PPIC PUBLIC POLICY INSTITUTE OF CALIFORNIA

Managing Water and Farmland Transitions in the San Joaquin Valley

Technical Appendix

CONTENTS

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Introduction

This technical appendix provides additional background information on some of the quantitative analysis presented in the main report of the same title. It follows the structure of the main report, but only includes the sections for which we provide additional background information. We refer readers to the main report for our assessments of the related policy and management issues; these are generally not repeated here.

Addressing Water Scarcity in the Valley

This section of the report draws principally on the findings from the PPIC study *The Future of Agriculture in the San Joaquin Valley* (Escriva-Bou et al. 2023), and particularly its technical appendix. An accompanying dataset, *PPIC Water Supply Constraints at the Local Scale in the San Joaquin Valley*, provides key information at the level of the 15 groundwater basins covering the valley floor and the 49 local areas (or subunits) that are explicitly modeled within those basins. These local areas group together lands served by a much larger number of local water districts if they have relatively similar access to agricultural water supplies.[1] The modeling of baseline water conditions uses standardized estimates of overdraft and surface water availability, using information for water years 2003–10. As described further in Escriva-Bou et al. (2023), these are the only years for which comparable data are available in all the valley's groundwater sustainability plans (GSPs), making it possible to do a consistent analysis for the whole valley; this period is also broadly representative of PPIC estimates of the valley-wide level of overdraft for the 30-year period 1988–2017.

Here we briefly describe additional results presented in this new study, which builds off this analysis. For context, Figure A1 displays the 49 local areas and their baseline cropped acreage, using 2018 land use estimates from the California Department of Water Resources (DWR).

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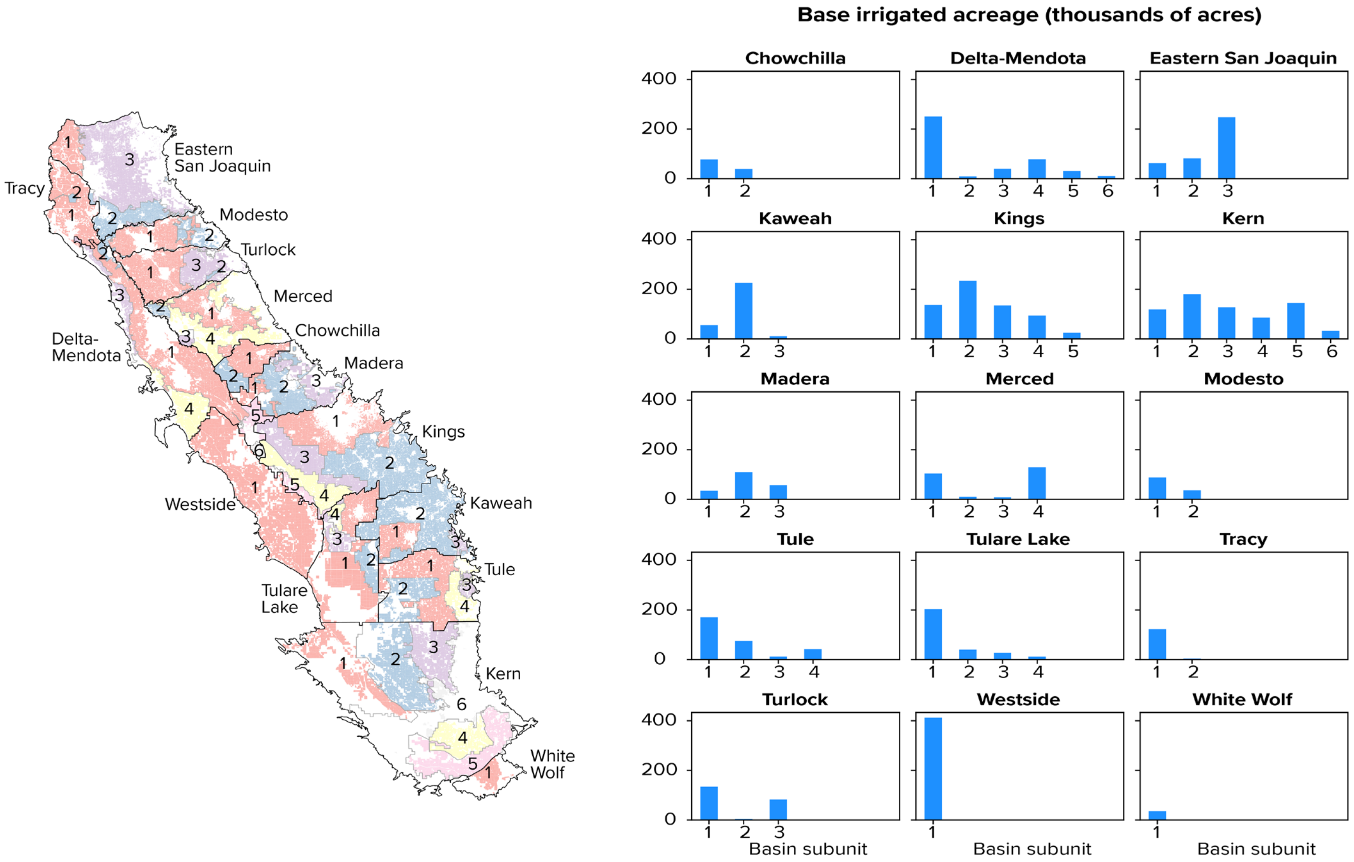
[1] These local areas are largely amalgamations of water agency service areas and undistricted lands with similar levels of surface water availability within each of the 15 SGMA basins, as shown in Figure 1(b) of the main report; we assume they have similar access to groundwater availability as well, given their locations within the same basin. Because some local areas group multiple water districts or groundwater sustainability agencies (GSAs), the results may differ from the specific conditions facing growers within individual water districts. Westside and White Wolf basins each have just one local area (in Westside's case, the basin is served by a single water agency and a single GSA).

FIGURE A1

Baseline crop acreage for the 49 local areas within the San Joaquin Valley's 15 groundwater basins



SOURCE: Escriva-Bou et al (2023).

NOTE: The map shows the 49 modeled local areas within their groundwater basins. Shaded areas depict cropped acreage; different colors are used to help distinguish the boundaries of the local areas within basins. In some basins the local areas are not fully contiguous. The bar charts show baseline (2018) cropped acreage for each local area, using DWR estimates from LandIQ. The x-axis identifies each local area (subunit) by its number (also shown on the map).

Water Trading Reduces the Costs of Managing Demand

Figure 3 in the main report displays geographically explicit estimates of the risk of land fallowing across farmland in the San Joaquin Valley by 2040, taking into account pumping cutbacks from SGMA and other water reductions from new environmental flows and climate change.[2] We estimate the fallowing risk under different trading scenarios for each parcel, applying risk estimates for 20 individual crop categories within each of the 49 local areas. This is calculated as the share of acreage within the crop category that would be fallowed in each local area under each scenario. The no trading scenario applies the same fallowing risk for all crops within the local area; other scenarios distinguish by crop categories. Figure A2 presents the average fallowing risks by local area for the different trading scenarios.

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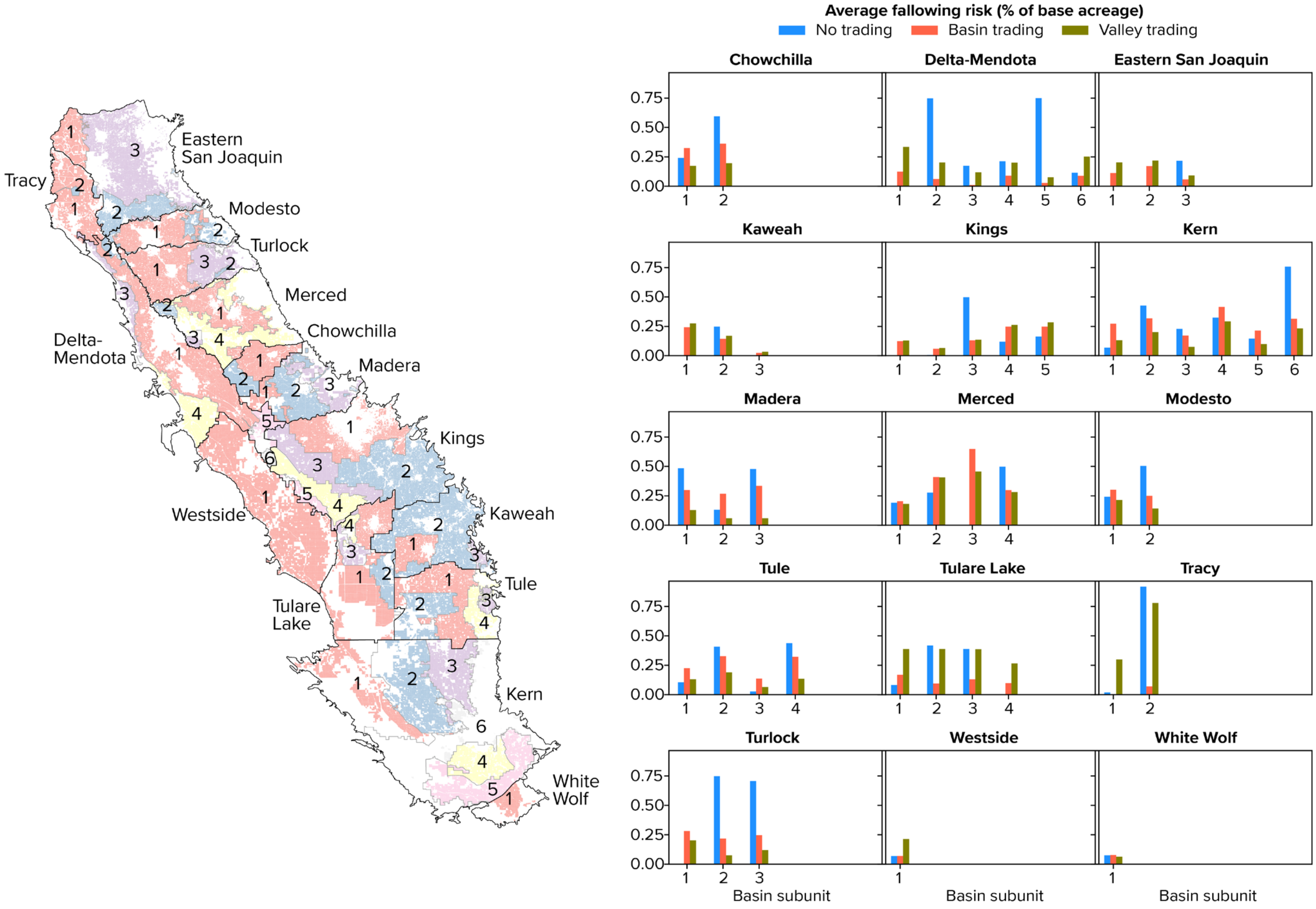
[2] Relative to our baseline estimates of average annual water availability, increased environmental flow requirements starting in 2009 have likely reduced the long-term average availability of surface water in basins that receive agricultural service contract deliveries from the Central Valley Project or deliveries from the State Water Project (e.g., Westside and parts of Kern). This could further increase the long-term water deficit in some basins.

FIGURE A2

Fallowing risk from water cutbacks by 2040 for local areas within groundwater basins under different trading scenarios



SOURCE: Authors' estimates.

NOTES: The map shows the 49 modeled local areas within each of the 15 groundwater basins. Shaded areas depict cropped acreage; different colors are used to help distinguish the boundaries of the local areas within basins. In some basins these local areas are not fully contiguous. The bar charts show how annual fallowing risk by 2040 (i.e., the percentage reduction in acreage relative to baseline acreage) changes under different trading scenarios. The x-axis identifies each local area (subunit) by its number (also shown on the map).

