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Water and the Future of the San Joaquin Valley

Technical Appendix C: Potential Economic Impacts of Reducing Water Use on San Joaquin Valley Agriculture

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ACRONYMS

af	acre-foot (feet)
CALVIN	economic-engineering optimization model for California's water system
CVP	Central Valley Project
DWR	California Department of Water Resources
GDP	gross domestic product
GSA	groundwater sustainability agency
IMPLAN	Economic Impact Analysis for Planning model
maf	millions of acre-feet
SJV	San Joaquin Valley
SWAP	California Statewide Agricultural Production model
SWP	State Water Project
taf	thousands of acre-feet
TDN	total digestible nutrients
USDA	United States Department of Agriculture
WIIN	Water Infrastructure Improvements for the Nation Act

Introduction

Although agriculture in the San Joaquin Valley is facing challenges from growing water scarcity, this sector has a history of innovation and adaptation. This appendix describes a modeling analysis to estimate potential economic impacts from implementing the Sustainable Groundwater Management Act (SGMA) and other possible future reductions in irrigation water supply, including climate-change-related shortages and environmental flow restrictions. We look at the impacts for crop production, as well as downstream sectors within the region that rely on this output, including dairies and beef cattle, and food and beverage processing.

Methods and assumptions for estimating impacts from changes in water availability are presented first. Then we show the results for crop production, dairy and beef production, and food and beverage products under different water availability and demand management scenarios. The last section presents the aggregate estimates for region-wide economic impacts of the scenarios considered.

One important caveat is that this analysis considers the costs, but not the benefits, of ending overdraft. Chronic groundwater level decline causes subsidence that damages major regional infrastructure, makes drinking water and irrigation wells go dry, increases energy required to pump water, and reduces reserves to cope with future droughts.[1] Stabilizing groundwater levels should result in lower costs to the region in the long run. As an illustration, one study focused on Kings and Tulare Lake basins found that implementing groundwater management would incur some initial costs, but lead to net benefits to the agricultural sector over the 88-year implementation horizon (MacEwan et al. 2017). The study only accounted for three costs of overdraft: (1) increased energy use to pump irrigation water, (2) replacement of dry irrigation wells, and (3) losing groundwater as the reserve for future droughts. It did not account for other significant costs of overdraft, such as the impact of land subsidence on infrastructure, or the benefits of groundwater management for the valley's urban and rural drinking water supplies and the natural environment.

Methods

We estimate the farm-related costs of ending overdraft by looking at a chain of effects. We first explore how farmers may change their cropping decisions when they have less groundwater to use, and the consequences for crop acreage and output and several measures of the economic value of production (Box C.1). We then look at related changes in downstream industries: effects of reduced feed crop output on the valley's dairy and beef industries, and effects of reduced crop and animal products on local food and beverage processing.

For modeling crop production and water use, we employed the Statewide Agricultural Production Model (SWAP) (Howitt et al. 2012).[2] As described below, this model includes 14 local regions within the valley, and we present results for five broad sub-regions. Since many downstream activities take place in different locations than crop production, the analysis of downstream effects is for the eight San Joaquin Valley counties as a group, using a 2015 model of the regional economy (IMPLAN).[3]

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[1] See the main report for further discussion of some of these issues, including subsidence impacts to infrastructure and dry wells.

[2] The SWAP model has been applied to various studies with emphasis in California as an ancillary model to CALVIN (Draper et al. 2003). SWAP applications include quantification of economic impacts on agriculture from climate change (Medellin-Azuara et al. 2012), drought (Medellín-Azuara et al. 2015), and salinity (Medellín-Azuara et al. 2008, Medellín-Azuara et al. 2014, MacEwan et al. 2016).

[3] IMPLAN is an input-output model which provides a snapshot of a region's economy and spillover effects from economic events from one sector to the rest of the economy, which includes other sectors, households and government. In this data source, crop revenues were slightly lower in 2015 ($16.8 billion) than our 2010 estimates from the SWAP model ($20.8 billion), which rely on USDA County Agricultural Commissioners' reports. In the analysis of regional economic results, we adjust the IMPLAN crop values to match our SWAP model results, by increasing the IMPLAN base values by 24%.

Box 2.2: Measures of Economic Value

In this report, we use several measures of economic activity to track the value of the valley's economy and assess the impacts of policy change.

- "Revenue" is the total income from sales of goods and services. The economic value of a business or industry is often characterized by its sales because that is the easiest information to obtain. Revenue is not an indicator of profitability, however, because it does not consider how sales compare with costs.
- "Profit" is revenues minus costs. It is the income that remains after subtracting all expenses and taxes. Farms, like other businesses, generally seek to maximize profits by increasing revenues and reducing costs.
- "Value added" is the contribution of a business or industry to the overall gross domestic product (GDP) of a region. It includes profit, compensation to employees, and taxes paid. It excludes the cost of goods and services purchased from other vendors or sectors, which have their own value added. This is the best measure of a sector's contribution to the overall economy, because the sum of value added from each sector equals total GDP for the region.
- "Employment" is another useful measure of economic activity. Here we use estimates that include both full- and part-time work, including both year-round and seasonal jobs. These are the best measures available for agricultural employment.

Economic sectors are interconnected. Farm revenues usually consist of sales of crop and animal products. Food and beverage processing industries would also be affected by reduced farm output.

When a policy affects farm output, there can be additional effects on sectors that supply farms—such as transportation, fertilizer, irrigation services—as well as spillovers to the broader economy because people have less money to spend. These "multiplier" effects are much more difficult to estimate accurately. They often overstate the impacts of policy change, because they assume that businesses will not adapt to changing economic conditions.

We focus on the direct economic effects of reducing groundwater use on crops, livestock, and related food and beverage processing industries. We do not include other multiplier effects, given the greater uncertainties in these measures.

Crop Production

We used the same version of SWAP developed for recent drought studies (Medellín-Azuara et al. 2015, Howitt et al. 2015) but with some updates as detailed below. SWAP calibrates agricultural production to a base set of inputs, including land used for crops, water, agricultural supplies, and farm labor; information is broken down by agricultural region and crop category. The model assumes that decisions on crop choice, use of production inputs, and the intensity of each production factor are made to maximize farm profits—revenues minus costs. Under relatively abundant water supply conditions (in this case, conditions in the 2010 water year), SWAP is adjusted to match exactly to the base input dataset.[4]

[4] Input data includes land and water use from the California Department of Water Resources for 2010, cost information from the University of California Cooperative Extension, and price and crop yield data from California Department of Food and Agriculture County Agricultural Commissioners' Reports.

As water or land become scarce due to change in hydrologic conditions or policies, SWAP selects input uses that maximize the net economic returns to land and water. In our analysis of water supply reductions, we look forward to 2040—the year by which most of the valley's sub-basins need to end long-term overdraft under SGMA—and assume that groundwater sustainability agencies will use a gradual, "glide path" approach.[5] This way, farmers needing to reduce acreage of perennial crops can plan over time, so they do not suffer large investment losses from removing mature productive orchards and vineyards.

The continued expansion of perennial crop acreage since our base case (2010), which lowers farmers' flexibility to reduce water use, could make the costs of adjustment higher than we show.[6] In some other respects, however, our assumptions about adjustment costs may be pessimistic. To focus on the effects of reducing groundwater use, we assume no changes in technology or crop prices. Continued improvements in crop productivity and demand for California's farm products could result in continued growth in farm revenues and profits despite lower overall water use. For crops in which California has a special advantage—like almonds and pistachios—reduced output could actually raise prices, helping to offset revenue losses. Farmers may also be able to lower the costs of using less groundwater by employing some water management techniques not formally included in our analysis, such as deficit irrigation (applying a bit less water to plants, which has little effect on yields of some crops) (see Chapter 2 in main report for a discussion).

