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Water and the Future of the San Joaquin Valley

Appendix D: Optimizing Supply and Demand Management Actions to Bring Groundwater Basins into Balance

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ACRONYMS

af	acre-foot (feet)
DWR	California Department of Water Resources
maf	millions of acre-feet
SGMA	Sustainable Groundwater Management Act
taf	thousands of acre-feet
VMP	value marginal product

Introduction

In previous appendices, we assessed the economic cost of enhancing supplies and reducing agricultural water use in the San Joaquin Valley to bring groundwater basins into balance under the Sustainable Groundwater Management Act (SGMA) (see Technical Appendices B and C, respectively). This appendix seeks to answer two key questions: how much supply augmentation is practical, and how much use reduction (and cropland fallowing) will be needed?

Some supply options are too costly for most farmland, but some crops—especially orchards and vines—are sufficiently profitable that they will warrant increased investments in supplies. From the standpoint of the regional economy, it makes sense to look for an optimal scenario where the cheapest supply options are implemented and less-profitable agricultural lands are fallowed.

But many uncertainties complicate the equation, including how much more water will be available from new supply options, and at what cost; and how much are farmers willing to pay for new supplies in a context of increasing water scarcity. To analyze how these uncertainties affect the final outcome, we estimate multiple scenarios with different mixes of supply options and water use reductions. Each supply option is analyzed across a range of water supply and costs. Similarly, we consider farmers' willingness to pay for new supplies under different conditions: it might be higher than under current conditions if technological advances or market conditions make it possible for agriculture to earn more profits from the water, but it could also be lower if water trading is more accessible as a tool for managing demand. We evaluate multiple combinations of supply and demand options that can bring groundwater basins into balance at the lowest cost. From these scenarios, we determined which options are more robust (i.e., options that are consistently feasible under different uncertainty parameters).

We first describe the methods used. We explain how we determined farmers' willingness to pay for new supplies. Then we describe how the costs of new supplies under different uncertainty parameters were obtained. Using farmers' willingness to pay and the costs of new supplies, we determine the optimal combination of supply and demand management options for multiple scenarios. Finally, we discuss our results and summarize our main findings.

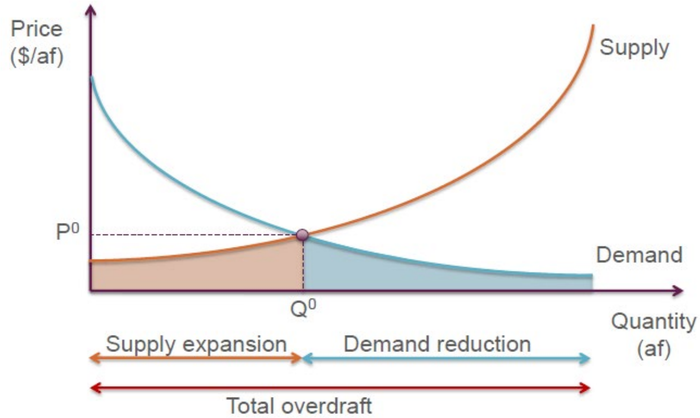
Methods

Our objective is to obtain an optimal combination of supply and demand management actions that lead to the least expensive portfolio of options to achieve groundwater sustainability, while also accounting for the many uncertainties regarding each option's costs.

We simulate a market for new water supplies in the San Joaquin Valley. The supply curve delineates the quantity of water supplied at different costs per acre-foot. The demand curve is formed by farmers' willingness to pay for new water. The point where the supply curve and the demand curve intersect leads to the minimum cost of supply expansion and demand reduction. Figure D1 shows a schematic of this methodology.

FIGURE D1

The optimal scenario minimizes the costs of new water supplies and losses caused by the reduction in water use



NOTES: To eliminate total overdraft, farmers can reduce the quantity of water demanded or expand the quantity supplied. The point Q^0 is the quantity of supply expansion for which farmers are willing to pay to avoid displacing the most valuable crops at a price P^0 ($/acre-foot). The shadings represent the total supply expansion costs (red) and demand reduction costs in terms of reduced profits from crop production (blue).

Figure D1 shows a theoretical case where all supply and demand reduction costs are known. As noted earlier, there are many uncertainties in this calculation. To deal with these uncertainties we used a Monte Carlo approach, where supply and demand curves are drawn multiple times, each time using random parameters within their likely ranges. Each new combination will lead to a different amount of supply expansion and demand reduction, with different combinations of supply options. This method allows us to show which options are consistently feasible—those that are more robust against the different uncertainties—and which options are always or almost always rejected.

This method makes the following assumptions:

- **The method is farm-centric**: Because nearly 90 percent of the valley's water use is for agriculture, we only analyze farmers' willingness to pay for new supplies to end overdraft. This might slightly underestimate the total expansion of water supplies, given that cities might also be interested in investing, with a higher willingness to pay. But given the low proportion of urban water use in the valley (~5% of applied water use or ~3% of net water use), this amount will not be significant.
- **Water moves freely on the valley floor**: We assume that any supply expansion can be used anywhere in the valley. This assumption might slightly overestimate the total supply expansion, given that some farmers will be willing to pay for some water that cannot be conveyed to their farms.