As described in the main report, water trading would shift the crop portfolio. In particular, farmers growing perennial fruits and nuts would seek to purchase water from those growing less-profitable field crops like alfalfa and cotton. As shown in Figure A3, in the no trading scenario, perennials make up two-thirds of the fallowed acreage (66%). With basin trading, that share drops to just over a quarter (28%), and with valley-wide trading of surface water, it falls even further (12%). The flip side is a sharp decline in alfalfa (which virtually disappears under valley trading), and large drops in other field crop acreage (except corn, a special case in this region).[3] If

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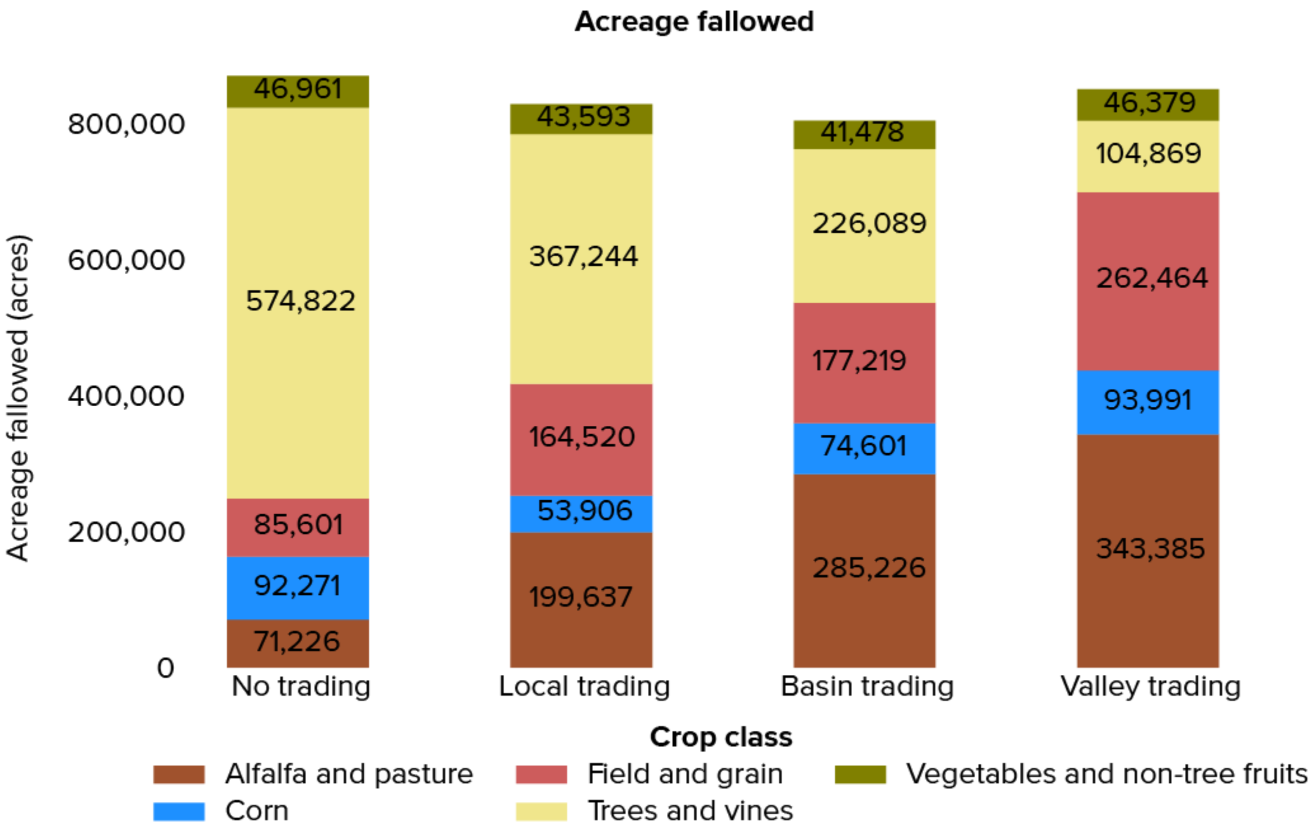
[3] In keeping with observed practice, we treat corn—largely grown near dairies to provide silage and help manage manure—as somewhat inflexible, limiting fallowing to 20 percent of current acreage when water conditions permit. As a result, its fallowed acreage decreases with local, and even basin trading, relative to the no trading alternative. With valley trading, corn acreage returns to roughly the same level as with no trading. In 2018 (our baseline year), corn occupied nearly 500,000 acres. The category of crops we refer to as "other field and grain" also included about 100,000 acres of miscellaneous grain and hay, much of which serves the same purpose. It also contains about 130,000 acres of wheat, some of which also is dedicated to silage production. We did not apply the same fallowing restrictions to this small grain acreage, so it is subject to more cutbacks than corn in our trading scenarios. There may be less incentive to trade water away from this acreage in the basin and valley trading scenarios if dairy farmers opt to manage this acreage the way they manage corn.

market conditions rebalance the relative profitability of different crops, these trading patterns could shift—for instance, if pressures on hay acreage in other western states give a sustained boost to local alfalfa prices).[4]

FIGURE A3

Changes in the valley's crop portfolio under different trading scenarios



SOURCE: Authors' estimates, drawing on analysis in Escriva-Bou et al. (2023).

NOTE: For baseline crop acreage and details of crop shifts by basin, see the technical appendix to Escriva-Bou et al. (2023). Perennial trees and vines include almonds, pistachios, and grapes, among others; the field and grain group includes cotton, small grains, and oilseeds, among others. Corn is broken out separately because it is mostly used as wet silage for dairies, and these lands are also fertilized by manure as part of dairy waste management programs.

As described in the main report, some of the surface water trading modeled here would require adjustments of local, state, and federal agency policies regarding transfers of water to other parties (particularly outside of the service areas of local water districts or the State Water Project and Central Valley Project). In addition, groundwater sustainability agencies (GSAs) would need to establish mechanisms for groundwater trading within their own boundaries and within their basins. Infrastructure limitations could also prevent some surface water trades from occurring. Whereas groundwater trades within the same basin can typically be accomplished by simply recording the transaction and allowing pumping to take place in the location of the buyer instead of the seller, surface water actually needs to move from seller to buyer, either directly or with the assistance of an intermediate party who has conveyance connections to both the buyer and seller.

In the main report, we recommend a regional analysis of conveyance priorities, taking into account both the potential for water trading that could benefit the regional economy and the potential for getting more recharge

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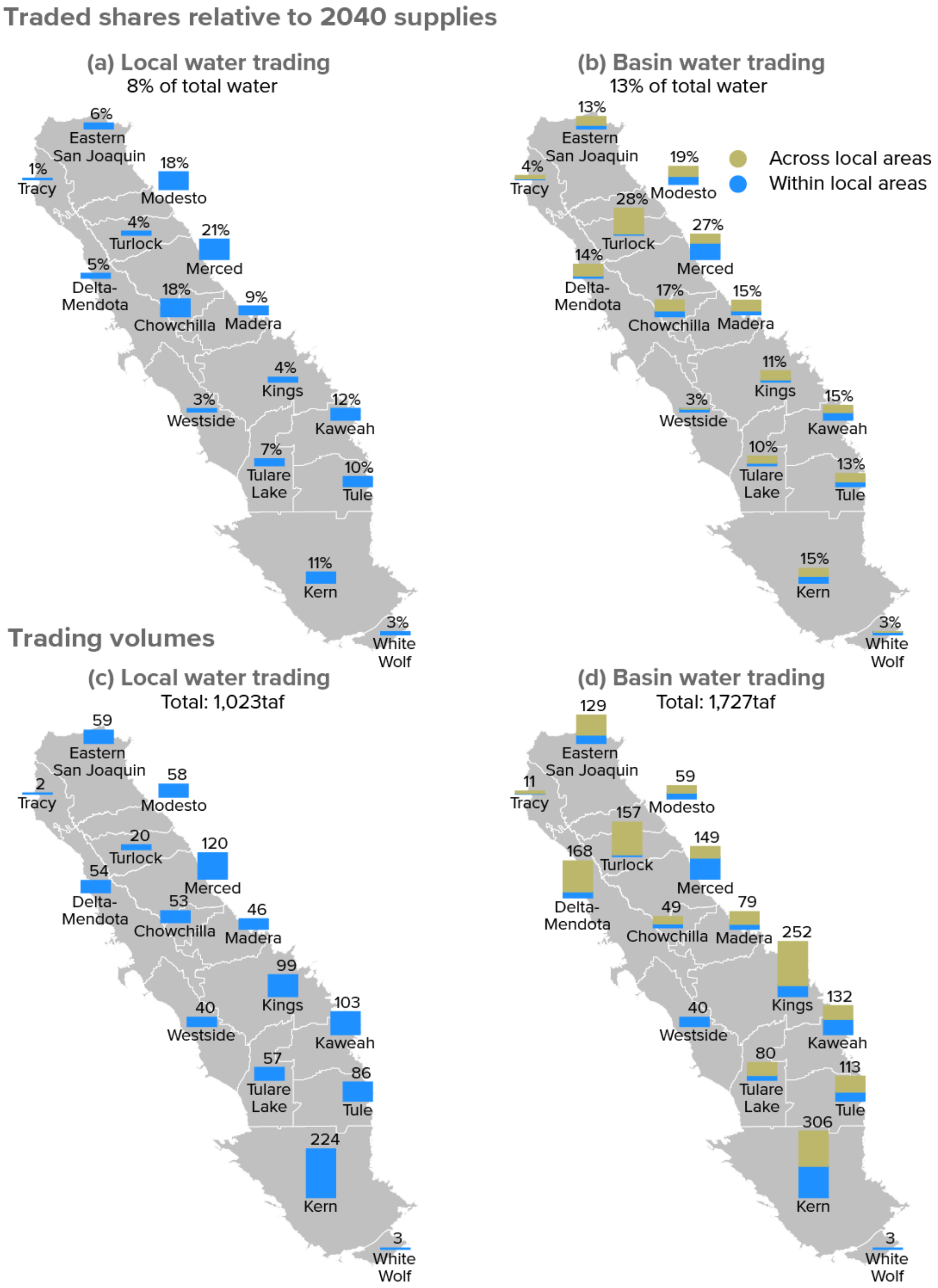
[4] Alfalfa is a major crop within the Colorado River basin, which is facing the prospect of large acreage cutbacks to cope with declining water supplies.

water to suitable lands. While it is beyond the scope of this study to evaluate the specific areas where conveyance capacity is too limited to support beneficial water trading, we did some preliminary analysis to provide a sense of how important this constraint might be. Figure A4 presents our estimates of the volume of water trading within each basin under local trading (panel a) and basin trading (panel b), expressed as a share of total irrigation water supplies that will be available in 2040, following cutbacks from SGMA implementation, new environmental flows, and climate change. As elsewhere, this assumes that all cutbacks are met with demand management only; new supplies would reduce the amount of fallowing required and likely also the extent of trading.

FIGURE A4

Trading volumes with local and basin trading, expressed as a share of total 2040 water supplies



SOURCE: Authors' estimates, drawing on analysis in Escriva-Bou et al. (2023).

NOTE: Taf is thousands of acre-feet. Panels (a) and (b) show the estimated volume of surface and groundwater trading that would occur with local trading (within local areas) and basin trading (where some water is traded within local areas and some is traded across local areas within the same basin), expressed as a share of each basin's 2040 supplies (post SGMA, environmental flow, and climate change cutbacks to supplies). Panels (c) and (d) show the total volumes traded in local and basin trading, respectively. For water availability by basin and subunit, see the dataset accompanying Escriva-Bou et al. (2023).

With local trading, just over 1 million acre-feet (maf) of water would move from one use to another within the 49 local areas. On average, this represents roughly 8 percent of irrigation water supplies in 2040, with higher shares where there were more diverse local crop portfolios in 2018 (our base year for land use). With basin trading, when trading is allowed to expand across local areas within the same basin, the total volume of trading increases to just over 1.7 maf (13%). Roughly 1.1 maf of this total is trades *across* local areas; trading *within* local areas falls to roughly 0.6 maf.

Trading *within* local areas—in either scenario—is generally unlikely to require additional infrastructure. These areas are defined by similarities in their surface water conditions; when they have surface water, they will typically have the capacity to get it from one user to another. Local groundwater trades could also be accomplished without infrastructure. Much of the trading *across* local areas could also be accomplished without additional infrastructure as groundwater trades, if these trades are not constrained by needs to avoid localized negative unintended results of pumping (e.g., subsidence or well failures).[5] However, trading surface water to some groundwater-only areas (such as parts of Modesto, Turlock, Chowchilla, Kings, and Tule basins—see Figure 1b in the main report) would likely require new or expanded conveyance capacity. If basin trading adds significant economic benefits (relative to local trading), this infrastructure expense is more likely to pencil out. Our modeling of crop revenues suggests that the additional gains from basin trading are significant in Chowchilla, Delta Mendota, Eastern San Joaquin, Kings, and Turlock (see Escriva-Bou et al. (2023), technical appendix Figure A12).