Geographic coverage and base case acreage, water, and revenues

Figure C1 shows geographic coverage of the model in the San Joaquin Valley. The model includes 14 local regions within the valley. Their boundaries are broadly similar (but not identical) to the valley's 15 groundwater sub-basins. SWAP treats each of its regions as a single farm; it assumes that a representative farmer in each region uses all farm water—along with other inputs—efficiently at the local level. This approximates conditions in which all surface and groundwater used by farms could be freely traded within a sub-basin.

We report results for the five valley subregions for which we have estimated long-term groundwater overdraft (see Technical Appendix A, Table A3 and Figure A20). Within the San Joaquin River hydrologic region, this includes the northwest (region 10) and northeast (regions 11, 12, and 13). Within the Tulare Lake hydrologic region this includes the southwest (regions 14 and 15), the southeast (regions 16, 17, and 18), and the Kern Basin (regions 19, 20, and 21). As in our water balance, we exclude the Delta portions of the San Joaquin Valley from our analysis (parts of regions 8 and 9). We assume that they do not experience overdraft, and that they do not adjust cropping patterns or water use. However, we do include these areas in our estimates of the valley's overall crop acreage and output.

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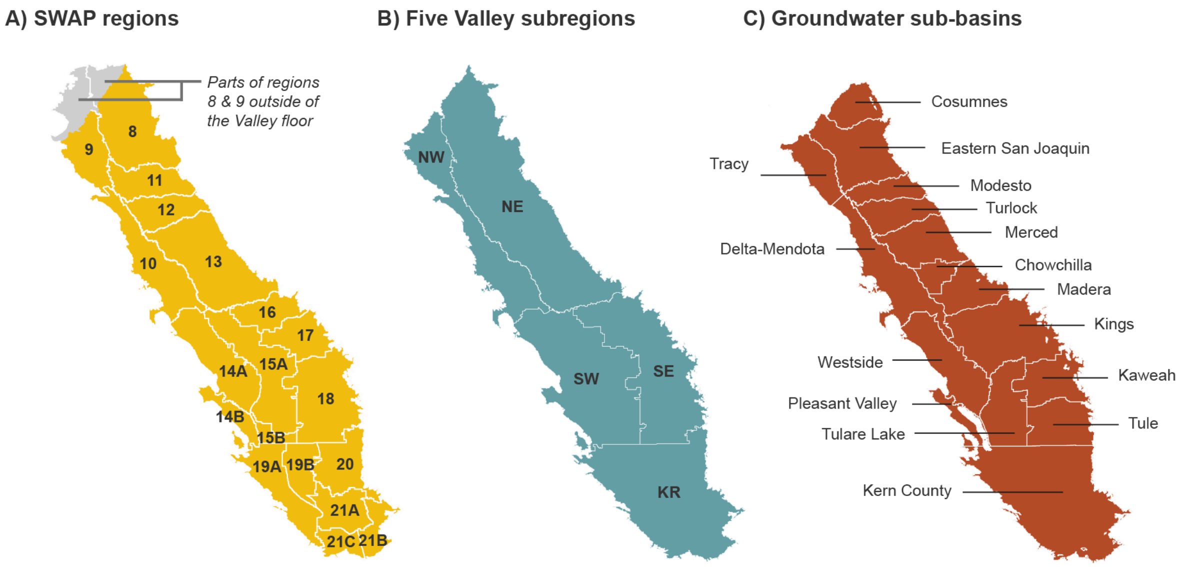
[5] Only four of the region's 15 sub-basins—all located in the San Joaquin River region—are not considered "critically overdrafted" under SGMA, with a deadline to begin implementing their groundwater sustainability plan in January 2020 and attain sustainability by 2040 (see Chapter 1 in main report). The four other priority basins have an additional two years to adopt and begin implementing their plans.

[6] From 2010–16 harvested acreage of all perennials in the eight valley counties grew by over 500,000 acres (+ 27%); almonds grew by 300,000 acres (National Agricultural Statistics Service).

FIGURE C1

Crop modeling coverage within the San Joaquin Valley and comparison with SGMA sub-basins



Base case values of land use, applied water and gross revenues for agricultural crops in the San Joaquin Valley in 2010 are provided in Table C1. About 5.2 million acres of land are cultivated each year in the study region, using 16.8 million acre-feet (maf) in applied water. Gross revenues are $20.8 billion, of which 81 percent is from trees, vines, and vegetables and non-tree fruits. Feed crops (silage corn, alfalfa, and irrigated pasture) occupy 27 percent of the total irrigated area and 33 percent of water applied to crops in the valley. These crops serve as an input to the large dairy and beef cattle sectors, which represent about one-third of the valley's total crop and livestock revenues.

TABLE C1

Irrigated acreage, water, and revenues by commodity group in the San Joaquin Valley in 2010

Crop Commodity Group	Irrigated Cropland (thousands of acres)	Applied Water (thousands of acre-feet per year)	Revenues (2010 $, millions)
Alfalfa and pasture	713	3,413	1,264
Corn	665	1,924	1,000
Other field and grain	1,187	2,913	1,729
Trees and vines	2,074	6,772	14,052
Vegetables and non-tree fruits	559	1,154	2,738
Total San Joaquin Valley	**5,198**	**16,177**	**20,784**

SOURCES: Irrigated crop areas and applied water from the California Department of Water Resources. Revenues are derived from USDA County Agricultural Commissioners' Reports.

Table C2 summarizes acreage, water use, and revenues for the five sub-regions. The northern part of the San Joaquin Valley accounts for roughly 40 percent of the irrigated area and applied water, and contributes 34 percent of crop revenues. The southern part of the valley has more acreage and water use (about 60%), but also a larger share of revenues (66%). Among subregions, the southeast generates the highest average revenue per acre and per acre-foot of water ($5,230/acre and $1,619/af). The northwest has the lowest average revenues ($2,716/acre and $855/af).

Overall, the San Joaquin Valley had 40 percent of its total irrigated area in permanent crops (using 42% of all irrigation water) in 2010. Permanent crops harden water demand, making it more expensive to reduce water use in dry years. Permanent crops use about half of the total applied water in the Kern basin and the eastern part of the valley, versus roughly one-third in the southwest, and 15 percent in the northwest.

TABLE C2

Irrigated acreage, water, and revenues by sub-region in the San Joaquin Valley in 2010

Crop Commodity Group	Land (thousands of acres)	Applied Water (thousands of acre-feet per year)	Revenues (2010 $, millions)
Northwest	742	2,357	2,015
Northeast	1,383	4,023	4,973
Southwest	1,112	3,177	3,917
Southeast	1,134	3,662	5,930
Kern Basin	827	2,958	3,948
Total San Joaquin Valley	**5,198**	**16,177**	**20,784**

SOURCES: See Table C1.

Dairy and Beef Production

Among animal products, dairies generated the most revenues ($7.8 billion), followed by beef cattle ($1.9 billion) and poultry and egg production ($1 billion).

Dairies and beef cattle consume feed crops and concentrate.[7] Feed crops in the valley considered in the SWAP model are alfalfa, silage corn, and irrigated pasture. Most corn in the San Joaquin Valley is for silage; unlike alfalfa, silage corn is often produced near the dairy farms as it is costly to haul over long distances. Current dietary requirements for silage corn and other wet roughage create some system-wide inflexibility in water and land allocation, beyond what is reflected in the market price for corn used in the SWAP model. To allow for this, we limit acreage reductions for corn silage in response to water shortages to 33 percent in the Kern basin (where the high share of acreage planted to trees and vines limits flexibility), and 20 percent in other areas. We also assume that the dairy industry will experience proportional losses when corn silage output goes down. This may overstate dairy losses, if improvements in feed technology make it possible for the sector to reduce its reliance on corn. We assume that dairies can replace local alfalfa with purchases from elsewhere at no additional cost, which could understate losses. Other factors could reduce the profitability and size of California's dairy industry, including water quality management challenges (see Chapter 3 in the main report), and shifts in consumer demand toward non-dairy beverages.