The main challenge of the method is to draw plausible supply and demand curves. We explain how we obtained the curves in the following sections.

Demand Curves for Willingness to Pay

The demand curves are obtained from farmers' willingness to pay to avoid permanent fallowing. To obtain the demand curves we used the agricultural production model described in Technical Appendix C.

In summary, we simulate a reduction of water supplies to the current agricultural landscape, representing the water cuts needed to end historical groundwater overdraft. From this scenario, we determine the reduction in different economic indices, such as revenues and profits. For farmers' willingness to pay, we are most interested in the value marginal product (VMP): the additional profits that farmers could earn with one extra acre-foot of water. This is their willingness to pay for new water investments, or to purchase water from others in a valley-wide water market. It is also the value forgone when farmers reduce demand, as shown in Figure D1.

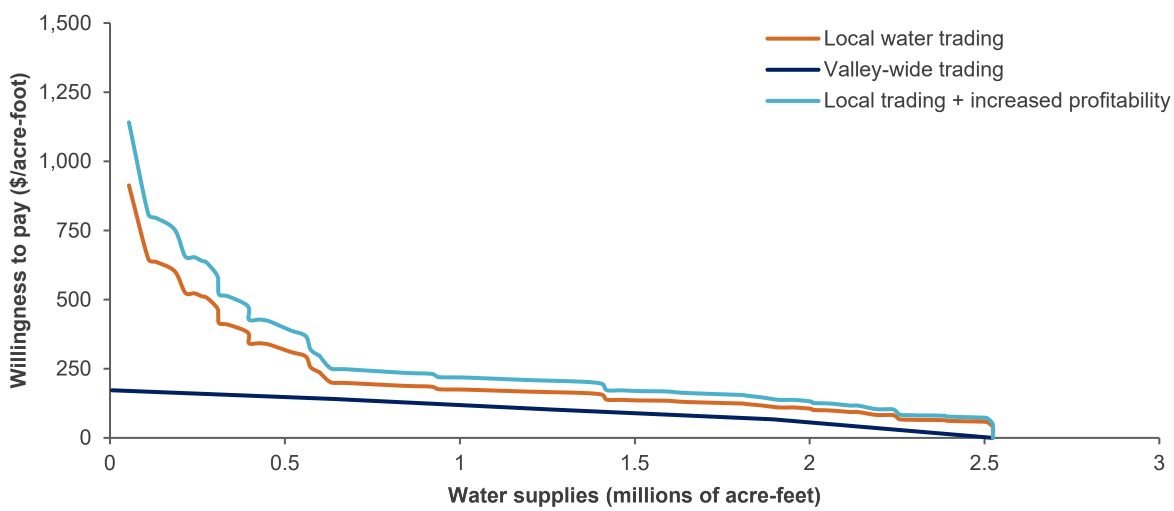
To account for uncertainties we developed demand curves using model results from three different scenarios:

- **Ending historical overdraft with local water trading**. According to our estimates, there is an annual average of 1.8 million acre-feet (maf) of unsustainable groundwater use in the valley. To end overdraft, net groundwater use has to be reduced by 1.8 maf, or roughly 2.5 maf of applied water use. In this scenario, we determine the willingness to pay for new supplies when current water supplies are constrained by 2.5 maf.
- **Ending historical overdraft with valley-wide trading**. This scenario assumes the same amount of water reduction as in the previous one, but we allow surface water to be traded throughout the valley.
- **Ending historical overdraft with local water trading and increased agricultural profitability**. The last scenario represents an increase in agricultural profitability, which could result from any combination of the following factors: shifts toward more profitable crops, higher prices for farm output, or cost-reducing technology. The reduction in use is the same as in the previous scenarios, but increased profitability raises willingness to pay by 25 percent.

Figure D2 shows the different demand curves resulting from the willingness to pay for these three scenarios. The scenarios with only local water trading show a steep curve with very high willingness to pay for the first 600-700 thousands of acre-feet (taf). The flat region on the right side shows that more than two-thirds of valley croplands that would go out of production with the 2.5 maf/year supply cutback are willing to pay less than $250 per acre-foot (af). Farmers growing crops with relatively high profit margins—especially trees and vines in water-scarce areas—have the highest willingness to pay for additional water. But for many fields and crops, profit margins are lower, and farmers cannot afford to pay more than about $150 to $250 per acre-foot for new water supplies. When valley-wide surface water markets are allowed, the price of water in the market falls below $200/af, because there are enough farmers earning less than this with their irrigation water; they are willing to sell it to farmers earning more. This also reduces the buyers' interest in investing in new supplies.