Figure A5 presents the estimated volume and share of surface water that would move across basins in the valley trading scenario, highlighting which basins are net sellers and which are net buyers, as well as major regional rivers and conveyance infrastructure. In total, over 0.7 maf in cross-basin trades would occur (6% of estimated valley-wide supplies in 2040). We are not able to estimate the additional surface and groundwater trades that would occur within each basin under this scenario, but it would be less than the amounts under basin trading (Figure A4, panels b and d). From a conveyance perspective, the total volume of cross-basin trades is not especially large relative to total surface supplies that are delivered annually through the valley's rivers and canals (10%). But the direction of some trades would be difficult to accomplish without new infrastructure. Most selling basins are on the valley's west side, whereas the main net buyers are in the northeast, Tule, and Kern. Kern—the largest buyer—is relatively well-positioned to access supplies from the west-side basins that would be selling some water; Tule might have some capacity to access additional surface water through a refurbished Friant–Kern Canal.[6] In contrast, the northeastern basins would likely need access to new east-west conveyance to be able to acquire water from willing sellers on the west side. Some of this conveyance would need to reach the same groundwater-only lands that currently lack capacity to receive surface water from other parties within their basins.

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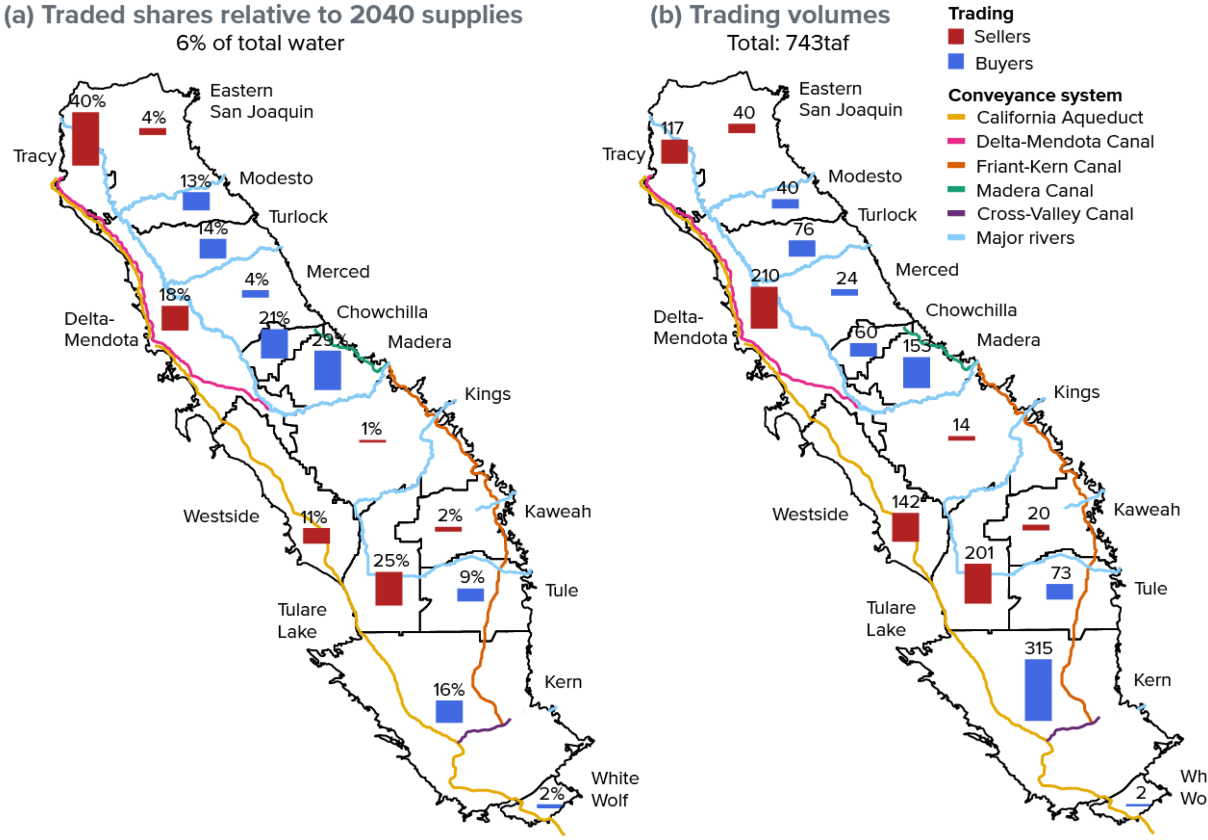
[5] In most basins, there is enough sustainable groundwater in local areas that would be selling water to accomplish the modeled levels of basin trading, although significant shifts in the location of pumping could cause localized impacts that might limit the volumes that could be safely traded. In Delta-Mendota, Kaweah, and Turlock (and to a lesser extent Merced), the modeled levels of trading could only be accomplished if some surface water is moved to the local areas that are net buyers.

[6] The Friant-Kern Canal has lost substantial capacity from subsidence in its southern reaches, but a project is now underway to restore capacity.

FIGURE A5

Cross-basin surface water trading under the valley trading scenario, expressed in thousands of acre-feet



(a) Traded shares relative to 2040 supplies

6% of total water

(b) Trading volumes

Total: 743taf

SOURCE: Authors' estimates, drawing on analysis in Escriva-Bou et al. (2023).

NOTE: Taf is thousands of acre-feet. The figure shows the estimated volume of cross-basin surface water trading that would occur with valley trading, with net sales shown in red and net purchases shown in blue. The total sold (743 taf) represents 6 percent of the valley's 2040 supplies (post SGMA, environmental flow, and climate change cutbacks to supplies); this is 10 percent of total surface supplies for crop irrigation. Additional surface and groundwater would continue to be traded within local areas and across local areas within each basin, likely less than the volumes shown in Figures A4b and A4d. For water availability by basin and subunit, see the dataset accompanying Escriva-Bou et al. (2023).

Addressing Concerns About Water Trading and Pumping

This section combines analysis on water and land use by crop within the 49 local areas from modeling in Escriva-Bou et al. (2023) with other information to draw insights about changes in pumping, land fallowing, and various potential impact areas under different trading scenarios.

Achieving groundwater sustainability will address many negative impacts of overpumping

Figure 4 in the main report displays our estimates of the percentage change in groundwater pumping by 2040 relative to current conditions. We assume that water users have both met SGMA requirements to end overdraft and adapted to the anticipated water reductions from new environmental flows and climate change.

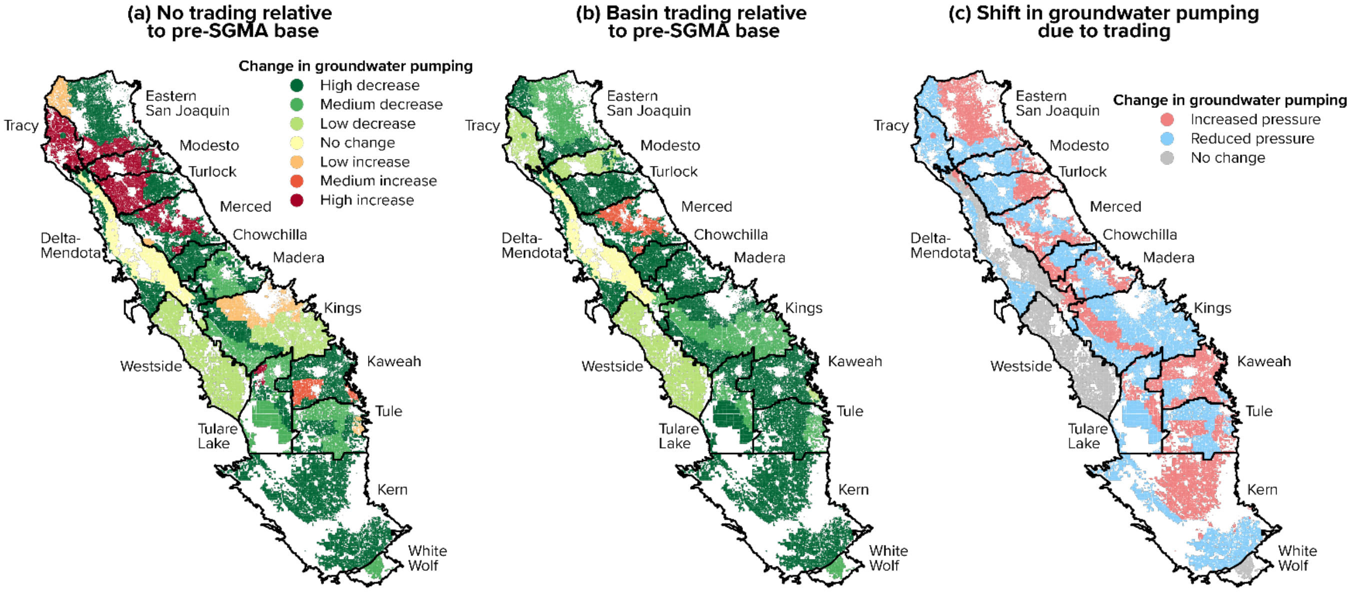
We present two scenarios—no trading and basin trading. In the no trading scenario, changes in pumping are identical across all lands within each of the 49 local areas, and in the basin trading scenario, both surface and groundwater can be freely traded both within and across local areas within each basin. We focus on basin trading to show how trading might shift the use of groundwater relative to the no trading case because our modeling framework enables us to break out groundwater and surface water use separately at this scale. While surface and groundwater are also traded freely within each local area in the local trading scenario, we are not able to readily distinguish between them. To determine the amount of groundwater that is traded, we take the model findings for the volume and direction of all water trades across local areas within each basin, and then assume that water users first trade available groundwater, with surface water trades closing the gap.

This approach provides an upper bound on the amount of groundwater that would move across different local areas within basins, and it is consistent with the idea that groundwater trading could be easier from a logistical standpoint—since unlike surface water, it does not require conveyance infrastructure.[7] As we discuss in the main report, when considering potential third-party impacts, the feasibility of groundwater purchases might be limited in some places if additional pumping (which occurs when a buyer purchases the right to pump a seller's groundwater credits) would cause undesirable localized impacts, such as subsidence or declines in groundwater levels that affect other wells. Additional safeguards may be warranted during the transition to 2040, when overdraft is still occurring.

Figure A6 reproduces Figure 4 in the main report, with an additional panel showing whether local areas are increasing or decreasing pumping when basin trading is introduced. Maps for both the no trading and basin trading scenarios show some areas where pumping would actually increase by 2040 relative to the present. These areas do not currently have overdraft, reflecting relatively high allocations of surface water per acre. (They actually enjoy a groundwater surplus by our estimates—see Escriva-Bou et al. (2023) for details.) As growers experience cutbacks in surface water—mostly from anticipated environmental flow changes, but also from climate change—our model predicts that they would increase pumping (while abiding by SGMA sustainability mandates). But when basin trading is allowed, these areas generally trade some groundwater to other local areas in their basin that are more water-scarce, and their pumping goes down.

FIGURE A6

Changes in groundwater pumping from water cutbacks by 2040, with no trading and basin trading



SOURCE: Authors' estimates.