Beef cattle are often divided into three segments: cow-calf, feeder, and feedlot, each with somewhat different feed crop requirements. The cow and calf segment relies mainly on irrigated and rainfed pasture in the foothills, along with other forages and grains. The feeder segment relies on irrigated pasture in the valley and other forage. The feedlot segment relies on concentrate and other forage and grains. During dry years, the higher value of water makes irrigated pasture less economical for feeding cattle. Our discussions with producers and other industry

[7] Concentrate is any feed that is low in fiber, high in total digestible nutrients (TDN), and supplies the primary nutrients of protein, carbohydrate, and fat. For example, grains, cottonseed meal, and wheat bran are concentrates.

experts suggest that the sector adapts by changing diet composition and selling cattle out of the valley. We assume that the beef industry will experience some losses when irrigated pasture acreage goes down, with a 4 percent reduction in irrigated pasture leading to a 1 percent reduction in the herd.[8]

Food and Beverage Processing

San Joaquin Valley crops and livestock products, including dairy and beef, serve as inputs for the downstream food and beverage processing sector. Processing revenues in 2015 were $39 billion, nearly 1.3 times the value of agricultural primary production in crops and livestock products (Table C3). However, this overstates the size of the processing sector, because these revenues must generally be high enough to cover the cost of purchases of crop and livestock products, as well as other inputs—effectively double-counting crop revenues. A better measure is value added—the sector's contribution to regional GDP. It includes profit, compensation to employees, and taxes paid. It excludes the cost of goods and services purchased from other vendors or sectors, which have their own value added.[9] Processing contributed $7.1 billion in regional value added in 2015.

Reduced output of animal products (notably milk) and some crops (notably almonds, tomatoes, and other fruits) can also affect local food and beverage processing. Processing plants may absorb small reductions in raw material availability by temporarily reducing output. Large reductions can pose bigger challenges, causing facilities to further downsize or relocate. We assume that processing industries will lower output when the supply of local agricultural raw materials falls.[10] This may overstate the costs of adjustment; some businesses would likely replace some local raw materials with (higher cost) products from elsewhere instead of reducing output.

Region-Wide Economic Effects

We use the IMPLAN model of economic activity to aggregate and quantify the potential economic costs from reducing farm water use in the eight-county San Joaquin Valley. We focus on the direct economic effects of reducing water use on crops, livestock, and related food and beverage processing industries, and we report changes in revenues, value added, and employment (See Box C.1).[11] Table C3 provides base case regional values for these sectors.

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[8] This assumption is based on discussions with some producers and other experts about irrigated pasture use by the cow-calf and feeder segments in the southern part of the valley.

[9] For a description of value added and other economic indicators used in the analysis, see Box 2.2 in the main report.

[10] The IMPLAN database includes estimates of inter-sectoral purchases from food and beverage processing sectors to crops, dairies, and beef cattle, and also what proportion of these inputs is obtained locally and what is imported from other regions in California or other parts of the country. We use changes in crop, dairy, and beef sectors' outputs as a proxy for availability of inputs in food and beverage processing, considering the proportion of these primary sectors' inputs acquired within the eight-county region.

[11] We do include contract labor in crop and animal production. In county economic accounts, this appears as a support service, not direct farm employment, and it is counted in IMPLAN as an indirect effect.

TABLE C3
Base case revenues, value added, and employment in the San Joaquin Valley

Agriculture-related sectors	Revenues ($ millions)	Value added ($ millions)	Employment
Crops	20,784	23,284*	219,792*
Dairy and beef	9,616	4,667*	41,674*
Food & beverage industries	38,820	7,139	66,124
Total	**69,219**	**35,091**	**327,590**

SOURCES: IMPLAN database for the eight-county region in 2015. Revenues for crops are from SWAP (see note 3 in the text).

NOTES: Employment includes full- and part-time jobs. * Denotes measures that were adjusted to include agricultural support services (mainly contract labor), which are an important input into San Joaquin Valley crop and animal production. This may overstate the total sector size. For revenues, we only include direct crop and animal product revenues, because we treat support services as an input that is covered by the proceeds of farm sales.

When a policy affects farm output, there can be additional effects on sectors that supply farms—such as transportation, fertilizer, and irrigation services—as well as spillovers to the broader economy because people have less money to spend. These "multiplier" effects are much more difficult to estimate accurately. They often overstate the impacts of policy change, because they assume that businesses will not adapt to changing economic conditions. By including both crops and the downstream livestock and food and beverage processing industries, we capture the effects of water use reductions on the main sectors that depend on crop production. We do not include other multiplier effects, given the greater uncertainties in these measures.

Water Supply and Demand Management Scenarios

We model the agricultural economy's response to adjusting water use under several different water supply and demand management scenarios.

On the water supply side we consider three scenarios:

1. Reducing water use to end historical overdraft;
2. Reducing water use to end historical overdraft and to manage other potential water supply reductions;
3. Scenarios 1 and 2, with some investments in supply augmentation.

We also considered two demand management scenarios:

4. Farmers are allowed to trade all water locally (the base case);
5. Farmers are allowed to trade surface water valley-wide.

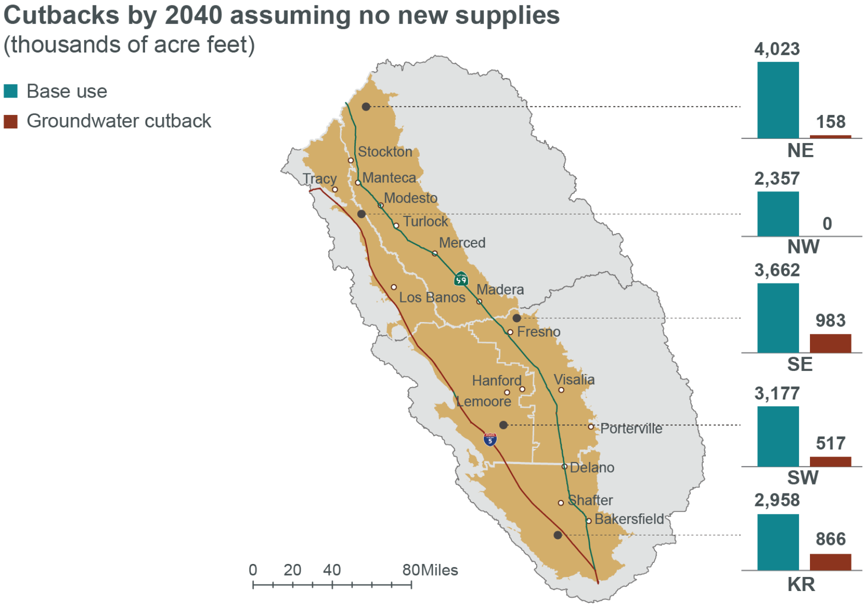
These scenarios are first evaluated using SWAP. We then use the SWAP results to determine impacts on downstream sectors using IMPLAN.

Reducing Water Use to End Historical Overdraft

To estimate reductions in water supplies from ending overdraft, we used our water balance estimates detailed in Technical Appendix A. Balancing the groundwater budget without new supplies requires reducing consumptive water use—the amount evaporated from soils and consumed by plants (see Box 2.1 in main report). For agriculture, this requires a somewhat greater reduction in applied water use—and groundwater pumping—than the amount of overdraft, because farmers need to apply more irrigation water to their fields than the amount crops consume. Ending the historical overdraft of 1.8 maf/year will require a pumping cutback of 2.5 maf/year—or 16 percent of applied farm water use (Figure C2). This share is higher in the southern valley, which relies more heavily on overdraft to sustain farming. In the Kern basin and the southeast, over a quarter of supplies are from groundwater overdraft.

FIGURE C2

Valley-wide irrigation water reductions needed to end overdraft, assuming no new water supplies



SOURCE: Author estimates using groundwater overdraft estimates in Technical Appendix A and baseline water use and irrigation efficiencies from SWAP.

NOTES: NE is northeast, NW is northwest, SE is southeast, SW is southwest, and KR is Kern basin. We use SWAP estimates of region-specific irrigation efficiencies to estimate the applied water use reductions required to end overdraft.

