County Water District, water users pay a pumping fee that covers the cost of bringing in Delta imports. In the Pajaro Valley Water Management Agency on the Central Coast, which is not connected to the statewide water system, water users pay to cover the costs of recharging the basin with local recycled wastewater and stormwater. For a discussion of groundwater basin funding, see Hanak et al. (2014b).

[49] Domestic wells are usually shallower than irrigation wells, and more likely to go dry with falling water tables. 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 the San Joaquin Valley, the Rosedale Rio Bravo Water Storage District has a similar practice.

years.[50] DWR estimates that about 300,000 acre-feet per year might be available for recharge, mostly in the wetter northern half.[51]

- **Reusing and repurposing local supplies.** In some parts of the valley, water reuse is an option—such as by irrigating fields with recycled wastewater from cities or oil wells, or desalting brackish groundwater. However, recycled water for irrigation has limits due to salinity and food safety concerns. And it usually does not increase overall supplies, because treated wastewater is generally already used by others downstream in the basin.[52] A similar issue arises with investments to expand supplies by increasing irrigation efficiency. Within the valley, irrigation water not consumed by plants generally returns to rivers or recharges aquifers, where it becomes available for reuse (Box 3). Although irrigation efficiency investments can have other substantial benefits—including improving the quality of crops harvested and reducing the discharge of fertilizers into streams and aquifers—greater irrigation efficiency often does little to expand usable supplies (Lund et al. 2011).
- **Improving Delta conveyance and Northern California storage.** Given the importance of Delta imports to much of the valley, options to increase—or at least stabilize—Delta supplies are of great interest (Nelson et al. 2016). The proposal to improve Delta conveyance by building tunnels underneath the Delta to move water from the Sacramento River to the pumps in the southern Delta—known as California WaterFix—is not currently projected to greatly increase imports beyond current levels, but it would improve their reliability.[53] And by increasing the flexibility of water operations in the Delta, new conveyance also could make it easier for water users to benefit from water trading and new storage in the Sacramento Valley.[54]
- **Reducing import demands in coastal urban areas.** Increased investments in water conservation and local supply development in coastal areas could potentially free up some Delta imports for valley water users—or at least reduce future competition for these supplies.
- **Changing environmental flow standards.** Today, many valley interests are pressing for relaxation of existing and proposed environmental flow requirements for the Delta and the San Joaquin River, which they hope would augment—or limit future reductions of—these major, relatively low-cost supplies. As described below, new approaches for allocating environmental water—involving voluntary settlement agreements among key stakeholders and regulators—may be a more promising approach for moving beyond conflict and toward more effective environmental management.

Many of the investment options described above are included in the Brown administration's California Water Action Plan (California Natural Resources Agency et al. 2016). Some could be eligible for state and federal matching funds—such as Proposition 1, a state bond approved by voters in 2014. To date, there has not been a full evaluation of potential supplies for the valley, or of the costs of all potential projects. It is unclear which actions

[50] Outflows from the San Joaquin River system averaged 3.5 maf from 1986-2015, but much of this outflow is not available for capture because it is used downstream for direct Delta diversions, Delta imports, and maintaining water quality in the Delta. See Figure 9 and related discussion.

[51] See California Department of Water Resources (2017). These estimates assume existing water project infrastructure; some additional supplies might become available with new surface storage projects.

[52] 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 dependent on Delta imports charged that the sale reduced the normal outflows from the San Joaquin River and would reduce normal Delta imports, and Del Puerto settled the claim (Morain 2015).

[53] For the supply estimates in the final environmental documentation for the project, see California Department of Water Resources and US Bureau of Reclamation (2016), Chapter 5. Sunding (2015) provides an economic analysis.

[54] For instance, improved Delta conveyance would make the construction of Sites Reservoir—a storage facility that would store Sacramento River water—more attractive because it would be easier to deliver the water to users south of the Delta, where water is scarcer (and more expensive). Lund et al. (2014) show that new conveyance significantly expands the potential for operating Central Valley surface and groundwater storage as a system. They estimate up to 5 to 6 million acre-feet of new storage capacity could be accommodated Central Valley-wide, potentially making up to 1.4 maf of water available to CVP and SWP water users south of the Delta. This analysis is focused on hydrologic capacity, and does not consider the economic or environmental costs and benefits of such investments.

will be cost-effective from the perspectives of direct beneficiaries and state and federal agencies. Because major infrastructure investments such as new Delta conveyance and new surface storage would take many years to complete, other actions to enhance supply—such as groundwater recharge—will be most useful in the near-term for meeting SGMA's requirement to bring basins into balance.