NOTE: Panels (a) and (b) show shifts in groundwater pumping to attain sustainability relative to the pre-SGMA baseline, considering supply cutbacks from SGMA, new environmental flows, and climate change by 2040 (see Figure 1a in the main report). Panel (c) shows changes in pumping pressure when basin trading is introduced. "Low" represents a change of less than 10%, "medium" a change between 10 and 25%,

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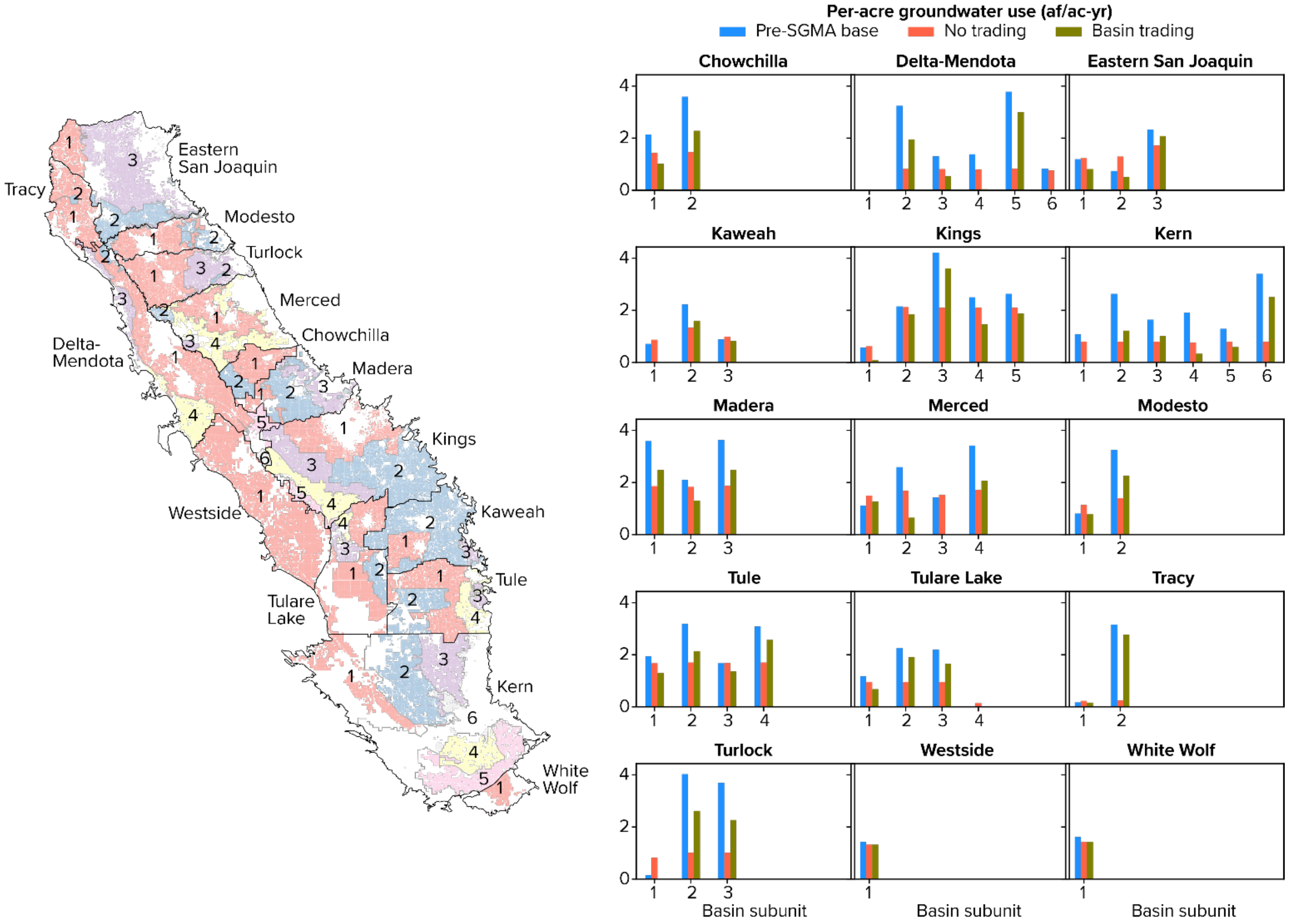
[7] Groundwater trading with a hydrologically connected area can be accomplished by simply recording the purchase/sale and shifting the location of pumping from the seller to the buyer, although in practice there might be a need to impose limits to avoid localized impacts.

and "high" a change greater than 25%. In some cases, large percentage changes may reflect small changes in actual volumes. Panel (a) assumes no trading and proportional groundwater use changes within each of 49 local areas, while panel (b) allows for trading of surface and groundwater within basins. In the no trading scenario, areas with pumping increases currently do not have overdraft; they increase pumping to compensate for the loss of surface water from new environmental flow requirements.

Although basin trading would lead to increased pumping in the most water-scarce areas relative to the no trading scenario (as shown in Figure A6, panel c), overall pumping declines would still be significant relative to current conditions (panel b). Figure A7 shows how pumping per acre shifts across each of the 49 local areas.

FIGURE A7

Changes in groundwater pumping from water cutbacks by 2040 by local areas within groundwater basins, with no trading and basin trading



SOURCE: Authors' estimates.

NOTE: The map shows local areas within each of the 15 groundwater basins. Shaded areas depict cropped acreage; different colors are used to help distinguish the boundaries of the local areas within basins. In some basins these local areas are not fully contiguous. The bar charts show how pumping per acre-foot changes from current conditions (pre-SGMA base) to 2040 with no trading and basin trading. In the no trading scenario, areas with pumping increases currently do not have overdraft; they increase pumping to compensate for the loss of surface water from new environmental flow requirements.

Subsidence threats may warrant special pumping limits

To estimate historical overdraft per acre-foot by local area (Figure 5b), we drew on the hydrologic analysis described in the technical appendix to Escriva-Bou et al. (2023). We took the estimated historical overdraft for the basin as a whole and apportioned it to each local area, based on their crop water demands and their surface water availability. Figure 5b scales this on a per-acre basis for irrigated lands. Within each basin, areas with a greater dependence on groundwater per acre have a higher overdraft per acre than areas with more surface water.

Groundwater trading could reduce pressures on rural drinking water supplies

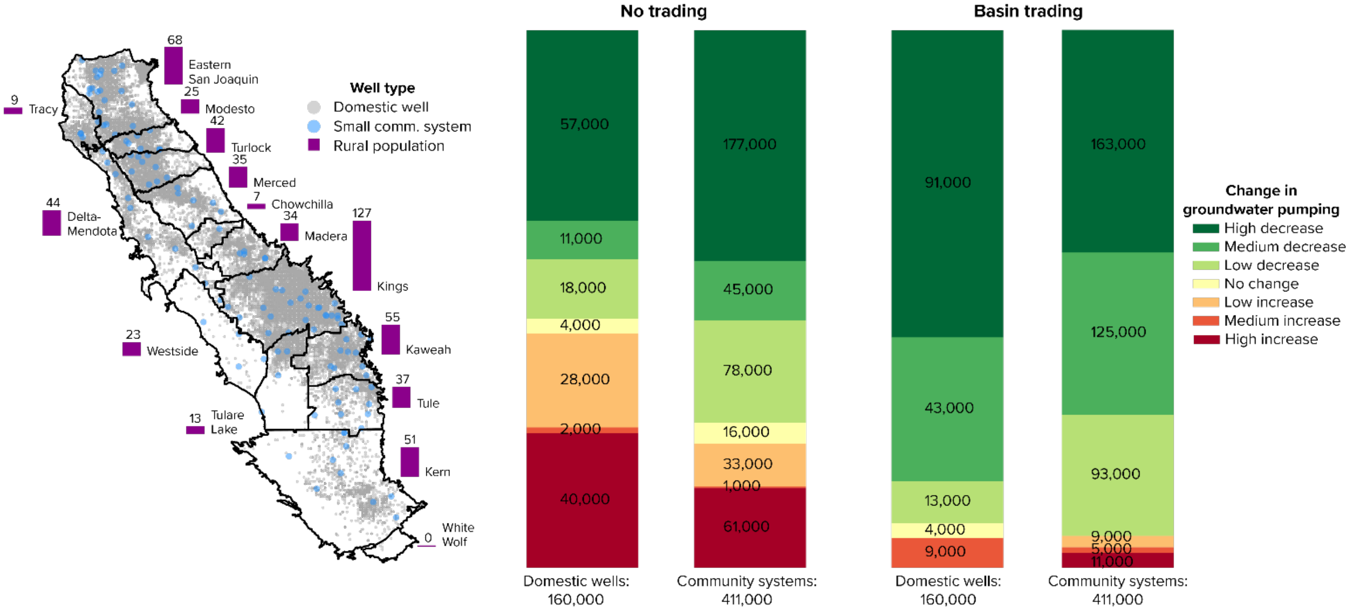
The analysis underlying Figure 6 in the main report uses the information on groundwater pumping changes by 2040 relative to the pre-SGMA baseline (shown in Figures A6 and A7 above) and relates it to locations of rural community water systems, using data on location and population served from the State Water Board. We assessed the changes in groundwater pumping within 1.5-mile buffer zones around communities located near significant irrigated cropland (>250 acres of crops within the buffer zone). In some cases, we created a single buffer for multiple systems in close proximity, so while the map shows 123 distinct locations, the buffers actually include a total of 304 communities, and represent nearly 411,000 residents. We excluded 88 small community water systems (serving roughly 60,000 residents) that are in urban and semi-urban locations with little adjacent cropland. We modeled changes in groundwater pumping taking into account modeled reductions in irrigation water use in the buffer zones, and used weighted averages for communities whose buffers overlie more than one local area. We undertook a similar analysis for domestic wells, but applied the average pumping changes for the local area in which the wells are located, since a comparable buffer analysis would not yield meaningful results.

Figure A8a displays locations of the valley's small community water systems and domestic wells, along with populations served by these wells in each groundwater basin. Figure A8b shows our estimates of the population served by community water systems or domestic wells in each of the pumping change categories for the no trading and basin trading scenarios. The areas where agricultural pumping would increase by 2040 in the no trading scenario reflect declines in surface water for irrigation from climate change and new environmental flow requirements, mainly in the northeast (see Figure A6 above and the related discussion). Groundwater trading within basins could reduce agricultural pumping in more densely populated rural areas because agricultural water demands are higher in less densely populated areas. The patterns are broadly similar for populations served by small community systems and domestic wells, though a larger share of the population relying on domestic wells would experience increased agricultural pumping with no trading. Domestic well users are also located in areas that would experience greater decreases in agricultural pumping with basin trading.

To facilitate a comparison of pumping changes in the community buffer zones and the 49 local areas, Figure A9 reproduces the maps showing changes in pumping under the no trading and basin trading scenarios for local areas (from Figure A6), alongside the maps of buffer zones (from Figure 6).

FIGURE A8

Location and changes in groundwater pumping by 2040 for rural well-dependent populations with no trading and basin trading



(a) Domestic and small community system well locations and population served

(b) Pumping changes for population served, with and without trading

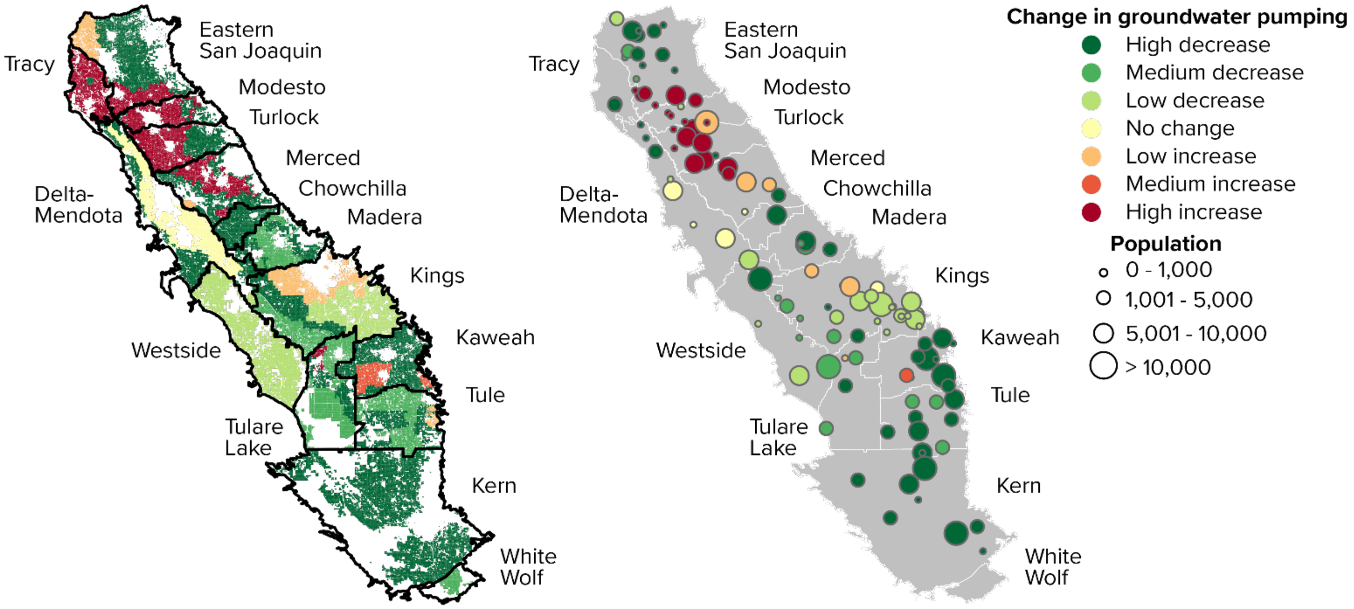
SOURCE: Domestic wells: CA Department of Water Resources (locations), PPIC estimates using county data from the Department of Finance (population); small community water systems: State Water Resources Control Board; pumping change estimates: PPIC.

NOTES: Panel (a) shows the location of small community water systems (blue dots) and domestic wells (gray dots) and the estimated population served by these water sources per basin (purple bars), shown in thousands of residents. Panel (b) shows the rural well-dependent residents reliant on domestic wells and small community water systems in areas with different levels of change in groundwater pumping relative to the pre-SGMA baseline. "Low" represents a change of less than 10%, "medium" a change between 10 and 25%, and "high" a change greater than 25%. "No change" is plus or minus 1 percent or less. In some cases, large percentage changes may reflect small changes in actual volumes. The no trading scenario assumes proportional groundwater use cutbacks within buffer zones (for community systems) or local areas (for domestic wells), while the basin trading scenario allows for trading of surface and groundwater within basins. See Figure A9 for maps of the pumping changes by local area and community water system.