Other Potential Water Supply Reductions

Other factors could affect future water supplies in the valley, requiring greater adaptations. In particular, the changing climate could affect water availability, as could proposed changes in required environmental flows in local rivers and the Delta as part of the State Water Board's update of the Bay-Delta Water Quality Control Plan. Water scarcity could also increase if urban areas increase their net water use to accommodate population growth.

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

Increased environmental flows. The State Water Board recently voted to require an increase in instream flows for three San Joaquin River tributaries—the Stanislaus, Tuolumne, and Merced Rivers. This will reduce water available for agricultural and urban users in the northeastern part of the valley. The board is also considering flow increases in the Sacramento River system, which could reduce Delta imports.[12]

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

Economic impacts from a more water-stressed San Joaquin Valley. To provide a rough sense of how increased water scarcity would affect the valley's economy, we apply the same methods used to estimate the costs of ending overdraft to look at the costs of filling a larger water deficit. For Delta imports, we assumed an average reduction of 375 thousand acre-feet (taf) per year relative to the 1988–2017 average. For the San Joaquin River tributaries, we assume an average reduction of 293 taf/year in surface water supplies, consistent with the State Water Board's new flow mandate.[13] Relative to filling the historical groundwater deficit, these changes increase the water supply gap by roughly one-quarter.

New Water Supplies

In Technical Appendix B we analyzed the potential increased water availability and cost of new supplies; and in Technical Appendix D we use an economic approach to estimate which supplies will be affordable for farmers. We conclude that about a quarter of the historical groundwater deficit might be filled with new supplies—especially from groundwater recharge projects. Here we consider scenarios where future water supply reductions are partially mitigated by these new supplies. We assume that the new supplies will be available in equal proportions in the sub-regions with historical overdraft.[14]

Demand Management Scenarios: Local vs. Valley-Wide Water Trading

Our analysis focuses on comparisons of two scenarios for farm water management. In the first case, the model assumes that all farm water—along with other inputs—is used efficiently at the local level. This approximates conditions in which all surface and groundwater used by farms can be traded freely within a basin. In the second case, we also allow farmers to trade surface water across the entire valley. This gives them more flexibility to move water to the most profitable uses, and draws water from the northern part of the valley to the southern part, where the groundwater deficit is greater.

These assumptions about flexible water management may be optimistic. There already is significant local and region-wide farm water trading within the valley (Hanak and Stryjewski 2012). But several factors could limit its expansion. In the local trading case, adjusting to reduced groundwater pumping will be more costly than our estimates show if groundwater sustainability agencies (GSAs) do not allow within-basin trading of groundwater—something that has yet to be developed. And in the valley-wide trading case, trading will be lower—and the costs

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

[13] We assume the long-term mean annual reduction in supplies with 40 percent of unimpaired flows for February–June for the through to the San Joaquin River near Vernalis. The board left open the possibility of approving a negotiated settlement, rather than these flow levels, as part of a comprehensive agreement on flow management in the Sacramento–San Joaquin Delta watersheds in 2019 (State Water Resources Control Board 2018).

[14] In practice, the distribution of new supplies will depend on a variety of factors. For instance, farmers in some regions might choose to invest more in new supplies, while others who are willing to invest might be prevented by constraints in conveyance that limit the movement of water.

of adjustment higher—if communities in the northern part of the valley restrict surface water trades, or if infrastructure is not available to move all the water farmers would like to trade.

As a very rough indicator of the implications of inflexible water management at the local level, we compare our results with local and valley-wide trading with the costs of ending overdraft if valley farmers have no opportunities to adapt their water use. The "inflexible local water use" scenario shown below assumes that acreages of all crops grown in a local area are reduced in the same proportion. This shows unrealistically high adjustment costs: even if there were no local water trading, many individual farmers have diversified crop mixes, and would make adjustments on their own farms to reduce acreage of less profitable crops first. However, it is a useful bookend to consider the potential economic risks if local surface and groundwater trading is not facilitated within basins.

Comparison of Water Availability under Different Scenarios

Tables C4 and C5 summarize the water supply reductions under the suite of scenarios considered, first to end historical overdraft (Table C4) and then to end overdraft and manage other potential reductions in water supply (Table C5).

TABLE C4
Reductions in applied water use to end overdraft

Sub-region	Local trading only		Valley-wide trading		Valley-wide trading and new supplies	
	Water reduction (taf/year)	Reduction (%)	Water reduction (taf/year)	Reduction (%)	Water reduction (taf/year)	Reduction (%)
Northwest	0	0	375	16	375	16
Northeast	158	4	388	10	310	8
Southwest	517	16	383	12	286	9
Southeast	983	27	606	17	294	8
Kern Basin	866	29	772	26	626	21
Total San Joaquin Valley	2,524	16	2,524	16	1,893	12

SOURCES: Authors' calculations (Technical Appendix A for overdraft, Technical Appendix D for new supplies, and water budgets by source from SWAP).

NOTES: We also ran scenarios with new supplies and local trading only, not shown here. In the scenario with inflexible local water use reported below, the water reductions are the same as in the local trading only case.

TABLE C5
Reductions in applied water use to end overdraft and manage other potential supply reductions

Sub-region	Local trading only		Valley-wide trading		Valley-wide trading and new supplies	
	Water reduction (taf/year)	Reduction (%)	Water reduction (taf/year)	Reduction (%)	Water reduction (taf/year)	Reduction (%)
Northwest	34	1	470	20	383	16
Northeast	486	12	469	12	396	10
Southwest	596	19	579	18	392	12
Southeast	1,064	29	865	24	615	17
Kern Basin	1,011	34	807	27	774	26
Total San Joaquin Valley	3,191	20	3,191	20	2,560	16

SOURCES: See Table C4.
NOTES: See text for estimates of potential supply reductions. We also ran scenarios with new supplies and local trading only, not shown here.

Modeling Results

This section provides estimates of the effects of ending overdraft on crops, dairy, beef, and food and beverage industries. First, we focus on the two demand-management scenarios with no new supplies: local water trading only, and valley-wide water trading. Then, we examine the effects of adding new supplies, and we consider the impacts of ending overdraft along with other potential supply reductions. Finally, we aggregate the results to obtain the regional economic impact of using less water in valley agriculture.

Adaptation of Crop Production

Overall, a reduction in 2.5 maf/year in applied water—without allowing for valley-wide surface water trading—would require fallowing 750,000 acres, or 14 percent of current San Joaquin Valley agricultural acreage. The southeast and southwest sections of the valley and Kern County would be most affected, reflecting their large groundwater deficits (Figure C3). Fallowed acreage would include almost 300,000 acres of field crops and grain, nearly 200,000 acres of alfalfa and pasture, 150,000 acres of trees and vines, 73,000 acres of corn, and 36,000 acres of vegetables and non-tree crops. Compared to their current acreage, alfalfa and pasture would be reduced by 28 percent, other field crops and grains by 25 percent, corn by 11 percent, trees and vines by 7 percent, and vegetables and non-tree crops by 6 percent. Farmers will try to adapt by displacing less profitable crops first.[15]

FIGURE C3

Land fallowing would mainly occur in the southern part of the valley if only local water trading is allowed

SOURCE: Author estimates.

NOTE: "Other field crops and grains" include cotton, other grains, and silage other than corn.

Reduced crop revenue from ending overdraft would be about $2 billion per year—nearly 10 percent of current total crop revenue (Figure C4). The southeast would see $836 million in revenue losses (14%). With $786 million in losses, Kern County would lose even a larger share of revenues (20%). The southwest also would see significant revenue losses—$357 million (9%). The northern part of the valley would only see minor losses.