Reducing Water Demand and Increasing Water System Flexibility

When supplies are too limited or expensive, the only option remaining is to reduce net water use, by idling land or switching to crops that consume less water.[55] When faced with scarcity, farmers will naturally choose the least profitable fields and crops to idle. Water trading—both within the valley and across regions—can lessen the overall costs of shortages. Trading makes it possible to compensate water-right holders with less profitable water uses for foregoing their own use, while keeping more profitable fields in operation. Both local and cross-regional trading is already common in parts of the valley. During the latest drought, it helped keep orchards alive in the most water-stressed areas.[56] Allowing trading of groundwater shares within managed basins could lower the costs of reducing overdraft. So could trading across basins.

Some cropping choices might also enhance system flexibility. In particular, alfalfa—an important forage crop for dairies—is a perennial that can be watered and harvested somewhat flexibly. When supplies are tight, farmers can reduce irrigation on these fields and reduce the number of cuttings without killing the plants. This approach also creates the opportunity to lease some water to others with reduced supplies.[57] And in wet years, alfalfa fields can be ideal for recharging groundwater, because they are generally watered with traditional flood irrigation systems rather than drip systems that apply less water.

Decisions on how to manage idled lands can also increase water supply flexibility. For instance, rotational fallowing may be a more economically attractive option than permanent land retirement for many farmers. This system of idling lands for a season at a time—typically with the use of cover crops—was once commonly practiced to restore soil health (Mitchell et al. 1999). Although using cover crops requires some water, it can provide both soil and air quality benefits, and it may improve soil moisture infiltration and retention, as well as long-term soil productivity (SARE 2007, Bowman et al. 2016). Some permanently idled lands may be suitable for generating revenue through solar installations, while some may be valuable as habitat.

Finally, the costs of water scarcity can be lowered by managing system infrastructure in more flexible, coordinated ways (Connell-Buck et al. 2011). One especially valuable approach is to jointly manage groundwater and surface water storage. Surface reservoirs have limited capacity to store water for dry years because they also need to make space every winter and spring to capture flood flows. Putting more of the water stored for dry years into aquifers can free up more space to capture winter and spring flows in surface reservoirs, and increase the total volume of water stored. Better coordination among federal, state, and local water projects can also make it easier to take advantage of recharge opportunities. As the climate warms, reservoir operating rules will need to be adapted to accommodate shifts in the timing of runoff from a shrinking snowpack.

Improving Water and Air Quality

Solutions to water and air quality problems include a variety of new management approaches, changes in technology, and agronomic practices.

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[55] This can include changes in urban landscaping within the valley, such as reductions in the use of turf grass, a relatively thirsty plant (see Box 4).

[56] For a discussion of water market rules and water trading patterns, see Hanak and Stryjewski (2012). For trading during the latest drought, see Howitt et al. (2015).

[57] Partial fallowing in this way is a strategy now being piloted in the Colorado River basin as a way to reduce net water use (Fleck 2016).

Nitrate

Nitrate contamination of the valley's groundwater is, in large part, a legacy issue associated with historic farming practices. Because it typically takes decades for nitrate to move through aquifers, near-term changes in farming practices can rarely resolve the problems of contaminated wells. For communities served by these wells, other solutions are needed—including connecting to alternative water sources and installing treatment systems to remove contaminants. This is an urgent public health issue that state policies have begun to address with a variety of legal, administrative, and funding tools.[58] Valley farmers may be called on to help financially—for instance, with a small fee on fertilizer sales—and they may at times be able to support physical solutions, by hooking up homes to deeper wells or cleaner surface water supplies.[59]

Although current farming practices are more efficient in the application of both pesticides and fertilizers, reducing nitrogen loading in groundwater is an important long-term public health objective. The Irrigated Lands Regulatory Program is promoting agronomic approaches that encourage the adoption of the "4 Rs" to reduce excess application of nutrients on fields: right fertilizer, right amount, right time, right place. Because they reduce fertilizer use, these practices can be economical for growers, especially those using drip irrigation. They are most challenging for dairies, because it is much harder to manage manure fertilization with precision.

Crop choices are another management option, because some crops require less nitrogen fertilizer. Grapevines have light fertilizer needs. Alfalfa, which fixes nitrogen, requires no nitrogen fertilizer at all. A recent analysis found that farming these two crops in soils with good recharge potential had the potential to clean up groundwater in a nitrate-contaminated area while generating net benefits for farmers (Mayzelle et al. 2015).

Salts

Some farmland on the west side has already been retired due to high soil and groundwater salinity. The main solutions under consideration by CV-SALTS are capital-intensive and costly: desalting and transporting salts through a "brine line" to the San Francisco Bay, and deep injection of salt into the ground.[60] For many growers, eventual retirement of salt-impacted lands may be a more economical option than major capital investments to remove salt. Some farming practices can also 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 costs of drainage and the impacts of salt accumulation in soils. One co-benefit of new Delta conveyance is that it would slow the pace of salt accumulation by reducing the import of salts into the valley (Medellin-Azuara et al. 2008).