FIGURE A9

Location of rural well-dependent communities and changes in groundwater pumping by 2040 with no trading and basin trading

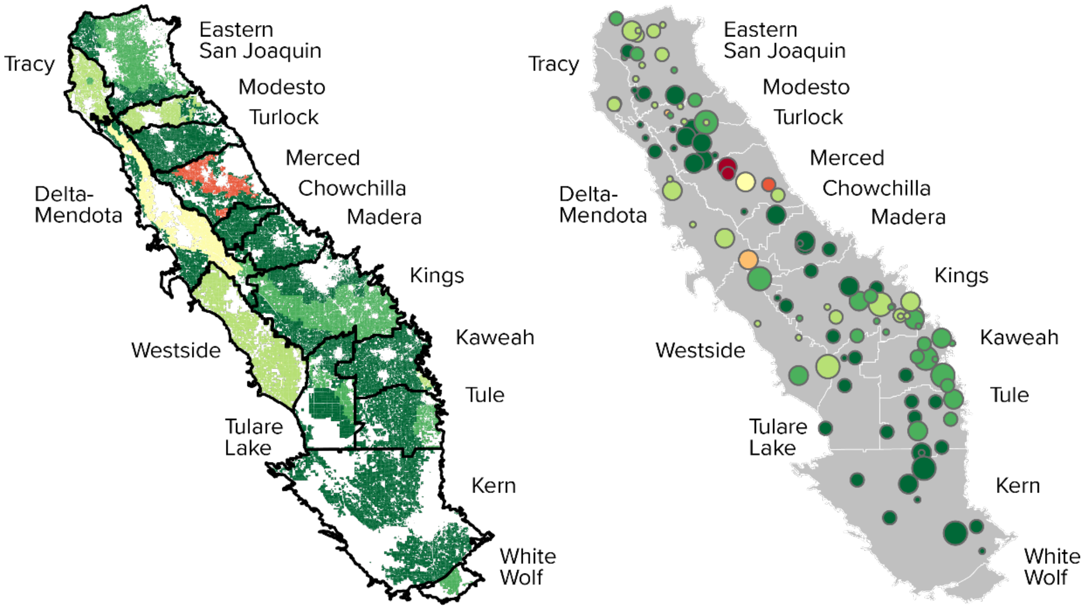
No trading relative to pre-SGMA base



(a) Local areas

(b) Community water system buffers

Basin trading relative to pre-SGMA base



(c) Local areas

(d) Community water system buffers

SOURCE: Small community water system locations: State Water Resources Control Board; pumping change estimates: PPIC.

NOTES: Panels (a) and (c) show groundwater pumping changes by 2040 in the 49 local areas under no trading and basin trading scenarios (as in Figure A6 above). Panels (b) and (d) show groundwater pumping changes around small community water systems that are located near significant irrigated cropland (>250 acres of crops within a 1.5-mile buffer zone around the community). Some buffers include multiple systems in close proximity. The colors show modeled changes in groundwater pumping by 2040, relative to the pre-SGMA baseline, taking into account reductions in irrigation water use to attain sustainability. "Low" represents a change of less than 10%, "medium" a change between 10 and 25%, and "high" a change greater than 25%. "No change" is plus or minus 1 percent or less. In some cases, large percentage changes may reflect small changes in actual volumes. The no trading scenario assumes proportional groundwater use cutbacks within each of the 49 local areas, while the basin trading scenario allows for trading of surface and groundwater within basins. Panels (b) and (d) show 123 buffer zones, which include 304 small community water systems, serving a population of nearly 411,000.

Addressing Concerns about the Impacts of Water Trading and Land Fallowing

Trading could slightly shift fallowing near communities with high dust risk

Figure 7 in the main report summarizes our analysis of how fallowing risks might shift under different trading scenarios for rural communities in areas where soils are most prone to wind erosion, based on the wind erodibility index (WEI) (mapped for California by Walkinshaw et al. 2021). This builds on analysis presented in an earlier PPIC study focused on dust risk issues that could arise with land fallowing in the valley (Ayres, Kwon, and Collins 2022). The method uses the same buffer zones around communities as above for the wells analysis. We classify these by their baseline dust risk and estimate the aggregate fallowing risk for lands within the buffers of each community. Of the 411,000 residents located within these 123 buffer zones, roughly 177,000 are in areas with a high wind erodibility index (average value greater than 86 within their buffer). Protecting these communities from wind-blown dust would entail treating somewhere between a low of roughly 24,000 fallowed acres (with local and valley trading) to roughly 29,000 (with no trading) and a high of roughly 34,000 acres (with basin trading).

Table A1 presents a more detailed overview of this analysis. Here, community dust risk exposure is broken into four categories, taking into account not only the soil characteristics measured by the WEI, but also baseline levels of small particulates ($PM_{2.5}$)—an indicator of prevailing air quality in the area. High and high-medium communities are those with a high WEI and high or low baseline level of $PM_{2.5}$, respectively; medium-low and low are those with a low WEI and high or low baseline level of $PM_{2.5}$, respectively. Figure A10 maps this more detailed picture of dust risk, and Figure A11 maps the fallowing risk levels for each community under the four water trading scenarios.

TABLE A1

Overview of rural community exposure to dust risk and fallowing risk under different water trading scenarios

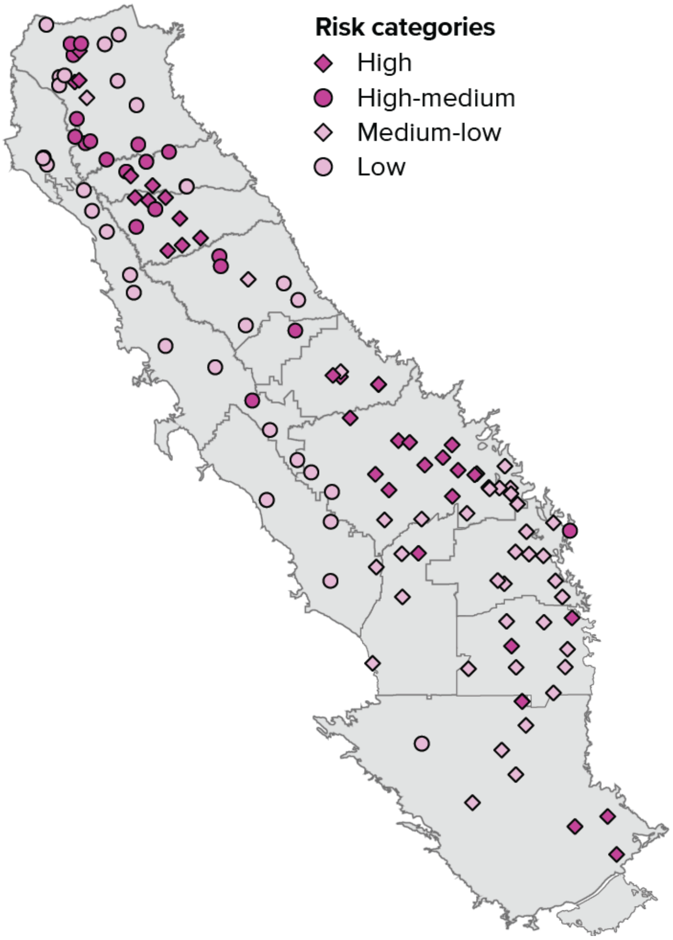
		Community water systems				Population				Expected local fallow acreage			
Trading scenario (rows)	**Baseline dust risk (columns)**	Low dust risk	Medium low dust risk	High medium dust risk	High dust risk	Low dust risk	Medium low dust risk	High medium dust risk	High dust risk	Low dust risk	Medium low dust risk	High medium dust risk	High dust risk
No trading	No fallowing	3	1	4	5	15,060	1,016	10,061	18,333				
	0-10% fallowing	13	13	4	12	20,369	44,592	16,530	47,130				
	10-25% fallowing	12	20	12	10	32,026	106,049	42,831	14,510				
	≥25% fallowing	2	6	0	6	1,825	13,020	0	27,576				
	Total	**30**	**40**	**20**	**33**	**69,280**	**164,677**	**69,422**	**107,549**	**19,735**	**32,689**	**10,950**	**18,071**
Local trading	No fallowing	6	7	5	7	18,897	21,206	10,311	33,708				
	0-10% fallowing	12	14	10	12	14,612	71,075	37,290	34,562				
	10-25% fallowing	8	9	5	4	20,576	46,945	21,821	7,523				
	≥25% fallowing	4	10	0	10	15,195	25,451	0	31,756				
	Total	**30**	**40**	**20**	**33**	**69,280**	**164,677**	**69,422**	**107,549**	**17,643**	**27,577**	**5,579**	**18,697**
Basin trading	No fallowing	3	1	0	0	3,837	934	0	0				
	0-10% fallowing	13	18	9	12	28,019	88,647	21,350	35,690				
	10-25% fallowing	11	12	5	8	29,423	43,907	30,338	30,888				
	≥25% fallowing	3	9	6	13	8,001	31,189	17,734	40,971				
	Total	**30**	**40**	**20**	**33**	**69,280**	**164,677**	**69,422**	**107,549**	**15,556**	**27,121**	**12,296**	**21,980**
Valley trading	No fallowing	0	0	0	0	0	0	0	0				
	0-10% fallowing	6	25	8	17	13,411	122,625	21,100	56,694				
	10-25% fallowing	13	9	8	12	9,642	33,566	34,219	33,488				
	≥25% fallowing	11	6	4	4	46,227	8,486	14,103	17,367				
	Total	**30**	**40**	**20**	**33**	**69,280**	**164,677**	**69,422**	**107,549**	**27,864**	**21,351**	**11,181**	**13,199**

SOURCE: Author calculations, using Walkinshaw et al. (2021) (Wind erodibility index), Di et al. (2021) ($PM_{2.5}$ levels), State Water Resources Control Board (water system mapping), and fallowing risk (Escriva-Bou et al. 2023).

NOTES: The table estimates community exposure to dust risk under different trading scenarios for rural communities with significant (>250 acres) amounts of agricultural land within 1.5-mile buffers, adjusted to account for the footprint of the community. Some buffers include more than one community water system. Baseline risks of dust exposure run from low to high (columns), based on a combination of the wind erodibility index (WEI) (which captures where soils are most prone to wind erosion) and $PM_{2.5}$ levels (which capture prevailing air quality). They are as follows: high (WEI>86, ambient $PM_{2.5}$>12 µg/m^3 over 2010–16), high-medium (WEI>86, $PM_{2.5}$<12 µg/m^3), medium-low (WEI<86, $PM_{2.5}$>12 µg/m^3), and low (WEI<86, $PM_{2.5}$<12 µg/m^3). Estimated changes in fallowing risk (rows) summarize the number of communities, total population, and total fallowed acreage in the buffer zones for each dust risk category in each trading scenario. Total cropped acreage in the buffer zones is approximately 529,000 (of which 203,000 surround communities with WEI >86); total acreage in the buffer zones is approximately 655,000 (of which 253,000 surround communities with WEI > 86).

FIGURE A10

Overview of rural community exposure to dust risk

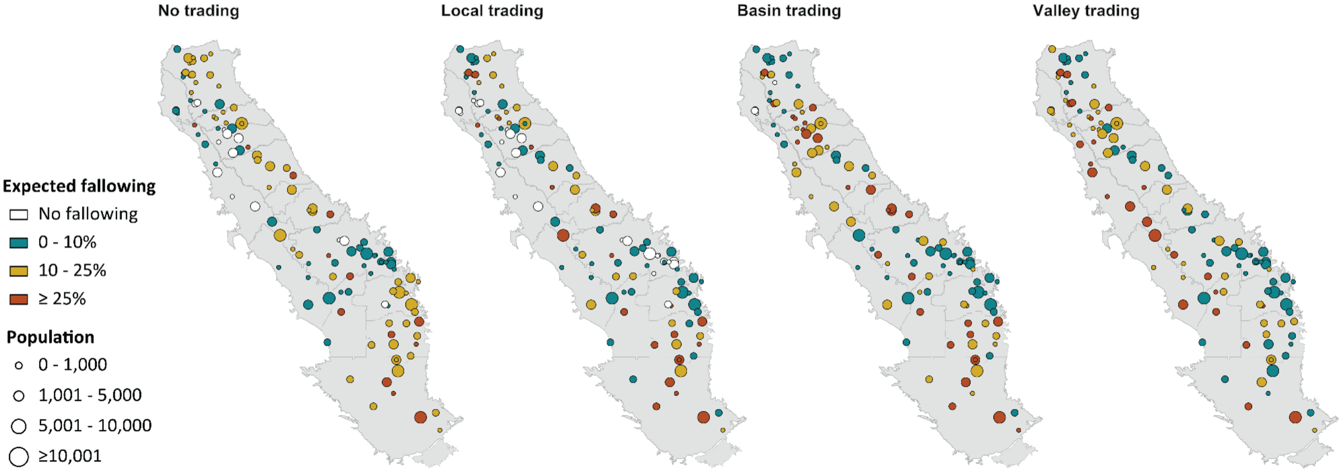


SOURCE: Author calculations, using Walkinshaw et al. (2021) (Wind erodibility index), Di et al. (2021) ($PM_{2.5}$ levels), State Water Resources Control Board (water system mapping).