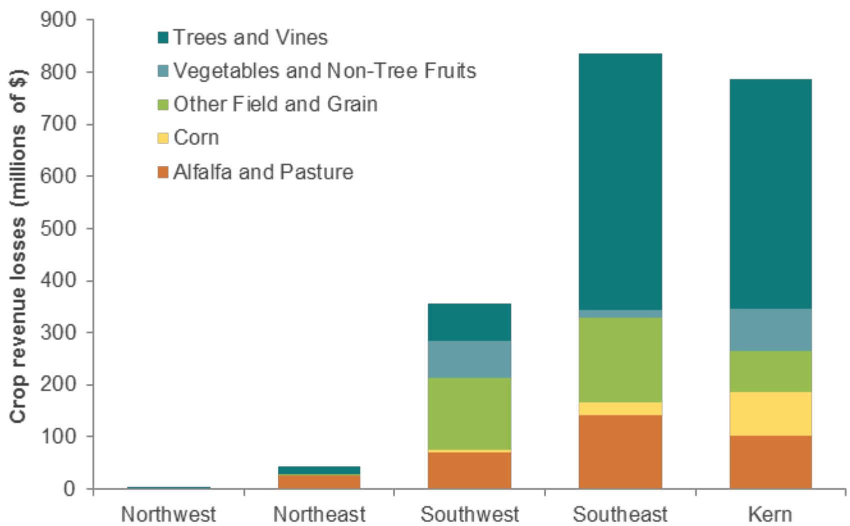
[15] We assume that crop rotation requirements are stable, given the large land area being considered.

Half of the total losses (more than $1 billion) would come from trees and vines being taken out of production. Next-highest are other field crops and grains ($381 million in revenue losses) and alfalfa and pasture ($338 million). Finally, vegetables and non-tree fruits would see a reduction in $165 million in farm revenues, and corn revenues would be reduced by $114 million.

Although this revenue decline is substantial relative to current levels (10%), it is less than the cutbacks in acreage (14%) or water use (16%). This reflects the fact that farmers have some flexibility to focus the water on activities with the highest returns.

FIGURE C4

Revenues would decrease significantly in the southern part of the valley if only local water trading is allowed



SOURCE: Author estimates.
NOTE: "Other field crops and grains" include cotton, other grains, and silage other than corn.

Valley-wide water trading would significantly lower the costs of ending overdraft

When surface water markets are allowed across regions, the price of water in the market falls to about $185 per acre-foot.[16] Water traded would move from north to south—where overdraft is more acute and economic losses from ending overdraft are larger. The southeast, southwest, and Kern Basin would be net water buyers. Most of this water would be moved using the California Aqueduct, the Delta-Mendota Canal, and the Friant-Kern Canal—along with the Cross-Valley Canal to facilitate exchanges, although additional investments in east-west conveyance capacity might also be warranted.

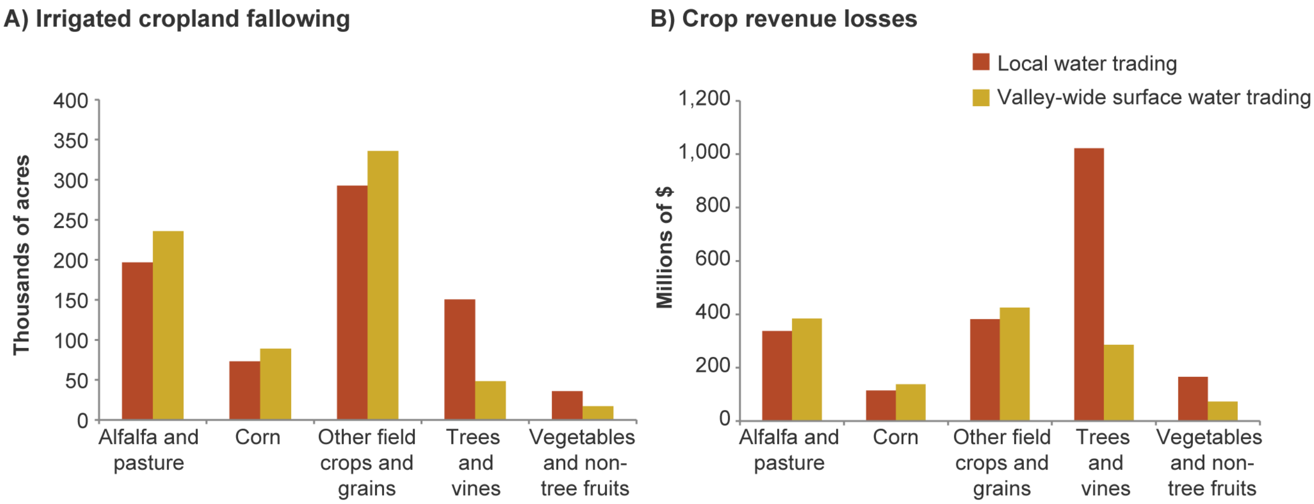
With the introduction of valley-wide trading, farmer's flexibility to adapt increases significantly, resulting in lower losses (Figure C5). The acreage fallowed falls slightly, to 725,000 acres, as trading creates more opportunities to shift to crops that use less water, keeping more land in production. But trading's main contribution is to lessen the need to fallow relatively profitable crops. Fallowing of trees and vines falls by two-thirds, and vegetable and non-tree fruits by more than half. Acreage declines in the other crop groups rise by 15 to 20 percent. The net result is much lower crop revenue losses, which fall from $2 billion to $1.3 billion per year

[16] This price represents the marginal value product (increased profits) of one additional unit of water when water is allowed to be transferred across regions in the valley. It is calculated by the SWAP model. As shown in Technical Appendix D, the marginal value product of water with only local trading varies considerably for different uses—ranging from a high of roughly $900/af for a small share of very profitable fields, to less than $200/af for more than half of all acreage.

(6% below current levels). Crop employment losses also fall, from 14,000 jobs (7%) with only local trading to 9,000 jobs with valley-wide trading (4%), because the more profitable crops also tend to use more labor (Medellín-Azuara 2015).

FIGURE C5

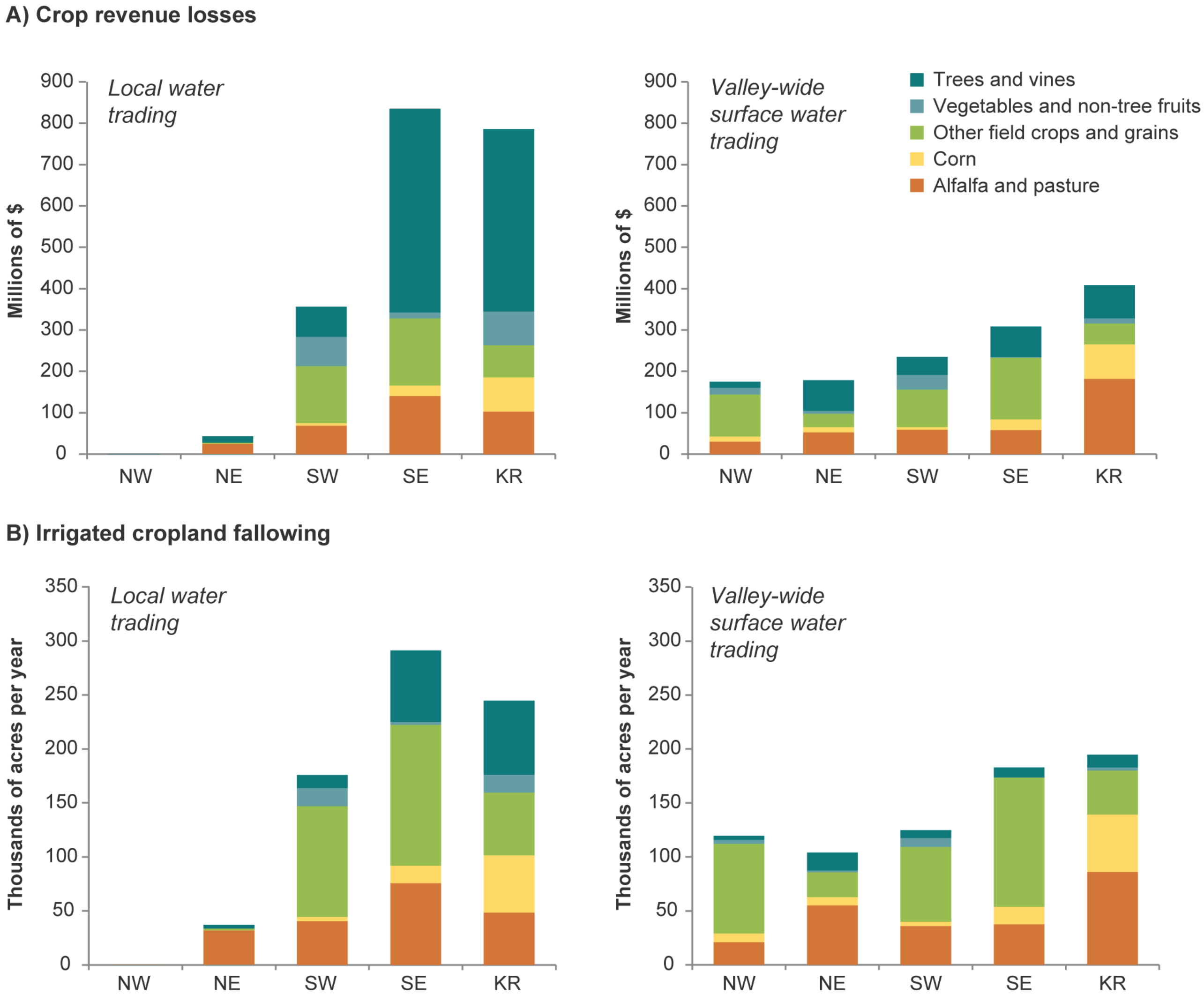
Valley-wide water trading would shift which crops are fallowed and decrease revenue losses