Dust

Given the likelihood of substantial increases in idled croplands in the valley, solutions will be needed to limit air pollution from these lands. The risks are greatest if fields are left barren, exposing large areas to dust. As noted above, cover crops on lands entering rotational fallowing are one mitigation approach that also provides soil quality benefits. Some management is also needed to prevent dust from permanently idled lands.

Reinvigorating the Natural Environment

Creative approaches will be key to improving conditions in the San Joaquin Valley's natural environment, given the many changes to the region's rivers, wetlands, and drylands since the establishment of farms and cities. One

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[58] For a discussion of new legal and institutional tools, see McCann and Hanak (2016). On funding, see Jezdimirovic and Hanak (2016) and Hanak (2015).
[59] For a discussion of the option of a fertilizer fee to help fund solutions, see Harter et al. (2012) and Hanak et al. (2014a).
[60] The Strategic Salt Accumulation Land and Transportation Study (SSALTS) finds a cost range of $650 to $2000 per acre foot per year—much higher than typical farm water costs—for removal, treatment and disposal of about 7 million tons of salt from all analyzed sources in the Central Valley (CV-SALTS 2016a).

promising direction is to move toward managing entire ecosystems rather than specific species. By setting realistic goals for these ecosystems, considering the benefits for human enjoyment of the environment alongside benefits to wildlife, and exploring opportunities to involve farmers and other residents in devising solutions, there may be opportunities to move parties beyond the culture of conflict that often permeates discussions of environmental management. As an example, valley residents might want to consider refocusing the current effort for restoring the San Joaquin River (Box 5).[61]

Box 5. An Ecosystem-Based Approach to San Joaquin River Restoration

At present the San Joaquin River restoration effort is focused on salmon recovery, but a more appropriate goal might be to resurrect the river and its riparian corridor as habitat for multiple species, not just listed fishes. The renewed river would also serve as an important place for recreation and outdoor education.

The key to the success of such a project is to be realistic about what is achievable, and recognize that the ecosystem being created is novel, not a restoration of what existed before the area was transformed by water and land development. In this novel ecosystem humans will be a constant presence, and plants and wildlife will be an unavoidable mixture of native and alien species. Thus the river resurrection could involve wildlife-friendly agriculture, such as alfalfa fields that serve as foraging areas for hawks nesting in riparian trees. Land retirement from agriculture could provide opportunities for re-creating upland habitat for native birds, mammals, and reptiles.

Beyond crafting visions for such efforts, tools and approaches are needed to put these visions into practice. Some useful tools already exist for collaborative projects on working lands. Several public-private conservation partnerships have enhanced wetland habitat and bird abundance on private lands through technical assistance and payments to help offset the costs to farmers.[62] These programs have worked with farmers to implement solutions such as fall flooding of agricultural fields in the southern half of the valley to generate habitat for migratory waterbirds. Rather than focusing on listed species, which are perceived to carry many risks for private landowners, the programs have typically focused on providing habitat for non-listed species, including waterfowl and shorebirds. Such voluntary programs should help keep common species common, and reduce the risk that more species are listed in the future.

These programs have paved the way for more flexible, market-based programs that are now being developed by various agencies and non-profit groups. Examples include the Central Valley Habitat Exchange and BirdReturns (Robbins 2014), which pay farmers to provide temporary habitat for wildlife. Unlike many conventional conservation programs, which require habitat to be created in perpetuity through "conservation easements," these efforts are based on the concept of dynamic conservation, in which habitat location can change from year to year. To date, these efforts have mainly focused on bird habitat in fields, but opportunities also exist to provide "just-in-time" flows at critical times for fish in streams.

More generally, new approaches to allocating water for the environment would also help. In water-scarce regions like the valley (and most of California), it is important for all sectors—including the environment—to use water

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[61] Ecologists refer to this kind of approach as "reconciliation ecology." For a discussion of this approach in the Sacramento-San Joaquin Delta, see Moyle et al. (2012 and 2016). Hanak et al. (2011), chapter 5, provide a general discussion of how the approach might be used in California.

[62] Agency sponsors include the Natural Resources Conservation Service's Wetlands Reserve Program, US Fish and Wildlife Service's Partners for Fish and Wildlife Program, and the state Department of Fish and Wildlife's California Waterfowl Habitat Program and Landowner Incentive Program (DiGaudio et al. 2015).

efficiently and effectively. One promising approach is to define shares of water for the environment that can be flexibly managed to support multiple species. This could be accomplished through voluntary settlement agreements involving diverse water users, regulators, conservation organizations, and other interested parties.[63] Such agreements are an alternative to traditional regulatory decisions on environmental flows. They can take a comprehensive approach to watershed management, establishing both environmental water budgets and goals for related management actions that can benefit species. This approach could improve environmental outcomes while providing more certainty to water users. It could be a key to overcoming conflict.