NOTES: See notes to Table A1 for a description of the risk categories.

FIGURE A11

Overview of rural community fallowing risk under different water trading scenarios



SOURCE: Author calculations, State Water Resources Control Board (water system mapping), and fallowing risk (Escriva-Bou et al. 2023).

NOTES: See notes to Table A1. The circles depicting communities by population size are larger than scale.

Smaller farms tend to be in areas facing less water scarcity, and some could benefit from trading

The discussion in this section of the main report draws on our new analysis of farm sizes on the valley floor, described further in a series of blog posts.[8] For all agricultural parcels of at least one acre in size, we used geospatial parcel real estate records from the valley's eight counties to identify farms, grouping parcels with the same owner as a single farm.[9] We combined this information with our detailed geospatial analysis of land use and water conditions. We estimate each farm's size by the total acreage currently cropped or idled and characterize cropping patterns using 2018 land use data from DWR; we identify water availability and fallowing risk from our hydroeconomic analysis of base case conditions and 2040 conditions under different trading scenarios (Escriva-Bou et al. 2023).

While this dataset enables us to get a good sense of the crop and water situation of different sizes of farms across the region with a high degree of spatial resolution, it does not enable us to identify which lands are owner-operated and which are rented.[10] In some areas, small farmers commonly rent their land from others.[11] And some

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[8] See Ayres, Joaquín Morales, and Hanak (2023) and Cole, Hanak, Escriva-Bou (2023). We thank Jeff Allenby and Hallah Elbeleidy of the Lincoln Institute of Land Policy's Center for Geospatial Solutions for their help in the early stages of this work, which involved accessing the parcel records and pairing them with agricultural land use data from DWR (Land IQ), and we acknowledge the financial support of the Lincoln Institute of Land Policy for this effort.

[9] This involved meticulous matching of owner information across parcel records by hand. In all, we were able to identify owners for 97 percent of the valley's 2018 cropland. When we were aware of farming enterprises that used multiple names, we treated them as the same farm. Where in doubt about discrepancies in owner names, we did not merge them into the same farm. This may explain in part why our total farm count is higher (at 34,583) than the count for irrigated farms in the eight valley counties in the reports from the 2017 Agricultural Census (18,661). That said, the USDA Census may also be affected by undercounts, particularly of smaller farms (Molinar, Yang, and Cha 2008). We also find a smaller count of large farms (especially those with more than 2,000 irrigated acres), possibly reflecting our inability to capture situations where agricultural parcels with different owners are managed by one larger entity. One other discrepancy to note: while the Census farm count covers the eight valley counties (which includes land outside of the valley floor), our dataset focuses on the valley floor, but it includes approximately 120 farms that lie partially in Alameda, Calaveras, and Mariposa counties.

[10] If a landowner rents their farm to another farming operation that has its own holdings, we count these as two separate farms; if a single landowner owns and operates farmland in multiple areas, we count this as one farm.

[11] This is the case, for instance, for many of the small farmers of Southeast Asian heritage who specialize in vegetables and non-tree fruits in the Fresno area (personal communication, Ruth Dahlquist-Willard, spring 2022).

farms—especially in the small- and medium-size categories—are rented to and managed as part of larger farming operations.[12]

Despite this limitation, this dataset can help provide insights into how SGMA implementation in different basins might affect farms of different sizes—a topic that has garnered considerable interest in recent years. The USDA's Agricultural Census, conducted every five years, provides much more detail on issues related to tenure, income, and other socioeconomic factors, but it is reported out at the county level—far too coarse a scale for unpacking SGMA implementation issues in the valley, given the large size of counties (most of which include multiple basins, as well as areas outside the valley floor) and the considerable heterogeneity in current water availability and future constraints, both within and across basins.

Figure 8 in the main report presents an overview of these data, showing the current breakdown of farm units and acreage for the valley as a whole and each of the valley's 15 groundwater basins, for three broad farm size classes: small (< 100 acres), medium (100–499 acres), and large (≥ 500 acres).[13] It also shows the possible reduction in acreage for farms in these three size classes by 2040, once water cutbacks from SGMA and other factors are in effect. These estimates are calculated by applying the crop-specific fallowing risks for each modeled local area (described above) to the acreage of each farm and then summarizing by farm size class. For farms that have land in multiple places, the fallowing risks are calculated at the local area level for each crop before aggregation.

As described in the main report, small farms tend to be located in areas that will be facing less pressure to cut back on their irrigated acreage by 2040, reflecting more robust water conditions. This can be seen in the no trading scenario in Figure 8, which projects significantly smaller proportional cutbacks for smaller farms than for larger farms. As described above, trading will tend to shift water away from the less-profitable annual crops (alfalfa and other field crops like cotton) toward more-profitable perennial fruits and nuts (Figure A3).

The potential changes for farms of different sizes under local, basin, and valley trading reflect the relative composition of their crop mixes. Figure A12 shows what crops small, medium, and large farms are growing and Figure A13 shows how acreage for each crop type is apportioned among farms of different sizes. Smaller farms are more heavily invested in perennials than larger farms, and less involved in vegetables and non-tree fruits, corn, and other field and grain crops. They also have a higher share of acreage in alfalfa and irrigated pasture. With local trading, water moves toward perennials within local areas, and on balance small farms are able to reduce their fallowing and keep more of their perennials in production. With basin and valley trading, there would be opportunities for small farms to sell the water now used for alfalfa, and fallowed acreage would increase correspondingly. Making the market accessible could provide small farms with opportunities to make trades, but these shifts would only happen if small farms opted to participate in the market.

In our more detailed work on farm sizes (see the blog series and related dataset), we provide breakdowns by a larger number of size classes and by basins.

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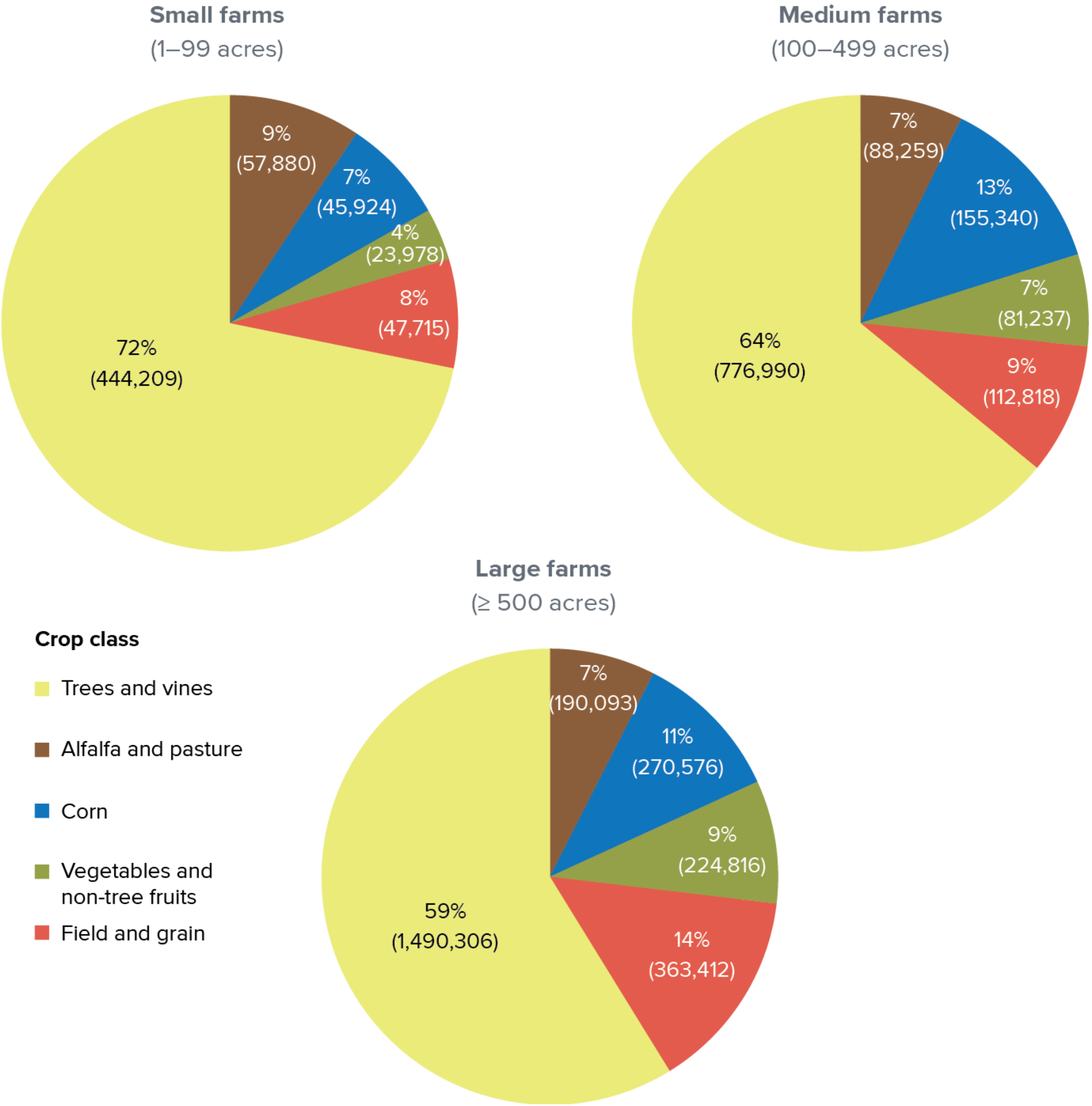
[12] In some cases, this reflects the fact that it is difficult to make an adequate return on farms below a certain size, unless one is growing relatively high-return crops, such as fruits, nuts, and vegetables. Some of our stakeholder advisors suggested, for instance, that farms below 100 acres would generally not provide adequate income for a household unless they were planted in such crops.

[13] Farms are apportioned into the size classes by the amount of irrigable acreage—a category including both cropped acreage and land classified as idle. The total cropped acreage in our dataset is 4,343,000, plus 378,000 acres of idled land.