SOURCE: Author estimates.
NOTES: "Other field crops and grains" include cotton, other grains, and silage other than corn. Total land fallowed falls from 75,000 acres with local trading only to 725,000 acres with valley-wide trading. Total crop revenue losses fall from $2 billion to $1.3 billion per year, respectively.

As expected, valley-wide trading also significantly shifts the distribution of land fallowing and crop revenue losses across the region (Figure C6). With only local trading, losses are concentrated in the southern valley. Valley-wide water trading cuts these losses dramatically by shifting some fallowing to the northern valley. This also means crop revenues—and farm employment—fall somewhat in the locations that sell water. However, farmers only sell if it makes them better off than using the water on their lands. With trading, farm profits increase across the entire valley, rising by more than $225 million overall (up 4%). The largest gains are in the northwest, where farmers earn roughly $100 million from selling water, and in the Kern basin, where they earn roughly $80 million by buying water and keeping more cropland in production.

FIGURE C6
Valley-wide water trading would spread out declines in crop acreage and revenues from implementing SGMA



SOURCE: Author estimates.

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

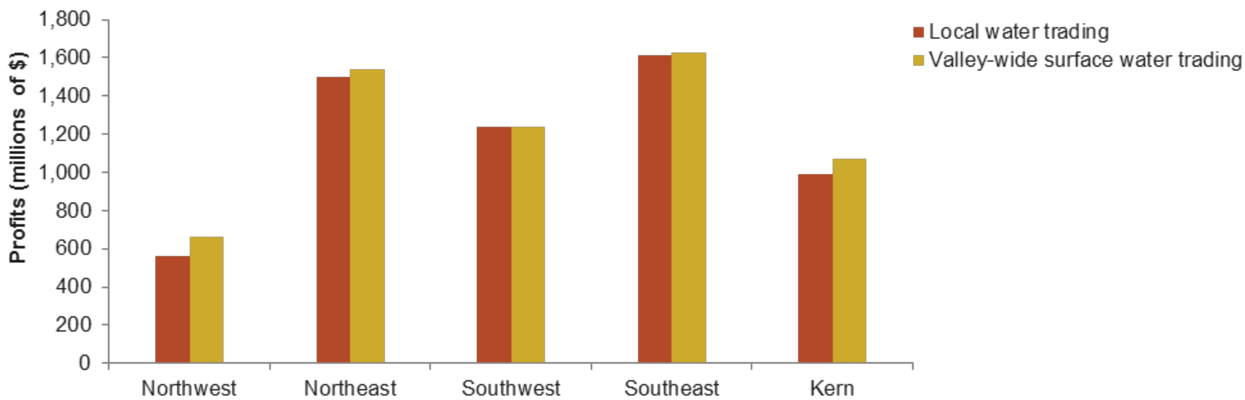
Profits would increase with valley-wide water trading and new supplies

Profits drive water markets. Water transfers work because both buyers and sellers can profit. When profits from crops (per unit of water) exceed the cost of water in the market, farmers are willing to buy water. Conversely, when the price of water in the market is greater than some farmers' profits per unit of water, they might be willing to sell their water.

Valley-wide water trading increases profits from crop production by $227 million per year for the entire San Joaquin Valley—a 4 percent increase from a local-trading only alternative. Profits either increase or remain stable across the valley subregions (Figure C7).[17] The largest benefits are to the northwest, with roughly $100 million of gains mostly from selling water, and the Kern basin, with $83 million in gains from avoiding fallowing of highly profitable lands. Profits increase by $17 million in the southeast, and they remain stable in the southwest. The total revenues from water sales amount to $104 million per year flowing from the drier south to the wetter north.

FIGURE C7

Markets increase profits from crop farming across the valley

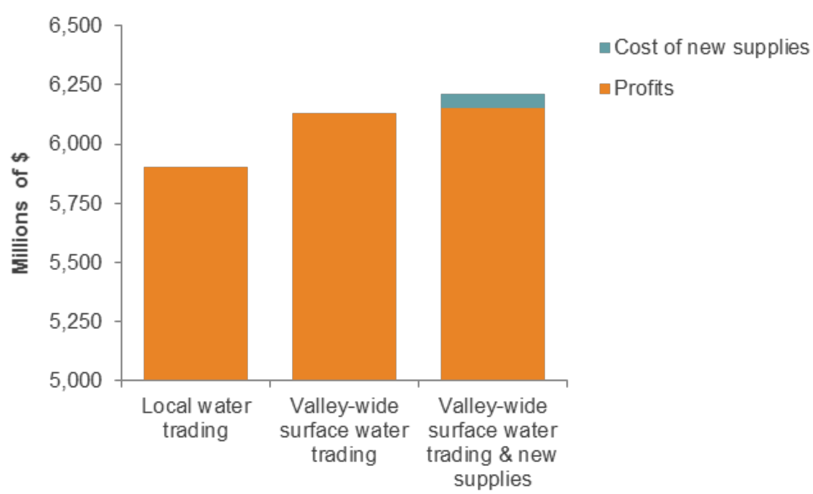


SOURCE: Author estimates.

Farm profits would also drive the expansion of new supplies. After making these investments, farmers have to be at least as well off economically. Figure C8 shows that new supplies would increase profits from crops by over $80 million per year without accounting for the cost of supplies, and by about $20 million per year when accounting for these costs. The overall impact on the region's economy is much more significant, given the benefits to downstream activities, as we show below.

FIGURE C8

Profits from crop production would increase even after paying for the expansion of water supplies



SOURCE: Author estimates.