Recognizing the Linkages

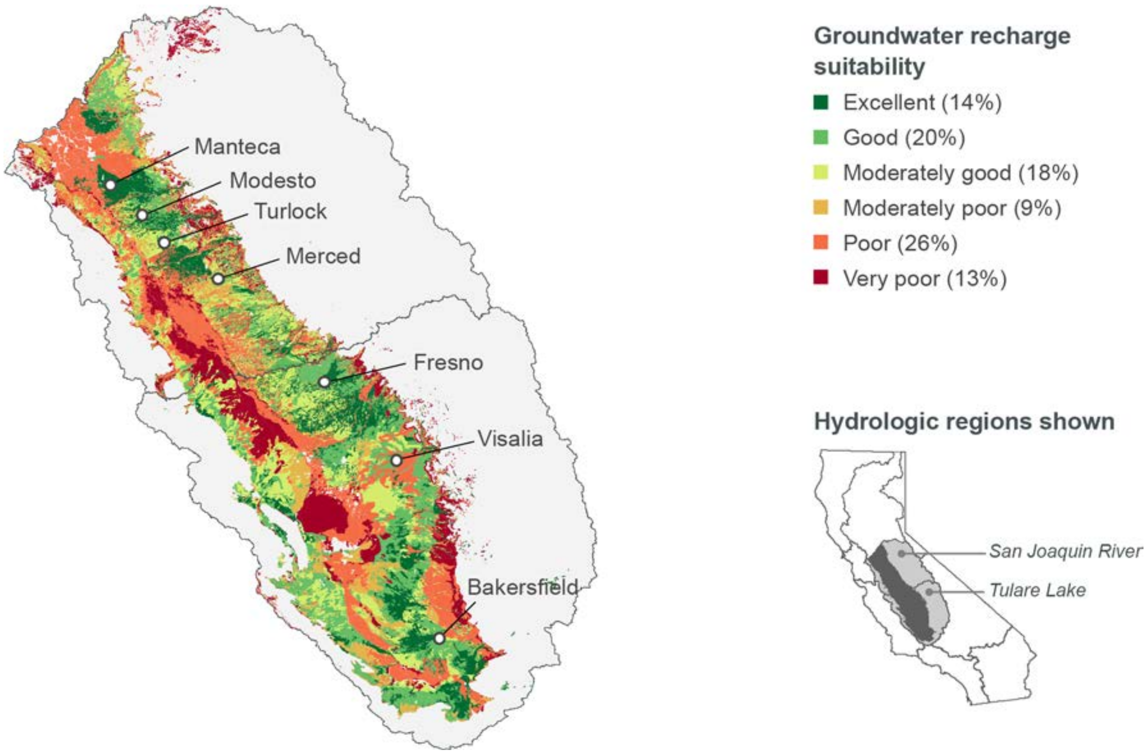
A recurring theme in the solution approaches outlined here is the potential for achieving multiple benefits from management actions. It will be easier to reap these benefits—and reduce the costs of adaptation—when solutions are considered at the right scale, recognizing opportunities that require cooperation and coordination among parties. Three areas where coordinated actions may be especially valuable are joint management of groundwater quantity and quality on farmlands, management of idled lands, and management of river corridors.

Groundwater Quantity and Quality

Managing groundwater quantity and quality can involve tradeoffs. Because groundwater moves within aquifers, groundwater recharge is best managed at a larger scale than most farms—ideally for entire basins. The characteristics of soils, irrigation systems, and crops also matter. Some soils are more permeable and recharge at higher rates, provided water is available and empty storage capacity exists in the aquifer (Figure 14). Flood irrigation systems, which channel water in furrows between plants, are most suitable for accepting large quantities of recharge water without harming crops.

[63] For a discussion of this concept in the lower San Joaquin River context and related experiences in Victoria, Australia, see Mount et al. (2016c). It could be employed in the settlement discussions now underway in the San Joaquin and Sacramento River watersheds.

FIGURE 14
Some San Joaquin Valley soils are more suitable for significant groundwater recharge



SOURCE: University of California, Davis Soil Resource Lab, Soil Agricultural Groundwater Banking Index (modified version).

NOTE: The figure shows the suitability of soils for recharge if all soils with restrictive layers that would inhibit recharge were modified by deep tillage, a practice common for some crops.

Meanwhile, groundwater nitrogen loading can be reduced by fertilizer application management (the 4Rs), drip irrigation and irrigation system maintenance, and crops that have low nitrogen requirements.[64] Managing nitrogen loads at the field scale is possible, but this can miss the benefits of more coordinated action. In many basins, it may make sense to make some cropping and irrigation choices based on the permeability of soils—placing clean, flood-irrigated crops like alfalfa in areas most suitable for recharge, and in areas where drinking water is contaminated and can benefit from flushing. (Alfalfa can also provide valuable habitat for some native bird species.) Drip systems and crops that leach more nitrogen might be better in areas with less recharge capacity. Coordinating these decisions at the basin scale—with an incentive system for farmers who invest in recharge—can bring widespread benefits. Flexible irrigation systems, which combine drip and flood irrigation, are also promising.[65] And involving city planners can be key because many prime recharge areas are located along the urban fringe, where they are at risk of being paved over for new development.