FIGURE A12

Distribution of major crop types for small, medium, and large farms (acres and percent of total)

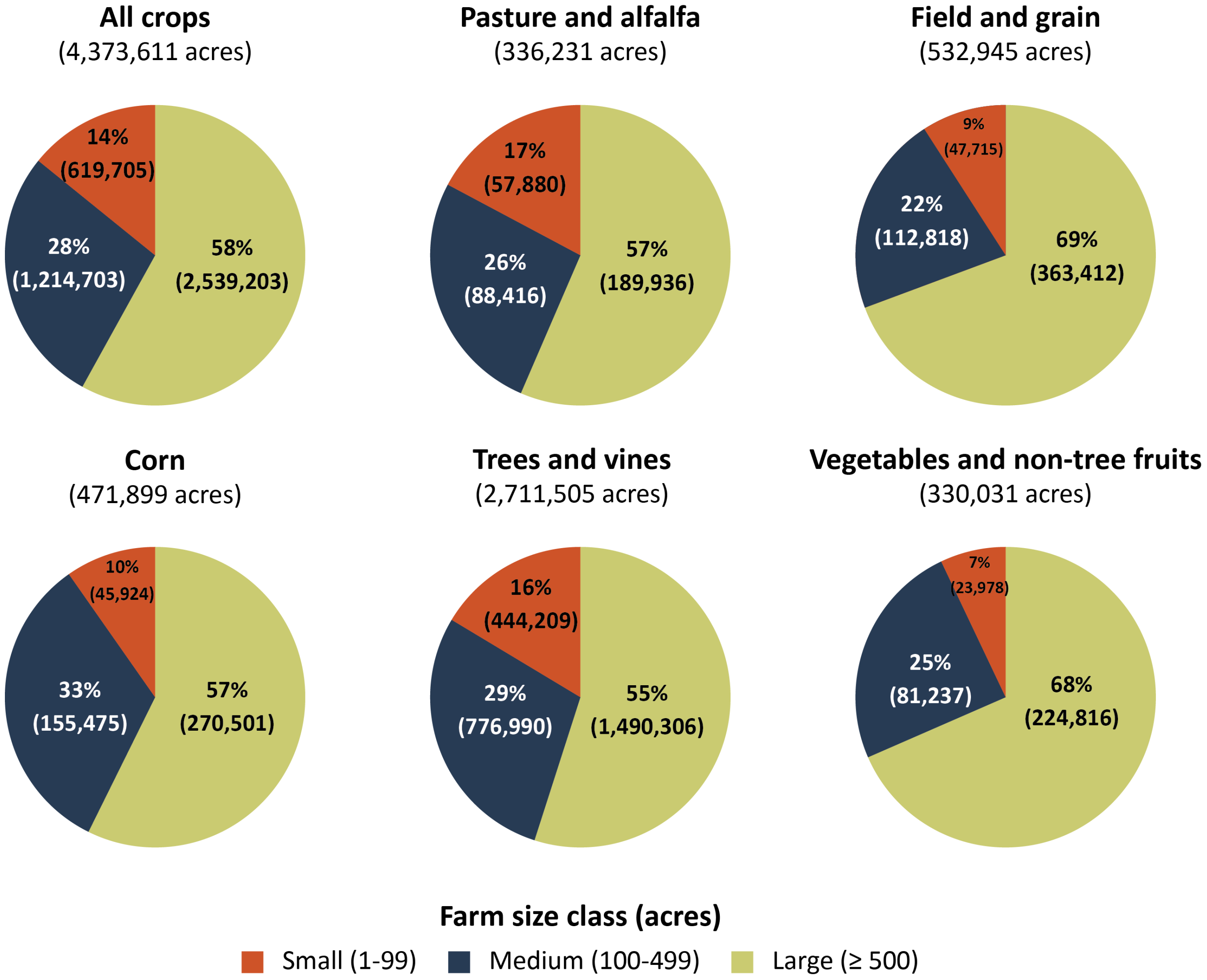


SOURCE: PPIC estimates, using 2021–21 parcel records from county assessors and 2018 land use data from DWR.

NOTES: See the text and Ayres, Joaquín Morales, and Hanak (2023) for more information. Vegetables and non-tree fruits include roughly 7,000 acres of nurseries here (these are excluded from this category in Figure A3).

FIGURE A13

Distribution of major crop types by small, medium, and large farms (acreage and share)



SOURCE: PPIC estimates, using 2021–22 parcel records from county assessors and 2018 land use data from DWR.

NOTES: See the text and Ayres, Joaquín Morales, and Hanak (2023) for more information.

Water trading could raise costs for the dairy industry, even as it benefits the regional economy

The analysis in Escriva-Bou et al. (2023) considers impacts of crop fallowing on the downstream sectors of dairy, beef, and food and beverage processing. Figure 2 in the main report summarizes these impacts on regional GDP and employment, and this section elaborates on the fact that water trading could exacerbate these impacts because of the crop shifting that could occur. For a further discussion of these impacts and estimates of the current size of these industries in the valley, see the technical appendix to Escriva-Bou et al. (2023).

Uncertainties persist around the potential impacts of land fallowing on county revenues

This section of the report discusses the potential fiscal impacts of land fallowing on county revenues, and the concerns that some counties have voiced about the potential for water trading to exacerbate these impacts.

To understand the potential fiscal impacts of land transitions under SGMA, we undertook a preliminary quantitative analysis of agricultural land values. We also looked at county-level shifts in fallowing under the different trading scenarios.

Fiscal analysis. For the fiscal analysis, we collected panel data (2015–20) on land values from appraiser reports in the San Joaquin Valley.[14] We retrieved ranges of land values for geographic subunits and categorized them by crop-county-area combination; for example, one such categorization was almond orchards (crop type) on the eastern side (area) of Fresno County (county). In many cases, the geographic subunits were identifiable as individual water districts or groups of districts. We further categorized these subunits by surface water availability and reliability (reliable, somewhat reliable, and no surface water) on the basis of their description in the appraiser reports as well as surface water availability measures from PPIC's previous research and datasets (Ehrens et al. 2021; Jezdimirovic et al. 2020).

We compared the evolution of land values in neighboring areas with similar cropping patterns to assess the association between groundwater reliance and land value changes in areas subject to SGMA regulation. The key variable is differences in the reliability of surface water access across the recorded agricultural production areas, which we assume captures some variation in expected future water availability. One caveat to this analysis is the lack of a pre-period for baseline comparison; interpretation of the estimated differences in land values requires an assumption that 2015 is an appropriate baseline, namely that expectations surrounding SGMA implementation did not affect land values prior to 2015. Another caveat is that 2015 represents a time of very high commodity prices for perennials; subsequent commodity price declines could also affect shifts in land values in more recent years. If these declines occurred to different extents in areas with different surface water access, that could affect our conclusions.

This analysis produced estimated differences in land values between groundwater-reliant lands and those with surface water for different crop types. Important takeaways include: 1) lands with no surface water supplies systematically experienced larger losses in value over the time period, and 2) these dynamics were pronounced in areas planted more intensively with perennial crops. For example, 2015–20 land value for areas with no surface water in Fresno County fell by approximately 25 percent, while similar lands with more reliable surface water supplies appreciated slightly over that timeframe. For 2020, the difference between lands with no surface water and those with some surface water was roughly 35 percent. For lands planted with perennials in the same region, the difference is starker, reaching a maximum of 50 percent. While this analysis suggests property tax bases may be affected significantly in some areas, the ultimate impacts on public revenues will be muted by the effects of Proposition 13 and existing Williamson Act contracts that reduce the tax income base relative to the true market value of these lands.[15] As some farmland loses water access and value, the relative decline in effective taxes may not be large.

As we describe in the main report, some lands losing water may transition to other relatively lucrative uses, including utility-scale solar and new residential development. While new residential development generally entails an increase in property taxes, this is not necessarily the case for solar development, in light of a recently renewed statewide property tax exemption on the value of improvements associated with solar development.

County fallowing patterns. Turning now to how water trading might shift fallowing across county lines, Table A2 presents an overview of the shifts in fallowing under the different water trading scenarios. Because most basins tend to lie principally within a single county, local and basin trading would not move much fallowing

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[14] Specifically, we pulled values from Gatzman et al. (2020) and earlier versions of the same reporting documents.

[15] Even with land value declines relative to the pre-SGMA period, resale of lands owned continuously by the same entity for a long time could still generate higher property taxes for counties because their Proposition 13 tax base would be reset to the new purchase price.

across county lines. But expanding valley-wide trading of surface water would significantly reduce fallowing in Madera County (down 24 percentage points relative to the no trading scenario) and Kern County (down 11 percentage points). The counties with increased fallowing include Kings (up 20 percentage points), and to a lesser extent Fresno and San Joaquin counties (each up 6 percentage points).

TABLE A2

Shifts in fallowing by county by 2040 under different water trading scenarios

County	Baseline crop acres (2018)	Acres fallowed from water cutbacks			
		No trading	Local trading	Basin trading	Valley trading
Fresno County	1,016,428	124,327	113,062	103,224	182,387
Kern County	729,669	189,543	183,053	191,375	110,397
Kings County	388,116	59,273	67,751	64,180	138,438
Madera County	340,851	114,102	107,770	92,237	32,768
Merced County	487,868	127,374	117,722	115,480	131,242
San Joaquin County	487,505	55,335	43,876	27,728	83,839
Stanislaus County	376,762	78,862	78,750	84,892	73,337
Tulare County	631,549	113,268	108,610	120,050	92,379
TOTAL	**4,458,748**	**862,083**	**820,594**	**799,166**	**844,786**

SOURCES: Author calculations, using Escriva-Bou et al. (2023).

NOTES: The table estimates county-level changes in cropped acreage from water cutbacks under the different water trading scenarios described above.

What Are Promising Options for Repurposing Farmland?

This section of the main report brings together findings from our previous studies on land use alternatives. Where possible we consider how areas most suitable for certain uses align with areas at highest risk of land fallowing by 2040.

Solar Development Is a Potential Win-Win for the Valley and the State

Figure 9 and the related discussion draw on the PPIC study by Ayres et al. (2022). The lands suitable for solar energy production (panel a) come from The Nature Conservancy (TNC) studies by Wu et al. (2019 and 2023). We use scenario 2 from that analysis, which presents lands that are suitable from the standpoint of solar radiation, excluding land with legal restrictions against energy development and administratively protected areas. For purposes of considering the potential areas where fallowed cropland might convert to solar, we opted against focusing on the more restrictive scenarios included in the TNC studies. Their scenario 3 excludes land that is considered prime farmland, but in the context of the considerable reductions anticipated in irrigation water availability, we considered this exclusion too limiting. Some lands currently considered prime might not have water for irrigation in the future, and solar development may be a viable alternative use.

Panel (b) in Figure 9 assembles all the cropland that is both suitable for solar development and at high risk of fallowing (>25%) in the no trading, basin trading, and valley trading scenarios.[16] Since the expansion of trading in the future is likely to be a hybrid of the various trading scenarios, this combined view provides a good sense of the most likely hot spots. Figure A14 displays each of these scenarios separately, to show how the risk areas vary. In all, just over 6.4 million acres of land are suitable for solar in the valley, including 3.9 million acres of cropland, and roughly 1.5 million acres of cropland that are at highest risk of fallowing.

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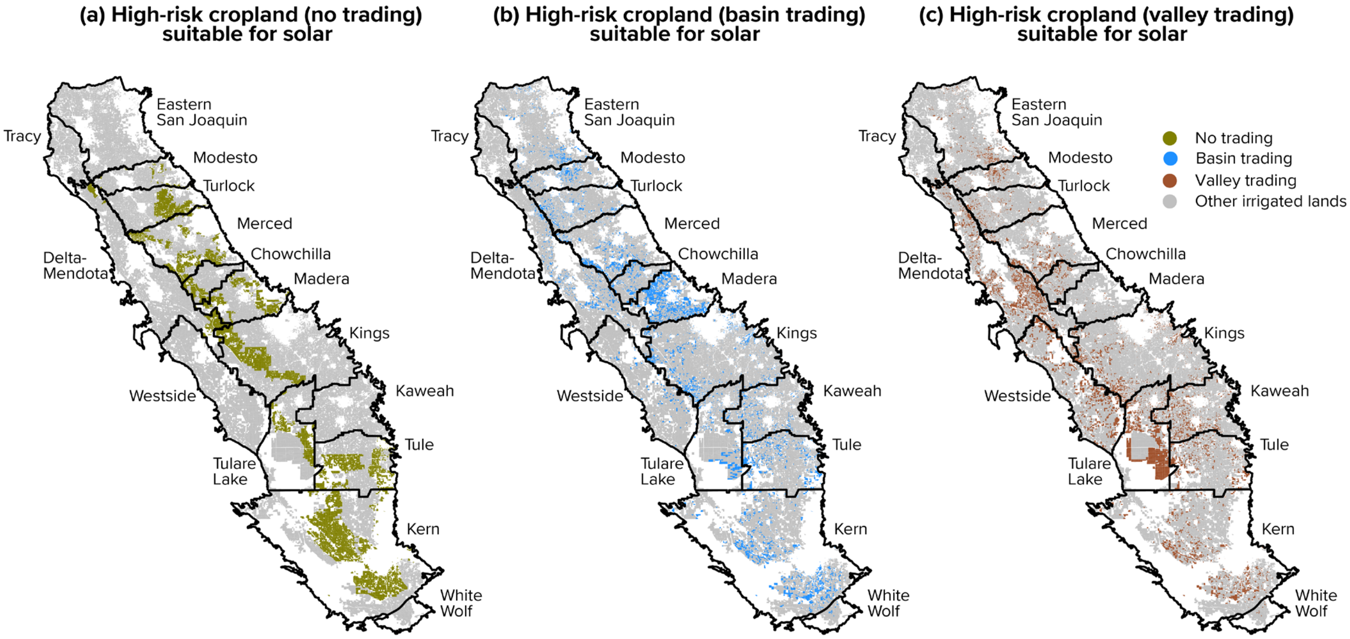
[16] The local trading scenario high-risk areas largely overlap with lands in that risk category in one or more of the other scenarios (see Figure 3).