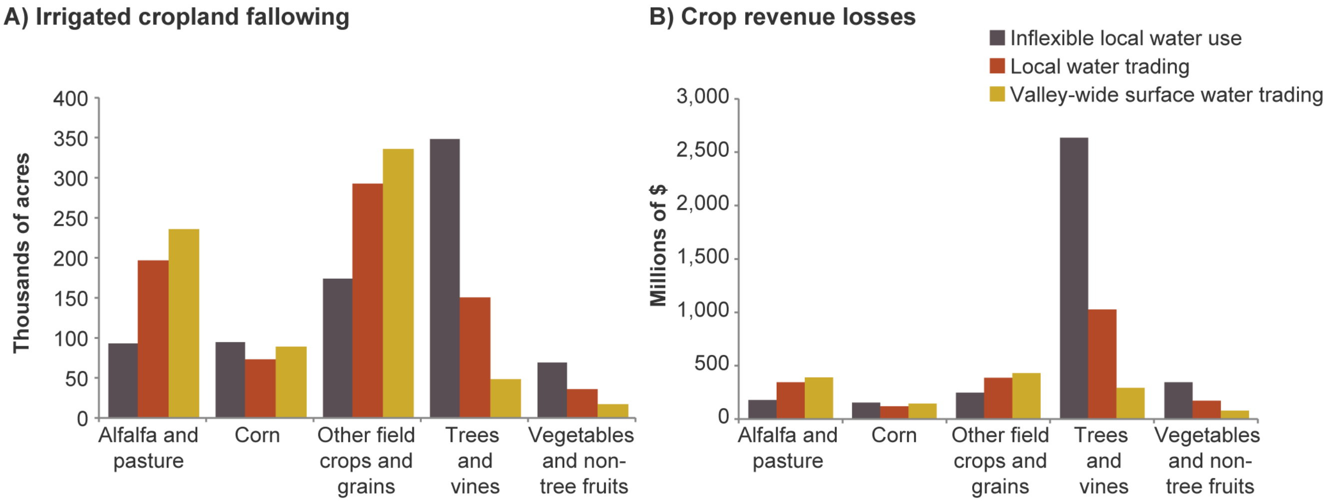
[17] In the model, farmers are willing to purchase water up to the point where they earn at least as much profits as they would without buying it.

Costs of adaptation would be much higher without flexibility in local farm water use

Figures C9 and C10 compare the results from our local and valley-wide water trading scenarios with a scenario where farmers have no flexibility to adapt crop water use in response to groundwater cutbacks. As noted earlier, this is an extreme scenario that overstates likely costs, because even if farmers are unable to trade water, many have some flexibility to adapt crop choices on their own lands.

FIGURE C9

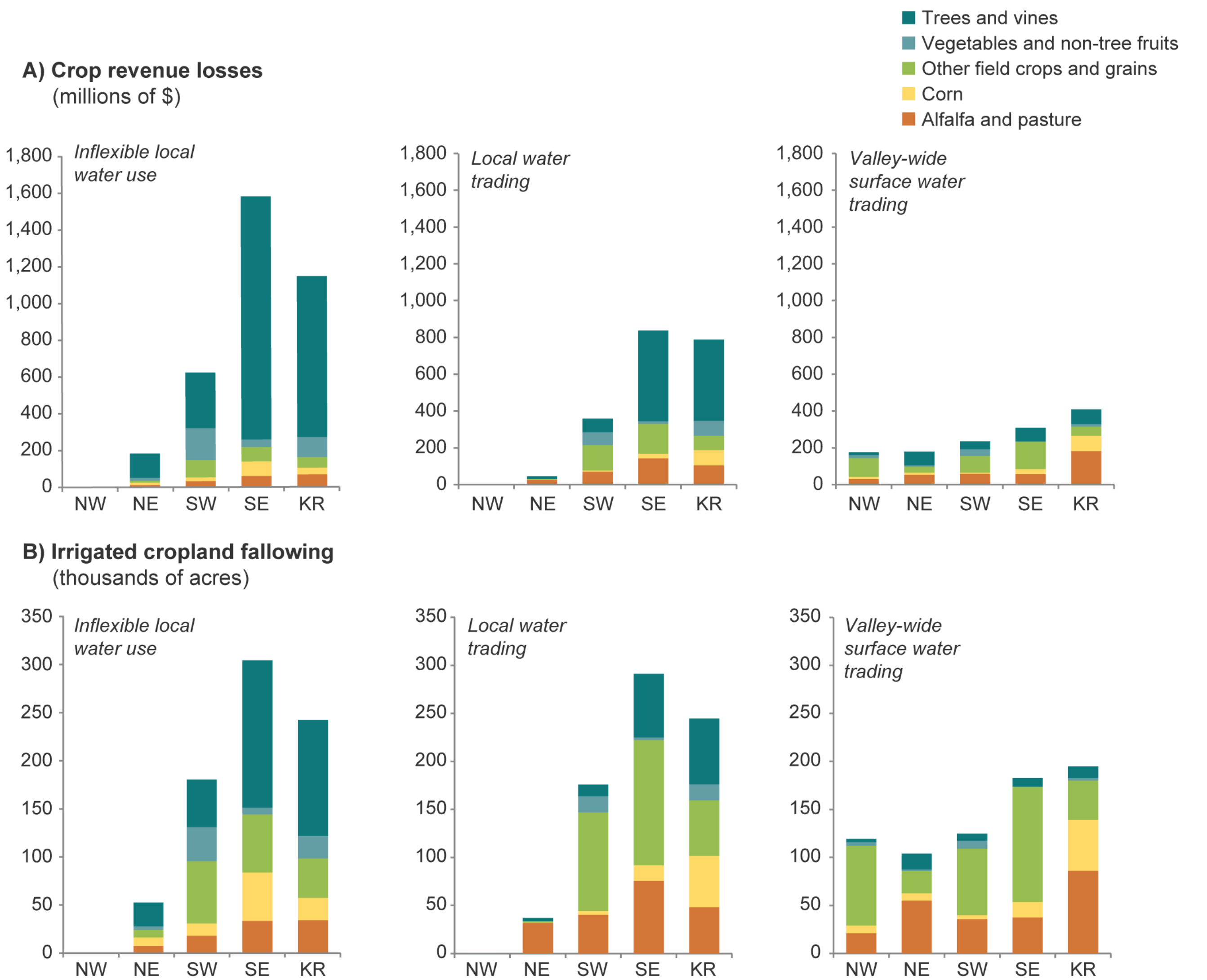
Tree crop fallowing and revenue losses from ending overdraft would be much higher without local flexibility to adapt farm water use



SOURCE: Author estimates.
NOTE: The "inflexible local water use" scenario assumes proportional acreage reductions in all crop groups at the local level to end overdraft.

Total acreage fallowed is slightly higher (780,000 acres) than in the local water trading case (750,000 acres), as farmers maintain higher acreages of some more water-intensive crops (especially alfalfa and pasture) (Figure C9A). Fallowing of trees and vines and vegetables and non-tree fruit acreage more than doubles. The crop revenue losses jump significantly, from $2 billion with local trading to $3.5 billion. This results principally from the increase in losses from trees and vines (Figure C9B). Losses of corn acreage are slightly higher than in the scenario with local trading, because we do not limit acreage reductions to protect supplies of corn silage for dairies. The bulk of increased economic losses occur in the valley's southern subregions (Figure C10).

FIGURE C10
Revenue losses from ending overdraft would be much higher in the southern valley without local flexibility to manage farm water use



SOURCE: Author estimates

Downstream Effects

Dairy and Beef Production

Reductions in production were estimated for dairies and beef cattle based on the estimated reduction in feed crops, using assumptions described above. For dairies, the projected declines in silage and corn acreage result in substantial declines in output: 10 percent of revenues in the local-trading only case (roughly $805 million dollars per year). With valley-wide water trading, this decline increases to 12 percent ($977 million per year) because some additional silage corn acreage would be fallowed to move water to higher value crops. Changes in feed cattle production were estimated based on the assumed relationship with irrigated pasture on the valley floor. With local trading only, there is an expected reduction of 8 percent ($150 million per year) in beef cattle production; valley-wide water trading increases this loss to 12 percent ($220 million per year) because irrigated pasture acreage declines further. Augmenting water supply does not change these estimates substantially.

Food and Beverage Processing

Food and beverage processing might also be impacted by crop fallowing and reductions in the dairy and beef sectors. We estimate that reduction in crops would cause losses of $2.4 and $1.9 billion/year in the local and valley-wide trading scenarios, respectively. Augmenting supplies reduces these revenue losses to $2 billion/year with local trading and $1.8 billion with valley-wide trading.