Land Idling and Habitat

Because the best farmlands often lack the most secure water rights, water trading across basins and regions can lessen the economic costs of land idling. Trading provides incentives for lower quality soils—like salinized

[64] Inadequate maintenance on fields with drip irrigation can lead to so-called "drip-flood" systems, with significant pooling of water.

[65] Such approaches are likely only suitable for some crops—e.g., deciduous trees and vines, but not citrus. Pilot work in this area is investigating how to manage water quality and plant health in flooded fields (Mohan 2016).

lands—to go out of production before prime farmland. Farmers can minimize overall costs by making such decisions at the farm level, based on market incentives.

But if all decisions about land idling are made in this way, there may be missed opportunities to get habitat benefits from land taken out of production. Coordinated approaches are needed to ensure that there is sufficient connectivity between habitat areas, and to incentivize the retirement of salinity-impacted lands before they become too salty to provide habitat benefits. This will rarely be possible at the farm scale and generally is more beneficial when done over large landscapes. It will require incentive systems—e.g., to compensate farmers who choose to retire habitat-suitable land early—as well as cost-effective programs to manage the retired land, something farmers themselves may not be able to take on.

It is also worth exploring opportunities to make it easier for lands fallowed in rotations to provide habitat benefits. Currently, farmers generally disk these fields, in part to prevent the establishment of endangered wildlife, which under federal rules can result in the loss of the right to farm them. For many species, temporary habitat may be better than no habitat at all. Indeed, it can be a key part of dynamic conservation programs that adapt as habitat needs change. Incentives—including solid regulatory assurances that farmers will not lose the right to farm the land—are key to making this work.

River Corridors

River corridors make up a relatively small area of the valley, but they support a high percentage of native species. Challenges and opportunities include flood management, environmental flows for listed and at-risk species, and the possibility of increasing riparian forests, groundwater recharge, and recreation benefits for local residents. Rather than developing piecemeal solutions for each of these issues, solutions can be bundled to provide multiple benefits. These broader solutions should enjoy greater support from a more diverse group of stakeholders, and may be eligible for funding from a broader group of programs.

Challenges of Coordination

Coordinated approaches like those outlined here are more challenging to implement than solutions that individual farmers or single institutions can implement on their own. They require more data, planning, and negotiation of roles, responsibilities, and incentives. They also requires a willingness for all parties—including regulators, landowners, water users, and other stakeholders—to take some risks to improve on the status quo. The valley's collective future will be more resilient—with a stronger economy, better public health, and a more vigorous natural environment—if parties work together to tackle challenges and achieve collective benefits. This makes institutional capacity a central issue, to which we now turn.

Crafting Solutions Within a Complex Institutional Landscape

Valley agriculture now faces major challenges to bringing groundwater basins into balance and managing water and air pollution and habitat as efficiently and effectively as possible. Although farmers, resource managers, and other parties are taking these challenges seriously, the regions' institutions are not especially well equipped to craft, adopt, and implement effective solutions outside of their own "boundaries." A highly decentralized, fragmented set of local and regional institutions makes it hard to take on coordinated, flexible, multi-benefit approaches—the kinds of solutions that are most likely to benefit the regional economy, society, and environment. And multiple state and federal agencies—vital partners in this challenge—often operate without adequate coordination and sometimes act at cross-purposes.

Coordinating Local and Regional Action

The Challenges

Under SGMA, sustainability plans must be developed for 15 of the valley's groundwater basins (Box 2). But because the law does not require a single management entity per basin, the valley is likely to have many more groundwater sustainability agencies (GSAs) than basins. At latest count, 76 agencies (including several counties) had filed applications to be GSAs within the valley, with more likely to form (California Department of Water Resources 2016). These entities will need to coordinate with each other to develop and implement groundwater sustainability plans (GSPs). They will also need to consider the practices and desires of tens of thousands of farmers and households that pump groundwater, hundreds of irrigation districts that supply surface water, and more than a thousand drinking water suppliers ranging from large systems in cities like Bakersfield and Fresno to tiny systems serving a handful of households with a single community well (Table 1).

The state's new programs to manage water quality add another layer of complexity. The ILRP is implemented by 12 irrigated lands coalitions, and CV-SALTS is anticipated to create new institutions for salt management. In addition to stretching the capabilities of local managers, this institutional fragmentation does not encourage coordination in the management of groundwater quantity and quality.

Finally, although the valley has numerous entities and programs to manage wetlands and terrestrial habitat, it lacks good models to build on for coordinated management of habitat over large landscapes.