FIGURE A14

Solar-suitable land at high risk for fallowing under different trading scenarios



SOURCE: PPIC estimates, using solar suitability data from Wu et al. (2023) and trading scenarios from Escriva-Bou et al. (2023).

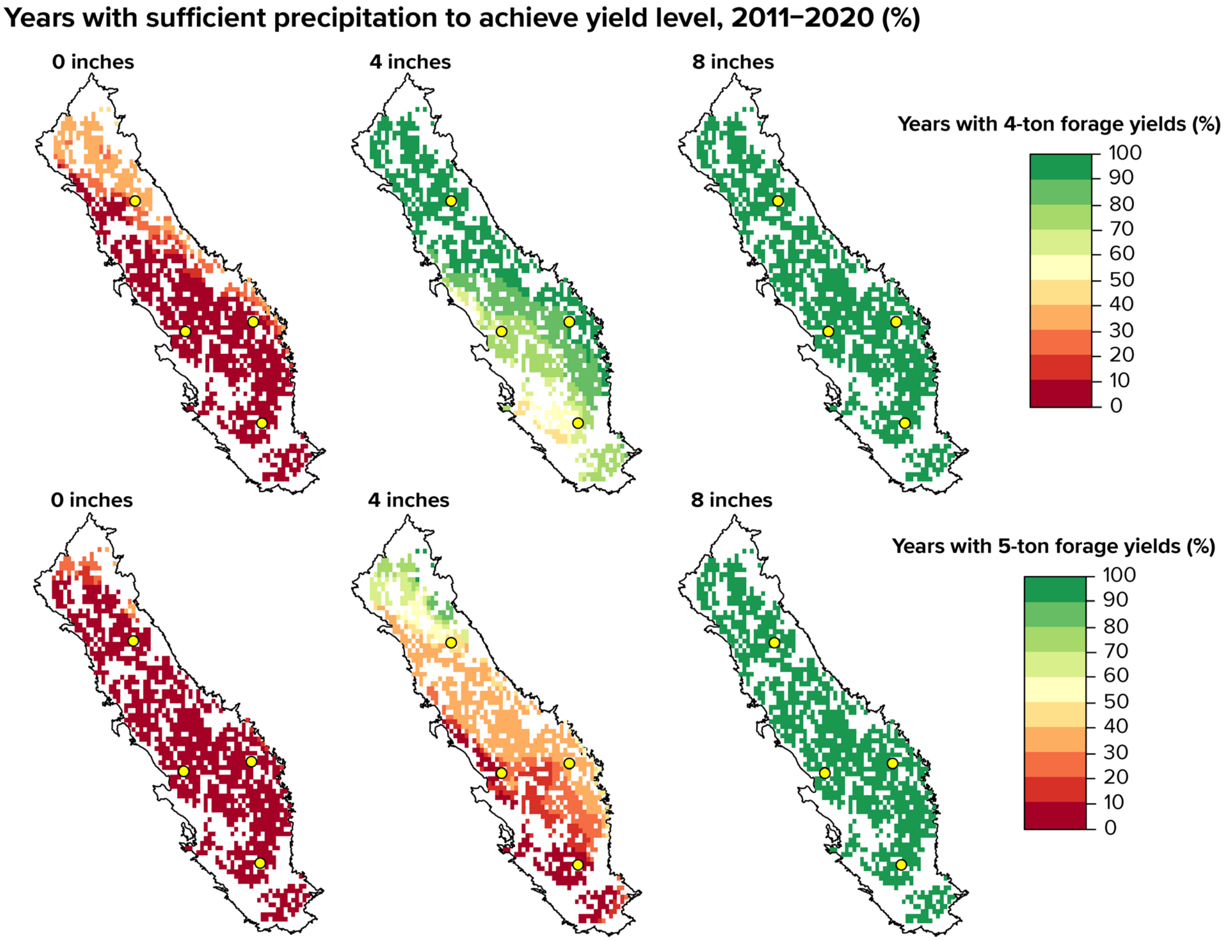
NOTES: Land suitable for solar energy production excludes land with legal restrictions against energy development and administratively protected areas. Highlighted acreage is current irrigated cropland that is both suitable for solar and at high risk (>25%) for fallowing under one of several trading scenarios: (a) no trading, (b) basin trading, and (c) valley trading. Areas in gray represent all other irrigated cropland. As described in the text, some lands that have already been fallowed for other reasons (pre-SGMA, therefore not shown here) would also be suitable for solar development.

Water-Limited Crops Could Keep More Land in Production

Figure 10 and the related discussion draw on the PPIC study by Peterson, Pittelkow, and Lundy (2022), and the updated modeling results in a journal article by the same team (Peterson, Pittelkow, and Lundy 2023). Figure A15 displays the more detailed modeling results, simulating the probability of getting consistent four- or five-ton forage yields with 0, 4, or 8 inches of supplemental irrigation to aid plant establishment. Forage yields of at least four tons were estimated to result in sufficient revenue to cover operating costs under some cost/price scenarios (see Peterson and Hanak 2022). Forage yields of five tons would result in sufficient revenue to cover operating costs under a wider range of cost/price assumptions.

FIGURE A15

Water-limited forage crops are widely feasible in the valley with small amounts of supplemental irrigation



SOURCE: Adapted from Peterson, Pittelkow, and Lundy (2023); DWR (2018 cropland data layer).

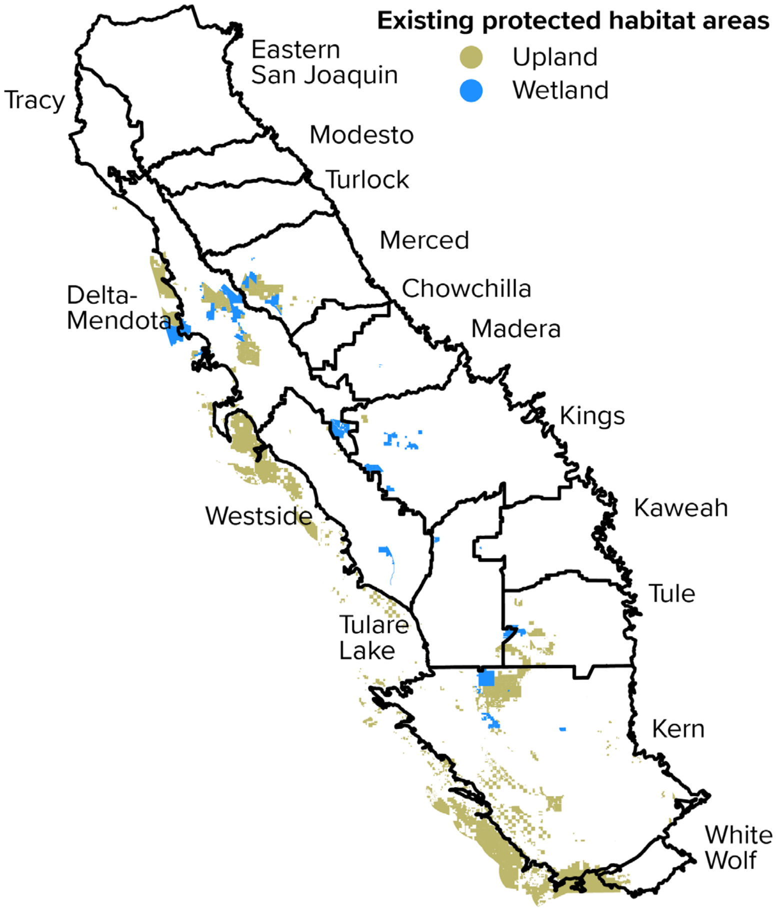
NOTES: The percent of years with sufficient precipitation to achieve the forage yield threshold (4 tons or 5 tons) was determined with a probit model fit to the outputs of a 20-year simulation of forage crop establishment and productivity and 10 years of historical precipitation. The left panel represents a dryland scenario with no irrigation; the middle panel allows for one application of 4 inches of supplementary irrigation; and the right panel allows for 8 inches of supplementary irrigation (two applications). Shown are all irrigated croplands within the San Joaquin Valley. Yellow dots represent four representative sites near Turlock, Five Points, Visalia, and Shafter for which model parameters were calibrated. Data constraints limit spatial resolution of suitability to areas of approximately 4 square kilometers.

Habitat Restoration Could Bring Benefits on Some Fallowed Lands

Figure 11 and the related discussion in the main report focus on the potential for habitat restoration on formerly irrigated cropland. Figure 11a shows the lands suitable for restoration on upland habitat, based on an assessment by The Nature Conservancy of areas suitable for one or more San Joaquin Desert ecosystem sentinel species (Butterfield et al. 2017). The upland areas of suitability in Figure 11a were mapped as five–kilometer buffers around existing protected habitat areas, shown here in Figure A16. As in the solar and water-limited cropping analyses, Figure 11 shows the overlap with lands at the highest risk of fallowing. We spotlight the no trading and valley trading scenarios to highlight the contrasting opportunities with different types of water management. As an example, valley trading could create substantial opportunities for restoration around existing wetlands in the Los Banos area.

FIGURE A16

Existing protected upland and wetland habitat areas in the San Joaquin Valley



SOURCE: The Nature Conservancy (Butterfield et al. 2017).

NOTES: Upland protected areas cover the bulk of existing restoration areas shown, with 886,653 acres; protected wetlands cover 120,924 acres. These areas include lands outside of, but adjacent to, the valley floor.

Although data limitations prevented us from undertaking a similar geospatial analysis of potential overlaps between lands with high fallowing risk by 2040 and lands that would be most suitable for riparian and wetland development, we did obtain geospatial information on lands identified in the Central Valley Flood Protection Plan as suitable for levee setbacks that would allow for more natural river movement—and enable the restoration of riparian corridors (Figure 17). This is likely only a subset of potential areas for riparian expansion. Such areas also tend to have relatively good access to surface water, so there is little overlap with areas at high risk of fallowing: of the nearly 84,000 acres shown, only a few thousand acres fall into the high fallowing risk category under the no trading, basin trading, or valley trading scenarios.

FIGURE A17

Potential levee setback areas for expansion of riparian habitat

SOURCE: Central Valley Flood Protection Plan.

NOTES: The figure shows areas where existing levees could be widened (set back) by half a mile to allow for more natural river movement (shown slightly larger than scale here). The total area covered is 83,545 acres, of which a few thousand acres overlap with lands at high risk (>25%) of fallowing under no trading, basin trading, or valley trading scenarios.

New Development Could Bring New Revenues While Saving Water

The discussion in this section of the main report includes some back-of-the-envelope estimates of the potential acreage that might be converted to new residential development by 2040 to accommodate projected population growth, and the potential net water savings of this conversion relative to an estimated 4 acre-feet of water use per acre in irrigated cropland. We drew on the analysis of residential landscape irrigation in Ayres et al. (2021a), which used detailed customer-level water use and land use data for three communities served by Cal Water Service: Bakersfield, Visalia, and Selma. We excluded estimates from a fourth community, Stockton, which is more urbanized and has a much lower (and likely less representative) amount of residential landscape irrigation. We assumed that 85 percent of the projected population growth for the region will take place on the valley floor, and that new development is solely single-family residential (SFR) homes in greenfield development on former cropland, with the historical proportions of hardscape and landscape footprints reflected in SFR developments in the nearest community for which we had data. Urban infill and multi-family development could reduce the acreage reported here. As described in the main report, growth projections are currently being updated and will likely be lowered. This would also reduce the estimates presented here.

We obtain a rough estimate of 50,000 acres of potential conversion of cropland to new development, with annual water savings of approximately 175,000 acre-feet. This estimate focuses mostly on the outdoor water use in new development; while households would also require water for indoor uses, almost all this water returns to the system as treated wastewater,[17] where it becomes available for reuse, either through groundwater recharge (the majority, in this region) or downstream use in areas where treated wastewater is discharged into rivers or streams.

The water savings estimates are based on statistical analysis of applied outdoor water use for residential customers. In the years following the 2012–16 drought, these amounts were 1.4, 2.7, and 3 acre-feet per acre of residential landscape (both irrigated and non-irrigated) in Selma, Visalia, and Bakersfield, respectively. When adjusted for the share of hardscape (buildings, driveways, sidewalks) on residential properties,[18] residential landscapes used 9, 21, and 21 percent as much water, respectively, as an acre of cropland irrigated with 4 acre-feet per acre. We did not include roads as part of residential acreage, on the assumption that cropland also is interspersed with unirrigated roadways.

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[17] We included 10 percent of indoor use in our overall estimates of water use and potential water savings.

[18] Landscaped shares of total acreage were 26 percent in Selma, 31 percent in Visalia, and 28 percent in Bakersfield.

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