Overview of Regional Economic Impacts

Table C6 summarizes the regional economic effects on the crop, dairy and beef, and processing industries of the different supply and demand management scenarios examined here.

Ending historical overdraft

Ending overdraft without new supplies, and with only local water trading, would reduce agriculture-related revenues in the valley by $5.3 billion (8% loss), value added–the best measure of economic activity—by $2.1 billion (6% loss), and roughly 21,000 full- and part-time jobs (6% loss). Relative to the total regional economy, this represents declines of 1.8 percent in revenues, 1.4 percent of value added, and 1.1 percent of employment.

When valley-wide water trading is allowed, the impacts are substantially reduced: relative to the case with local trading only, agriculture-related revenue losses fall by 18 percent, value added losses fall by 28 percent, and employment losses fall by 27 percent. These improvements occur despite higher losses (by about 25 %) in the downstream beef and dairy sectors from increased fallowing of corn and irrigated pasture.

New supplies would also help reduce the costs of ending overdraft. With valley-wide trading and new water supplies, revenue losses fall by 26 percent (from $5.3 to $3.9 billion per year), value added losses fall by 37 percent (from $2.1 to $1.3 billion), and employment losses fall by 40 percent (from 21,000 to less than 13,000 jobs). This highlights the value of a portfolio approach to addressing overdraft—combining cost-effective supplies with flexible demand management. Relative to the size of current agricultural economy in the valley, the losses from balancing groundwater basins with this portfolio approach represent declines of 6 percent of agricultural revenues, and 4 percent of value added and employment. This corresponds to 1.3 percent of total regional revenues, 0.9 percent of regional value added, and 0.7 percent of regional employment.

Potential impacts of additional supply constraints

Relative to filling the historical groundwater deficit, the additional changes we considered—including reduced Delta imports of 375 taf/year and reduced diversions from the San Joaquin River tributaries by 293 taf/year—would increase the water supply gap by roughly one-quarter. The same adaptation tools—efficient allocation of farm water at the local level, valley-wide water trading, and a cost-effective portfolio of new supply investments—would help minimize the added costs to the valley economy. With all these strategies, annual revenue losses from crops, animal products, and processing would increase from $3.9 to $4.7 billion, value added losses from $1.3 to $1.7 billion, and employment losses from 12,700 to 15,900 jobs—roughly 5 percent of the valley's current farm economy, and 1 percent of the overall regional economy (Table C6).

TABLE C6

Overview of regional economic losses of reducing agricultural water use under different scenarios

	Ending historical groundwater overdraft			Ending groundwater overdraft and adapting to other potential water supply reductions		
	Local trading	Valley-wide trading	Valley-wide trading + new supplies	Local trading	Valley-wide trading	Valley-wide trading + new supplies
Water reduction (maf)	2.52	2.52	1.89	3.19	3.19	2.56
Land fallowing (acres)	748,799	725,803	534,670	952,441	911,951	735,922
Crop production						
Revenues ($ millions)	2,020	1,307	956	2,552	1,674	1,327
Value Added ($ millions)	1,369	799	580	1,732	1,028	813
Employment	14,394	9,014	6,579	18,093	11,774	9,159
Dairy & beef products						
Revenues ($ millions)	956	1,196	1,162	1,079	1,286	1,200
Value Added ($ millions)	358	445	432	401	480	447
Employment	2,965	3,725	3,620	3,362	3,998	3,738
Processing industries						
Revenues ($ millions)	2,400	1,905	1,784	2,947	2,157	2,140
Value Added ($ millions)	413	297	273	512	326	330
Employment	3,908	2,738	2,512	4,913	2,957	3,023
Cost of new water supplies	0	0	62	0	0	62
Total economic impacts						
Revenues ($ millions)	5,376	4,408	3,963	6,578	5,118	4,729
Value Added ($ millions)	2,141	1,542	1,347	2,645	1,835	1,651
Employment	21,266	15,477	12,711	26,367	18,728	15,920

SOURCE: Author calculations

REFERENCES

Draper, Andrew, Marion Jenkins, Kenneth Kirby, Jay Lund, and Richard Howitt. 2003. "Economic-engineering optimization for California water management." *Journal of Water Resources Planning and Management* 129(3), 155-164.

Hanak, Ellen and Elizabeth Stryjewski. 2012. *California's Water Market, By the Numbers: Update 2012*. Public Policy Institute of California.

Howitt, Richard, Josue Medellín-Azuara, Duncan MacEwan, and Jay Lund. 2012. "Calibrating disaggregate economic models of agricultural production and water management." *Environmental Modelling & Software* 38(0), 244-258.

Howitt, Richard, Duncan MacEwan, Josue Medellin-Azuara, Jay Lund, and Dan Sumner. 2015. *Preliminary analysis: 2015 drought economic impact study*. UC Davis Center for Watershed Sciences.

MacEwan, Duncan, Richard Howitt, and Josue Medellín-Azuara. 2016. "Combining Physical and Behavioral Response to Salinity." *Water Economics and Policy*, 2(01), p.1650010.

MacEwan, Duncan, Mesut Cayar, Ali Taghavi, David Mitchell, Steve Hatchett, and Richard Howitt. 2017. "Hydroeconomic modeling of sustainable groundwater management." *Water Resources Research*, 53(3), pp.2384-2403.

Medellín-Azuara, Josue, Richard Howitt, Jay Lund, and Ellen Hanak. 2008. "Appendix I: Economic effects on agriculture of water export salinity south of the Sacramento–San Joaquin Delta." in: *Comparing Futures for the Sacramento–San Joaquin Delta.* Public Policy Institute of California.

Medellin-Azuara, Josue, Richard Howitt, Duncan MacEwan, and Jay Lund. 2012. "Economic Impacts of Climate-Related Yield Changes in California." *Climatic Change* 109(Supplement 1), S387-S405.

Medellín-Azuara, Josue, Richard Howitt, Ellen Hanak, Jay Lund, and William Fleenor. 2014. "Agricultural Losses from Salinity in California's Sacramento-San Joaquin Delta." *San Francisco Estuary and Watershed Science*, 12(1).

Medellín-Azuara, Josue, Duncan MacEwan, Richard Howitt, George Koruakos, Emin Dogrul, Charles Brush, Tariq Kadir, Thomas Harter, Forrest Melton, and Jay Lund, 2015. "Hydro-economic analysis of groundwater pumping for irrigated agriculture in California's Central Valley, USA." *Hydrogeology Journal* 23(6), 1205-121

Mount, Jeffrey, Ellen Hanak, Ken Baerenklau, Van Butsic, Caitrin Chappelle, Alvar Escriva-Bou, Graham Fogg, Greg Gartrell, Ted Grantham, Brian Gray, Sarge Green, Thomas Harter, David Jassby, Jelena Jezdimirovic, Yufang Jin, Jay Lund, Henry McCann, Josué Medellín-Azuara, David Mitchell, Peter Moyle, Alan Rhoades, Kurt Schwabe, Nathaniel Seavy, Scott Stephens, Daniel Swain, Leon Szeptycki, Barton "Buzz" Thompson, Paul Ullrich, Joshua Viers, and Zexuan Xu. 2018. *Managing Drought in a Changing Climate: Four Essential Reforms.* Public Policy Institute of California.

Pathak, Tapan, Mahesh Maskey, Jeffery Dahlberg, Faith Kearns, Khaled M. Bali, and Daniele Zaccaria. 2018. "Climate Change Trends and Impacts on California Agriculture: A Detailed Review." *Agronomy* 8, 25.

SWRCB (State Water Resources Control Board). 2018. Media Release: "State Water Board Adopts Bay-Delta Plan Update for the Lower San Joaquin River and Southern Delta." December.

Swain, Daniel, Baird Langenbrunner, David Neelin, and Alex Hall. 2018. "Increasing Precipitation Volatility in Twenty-first Century California." *Nature Climate Change*, 8(5), 427.

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