The Opportunities

The region's farmers have strong traditions of coordinating water-related actions. This includes longstanding collective efforts to develop and operate surface water systems, and expanding systems of water trading and groundwater banking. In some areas (e.g., around Fresno, Clovis, and Visalia), cities have become key partners. These efforts provide a model for further cooperation on a variety of challenges facing the valley.

Some broader regional approaches have also been launched. Since the early 2000s, with support from state bond funding, the region has formed 17 integrated regional water management (IRWM) organizations to promote coordination on water management issues and achieve multiple benefits. Before the enactment of SGMA, these organizations had begun to facilitate new collaborations on water planning and management—including addressing safe drinking water quality in rural communities. The valley has also begun to experience more regional approaches to resource planning. 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 Greenprint, an effort to support land-use and resource-management planning in the valley's non-urban areas with maps and other tools.

TABLE 1

Management and oversight of most water and land use decisions in the valley are decentralized and fragmented

Local entities with water and land use decision making responsibilities	Number	Drinking water	Irrigation water	Water pollution	Floods	Land use	Habitat	Air quality
Local governments:								
Cities	62	◐	○	◐	◐	◐	◐	○
Counties	8	◐	○	◐	◐	◐	◐	○
Water supply:								
Agricultural groundwater users (irrigation wells)	>19,900	●	●	●				
Irrigation water suppliers	~150		◐	●				
Community water systems[3]	671	◐		◐				
State small water systems	~300	●		●				
Household groundwater users (domestic wells)	~70,000	●		●				
Non-community water systems (e.g., schools)	~1,300	●		●				
Flood control:								
Land reclamation/levee districts	65				◐	◐	◐	
Flood control districts	25				◐	◐	◐	
Water pollution management:								
Wastewater agencies[2]	179			◐				◐
Drainage districts	97			◐	◐			
Central Valley Salinity Alternatives for Long-term Sustainability (CV-SALTS)	1			◐				
Habitat:								
National wildlife refuges (incl. Grasslands Wildlife Management Area)	10					◐	◐	
California Department of Fish and Wildlife ecological reserves & wildlife areas	27					◐	◐	
State Parks	10					◐	◐	
Private conservation areas (e.g., land trust preserves)	54					●	●	
Resource conservation districts	27					◐	◐	
Conservation easements held by non-profits and state agencies	105					◐	◐	
Conservation easements held by federal agencies	~390					◐	◐	
Habitat conservation plans/Natural community conservation plans	24					◐	◐	
Safe harbor agreements	3					◐	◐	
CDFW-approved conservation banks	7						◐	
Integrated resource management:								
Integrated regional water management regions	17	●	●			●	●	
Irrigated lands coalitions	12		●	●		●	●	
Groundwater sustainability agencies (15 SGMA sub-basins)[3]	>76	◐	◐	◐		◐	◐	

● Resource management ○ Regulation ◐ Resource management and regulation

SOURCES: Developed by the authors from various sources (see Technical Appendix B, Table B4).

NOTES:
(1) There are 481 community water systems with fewer than 200 service connections, 85 systems with 200-1,000 connections and 105 systems with more than 1,000 connections.
(2) Wastewater agencies include 58 cities, 118 special districts and 3 private utilities.
(3) The valley has 15 basins that must have management plans under SGMA. As of January 2017, there were 76 GSAs formed in the San Joaquin Valley (California Department of Water Resources 2016b). The final number will be known by July 1, 2017.

To succeed in implementing SGMA, some of the larger, more established institutions with greater administrative, technical, and management capacity—such as large irrigation districts, cities, and counties—will need to lead in GSP development. In some parts of the valley, IRWMs can play this role. All GSPs will need to include a broad range of perspectives, including those of smaller and less powerful interest groups, such as disadvantaged communities. Over time, consolidation of GSAs will be desirable. And some organizations—whether IRWMs, GSAs, or other entities such as joint powers authorities—will need to serve as the umbrellas for coordinating the many interests who will need to work together to manage water quantity and quality and related land-use decisions. In doing so, valley interests may look to adopt some of the best practices from elsewhere in California—such as water agencies taking on environmental management goals, and coordinated participation and use of private lands for farming and habitat management.[66]

Aligning State and Federal Action

Although local parties—especially local governments and water agencies—will likely lead most of the initiatives outlined here, state and federal agencies have important regulatory, management, and funding roles that can hasten or impede solutions (Table 2). These agencies can best support successful adaptation in the valley by encouraging flexible, cost-effective, multiple-benefit approaches. The following examples illustrate helpful shifts in policies and practice.

Align Funding and Technical Support with Key Regional Goals

State and federal agencies can provide valuable support for meeting key regional goals of implementing SGMA—in tandem with water and air quality and habitat improvements—by aligning their funding programs and technical support with these goals.

Federal agencies—including the US Department of Agriculture's Natural Resource Conservation Service (NRCS) and Farm Service Agency (FSA) and the US Bureau of Reclamation—are key sources of funding for conservation-oriented investments in the agricultural sector, including on-farm and irrigation system improvements, soil conservation, and land and water conservation for habitat (Mount et al. 2016d). But at present, these programs provide funds without much consideration for strategic regional challenges. For instance, they place a heavy emphasis on funding efficient irrigation technology, which can improve water quality but may limit groundwater recharge in the most suitable areas. Beyond more strategic use of dollars for such efficiency upgrades, it would be valuable to augment support for programs that support soil health and wildlife habitat, particularly as land moves out of production on a rotational or permanent basis.[67]

State and federal programs should also prioritize funding and technical support to improve water information infrastructure in the valley, as this will be essential for successful implementation of basin plans and pollution and habitat management goals. Support for modern measurement devices, coordinated data systems, and groundwater models is a priority, along with mapping and planning to facilitate coordinated efforts on managing groundwater recharge, groundwater quality, and habitat opportunities. This is an urgent priority that can help inform the development of Groundwater Sustainability Plans over the next few years.

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[66] Examples of water agencies taking on environmental management roles include Sonoma County Water Agency's work on Coho salmon and steelhead restoration efforts, Yuba County Water Agency's work on environmental flows and habitat, and Santa Clara Valley Water District's assumption of watershed and habitat management responsibilities. The Sacramento Valley now has numerous examples of coordinated participation of a variety of partners (farmers, local water agencies, state and federal fisheries agencies, and environmental non-profits) to improve habitat for birds and fish on working farmland.
[67] Strategic use of funds available in some counties to mitigate species impacts from the development of solar energy and other projects would also be beneficial.

TABLE 2

Numerous state and federal agencies are involved in water and land use decisions in the valley

State and federal agencies with water and land use decision making responsibilities	Drinking water	Irrigation water	Water pollution	Floods	Land use	Habitat	Air quality
State:							
California Air Resources Board							○
California Department of Conservation			○		○	○	
California Department of Fish and Wildlife	○	○	○	○	◐	◐	
California Department of Food and Agriculture		●					
California Department of Water Resources	◐	◐	◐	◐		◐	
California Public Utilities Commission	○						
California State Water Resources Control Board	◐	○	◐			○	
Central Valley Flood Protection Board				◐			
Central Valley Regional Water Quality Control Board			○				
San Joaquin River Conservancy						●	
San Joaquin Valley Unified Air Pollution District[1]							○
Federal:							
Federal Emergency Management Agency				◐			
Federal Energy Regulatory Commission	○	○		○		○	
National Marine Fisheries Service	○	○	○	○	○	○	
US Army Corps of Engineers		◐		◐	○	○	
US Bureau of Land Management					◐	◐	
US Bureau of Reclamation	◐	◐	◐	●		◐	
US Department of Agriculture, Farm Services Agency					◐	◐	
US Department of Agriculture, Natural Resources Conservation Service					◐	◐	
US Environmental Protection Agency	○		○			○	○
US Fish and Wildlife Service	○	○	○	○	○	○	

● Resource management and funding ○ Regulation ◐ Resource management, funding and regulation

SOURCES: Updated by the authors from Hanak et al. (2011).

NOTES: The San Joaquin Valley Unified Air Pollution Control District has primary responsibility for controlling air pollution from stationary sources within the valley. The valley also has a Joint Powers Authority—the San Joaquin Valley-wide Air Pollution Study Agency—to commission and administer air quality studies.

Develop Multi-benefit Approaches to Revitalizing Ecosystems

To enhance the valley's riparian, wetland, and terrestrial ecosystems, state and federal regulators should seek to incentivize multi-benefit solutions. This will generally require more flexible, coordinated approaches to environmental regulation. For instance, agencies could promote watershed-level voluntary settlements for environmental flows and related habitat improvements such as restoration of riparian corridors. These settlements could designate shares of environmental water that can be managed flexibly for the benefit of multiple species—not just those already listed as threatened and endangered—and bring other environmental benefits like recreation and open space. As another example, the federal government could remove regulatory disincentives and explore financial incentives to support environmentally beneficial management of rotationally fallowed lands, so that farmers do not feel compelled to disk them. This change could provide opportunities for temporary habitat and improve air quality. To help coordinate such efforts, state and federal wildlife agencies could work with local parties to develop a valley master plan that maps habitat areas and outlines strategies that could be incorporated into local general plans and groundwater sustainability plans.

Moving Forward

In assessing the way forward for effective institutional support of valley transitions, a key question remains: what are the best management activities that local and regional organizations can provide? State and federal agencies only passively manage many of the resource issues they are charged with shepherding. Their regulatory roles have often overshadowed practical management actions. Local and regional agencies may be able to participate more actively to support important management practices and solutions on both private and public lands. The key is fostering another set of "4Rs": the right institutions and right activities at the right place and right time. Shedding or consolidating what is not working may have to go hand-in-hand with adding what will work. This will require creativity, leadership, and a willingness to make difficult political decisions. The state can help by providing incentives, along with deadlines to motivate local interests to find common ground.

Conclusion

The San Joaquin Valley is at a pivotal moment. As a national agricultural powerhouse at the epicenter of many of California's most difficult water management problems—including groundwater overdraft, drinking water contamination, and declines in habitat and native species—it faces unprecedented challenges and inevitable change. These adjustments will entail some near-term costs, including the likely retirement of some less productive irrigated land. But done well, there are opportunities for substantial benefits from improving the valley's water management. These include more reliable water supply for the region's most valuable agricultural activities, safer water and air for a growing population, and a reinvigorated natural environment that supports diverse plant and animal life as well as improved outdoor recreational opportunities.

This preliminary review of approaches to address these challenges is a prelude to a larger effort to assess the scope for efficient, effective, and equitable adaptation pathways for the valley, to be released in 2018. This initial review suggests that the most promising approaches 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 problems from land retirement while benefitting nature. And fostering flexible, realistic approaches to managing ecosystems can reduce conflict over environmental management while improving its effectiveness.

These types of solutions call for greatly increased coordination (and ideally some consolidation) among the many local and regional parties involved in water and land management and regulation within the valley. This will not be easy. But valley farmers and residents have a history of creatively adapting to changing conditions, and they can meet these new challenges in ways that provide a foundation for long-term regional prosperity. The state and federal governments can provide vital assistance in these transitions through well-directed incentives, technical support, and flexible regulation and management.

The issues facing the valley are complex and will require a comprehensive response. A valley-wide conversation on the changes that lie ahead can help determine how to tackle the challenges outlined in this report and next steps for creating a more promising future for the region. 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. 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 *What If California's Drought Continues?* and *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.

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.

Brad Arnold is a research assistant with the Center for Watershed Sciences at the University of California, Davis. His research focuses on the use of optimization planning models to assess regional water supply and demand conditions; primarily the impacts of changing irrigation practices and conjunctive management on developing sustainable groundwater use strategies. Previously, he worked as a licensed engineer providing technical assistance to government agencies and water management districts—primarily in the Central Valley—with planning of integrated regional management activities and water supply evaluations. He holds a MS in agricultural and natural resources engineering and is currently pursuing a PhD in water resources engineering from the University of California, Davis.

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 a water management specialist at the California Water Institute and Center for Irrigation Technology at California State University, Fresno. His main focus has been water quality, water policy, and integrated regional water management planning in the San Joaquin Valley. Recently he assisted two San Joaquin Valley counties with groundwater ordinances designed to assure availability of groundwater for county users while also meeting the goals of the new state groundwater law. Previously he was general manager of the Tranquility Irrigation District in western Fresno County for 18 years, and also worked for 13 years at the Central Valley Region Water Quality Control Board.

Thomas Harter is the Robert M. Hagan Endowed Chair for Water Resources Management and Policy at the Department of Land, Air, and Water Resources. 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.

Richard Howitt is a Steyer-Taylor Fellow at the PPIC Water Policy Center, professor emeritus of agricultural and resource economics at the University of California, Davis, and a principal at ERA Economics. He has published widely on agricultural and environmental resource allocation, with special emphasis on agricultural land use, water markets, and the application of optimization models to resource allocation questions. In addition to serving as a reviewer for seven scholarly journals, he is a member of the Western Agricultural Economics Association, the Association of Environmental and Resource Economics, and the UC Davis Center for Watershed Sciences' Delta Solutions Group. He holds a PhD from the University of California, Davis.

Jelena Jezdimirovic is a research associate at the PPIC Water Policy Center. She works on data collection, analysis, and visualization. Her research interests include water marketing, water finance and groundwater management. 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.

Duncan MacEwan is a principal economist at ERA Economics specializing in agriculture and water. He previously worked as a consultant economist with CH2M and as a postdoctoral scholar in the Department of Agricultural and Resource Economics at the University of California, Davis. He manages a portfolio of projects at ERA, where he leads client-focused studies on topics including economic feasibility, financial feasibility, and water supply and regulatory impacts to agriculture. Some recent examples include the California drought impact analyses, Sites Reservoir feasibility study, San Luis feasibility study, cannabis cultivation regulatory impacts, and assessing water risk for agricultural investment decisions. He has presented and published peer-reviewed work on sustainable groundwater management, water quality, and calibrated economic modeling methods.

Josué Medellín-Azuara is a research scientist at the Center for Watershed Sciences at the University of California, Davis who focuses on water resources economics. 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 the 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: 415.291.440
F: 415.291.4401
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PPIC Sacramento Center
Senator Office Building
1121 L Street, Suite 801
Sacramento, CA 95814
T: 916.440.1120
F: 916.440.1121