FIGURE D2

Farmers' willingness to pay for new supplies under different scenarios

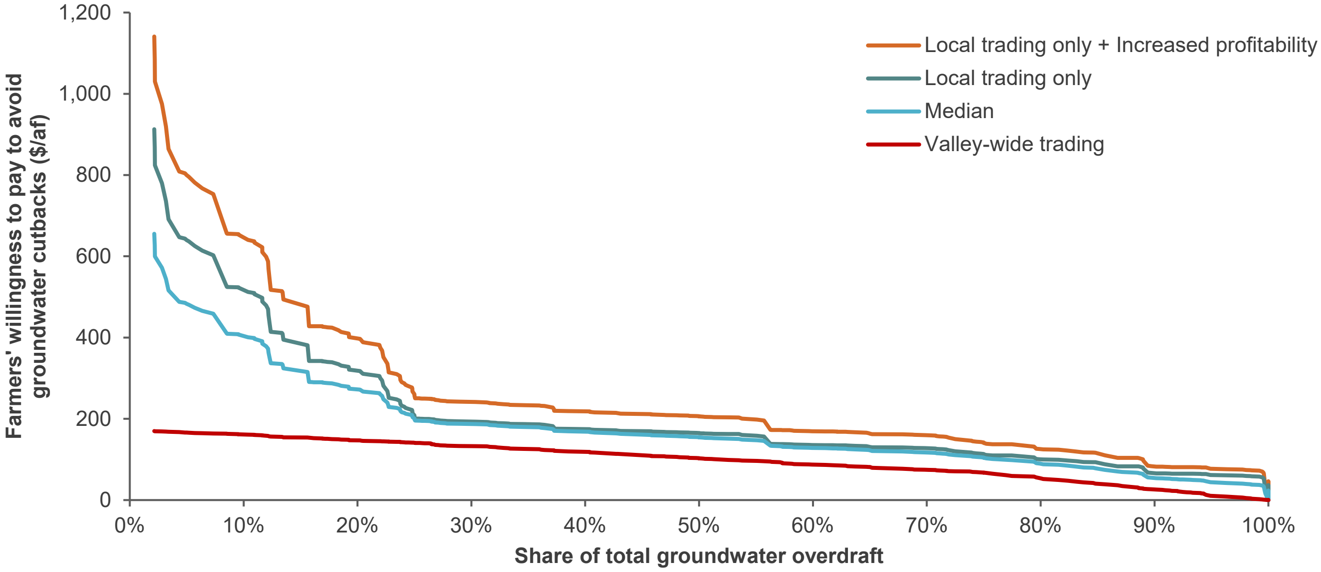


SOURCE: Author calculations.

Another way to see these demand curves is by looking at the share of farmers that will be affected by groundwater cutbacks and the amount they would be willing to pay to avoid these cutbacks. Figure D3 presents the demand curves in terms of the willingness to pay to avoid a percentage of cutbacks equal to the total volume of overdraft.

FIGURE D3

Farmers' willingness to pay for new supplies to avoid a certain share of groundwater cutbacks



SOURCE: Author calculations.

In the highest scenario for willingness to pay—when only local trading is allowed and considering increased farm profitability—some farmers would pay:

- more than $800/af to avoid 5% of total overdraft (125 taf);
- more than $700/af to avoid 8% of total overdraft (~200 taf);
- more than $600/af to avoid 12% of total overdraft (~300 taf);
- more than $500/af to avoid 13% of total overdraft (~340 taf)

When we consider that some amount of valley-wide surface water trading can help reduce costs, and using the median between the "Local trading + Increased profitability" and the full "Valley-wide trading" scenarios, some farmers would pay:

- more than $600/af to avoid 2% of total overdraft (56 taf);
- more than $500/af to avoid 4% of total overdraft (~100 taf);
- more than $400/af to avoid 10% of total overdraft (~260 taf);
- more than $300/af to avoid 16% of total overdraft (~400 taf);

These results show that only a small share of farmers affected by groundwater cutbacks—13 percent in the highest willingness to pay scenario, and 4 percent when some water is traded across basins in the valley—would pay more than $500 per acre-foot for the water supply expansion.

Supply Curves

Supply curves show the cost per acre-foot of water for new supplies. They are based on the cost estimates and increased water availability shown in Technical Appendix B. From the 14 different supply options selected (shown in Tables B4 and B5), we used the following approach to obtain a single supply curve:

1. Each of the 14 supply options are classified as single project (based on a single project such as a surface reservoir) or multiple projects (a combination of many projects, such as urban conservation actions or groundwater recharge projects).

2. For each single-project option:
    a. Randomly select the size of the project (water availability) from its likely range.[1]
    b. Randomly select the cost of the project from its likely range.
3. For each multiple-projects option:
    a. Randomly select the size of each project (water availability) from its likely range.
    b. Randomly select the cost of each project from its likely range.
    c. Do the previous steps repeatedly until the total amount of increased water availability reaches the total available water from the action.
4. Sort all the projects obtained in steps 2 and 3 from lowest to highest cost.

With all these steps, we derive a supply curve formed by multiple projects of specific cost and increased water availability. For each single-project option we obtain only one point, while for each multiple-project option we obtain as many points as needed to get the maximum amount of water available for the option with different costs. Using a Monte Carlo approach, we repeat the same method multiple times to build multiple supply curves (Figure D4).

TABLE D1

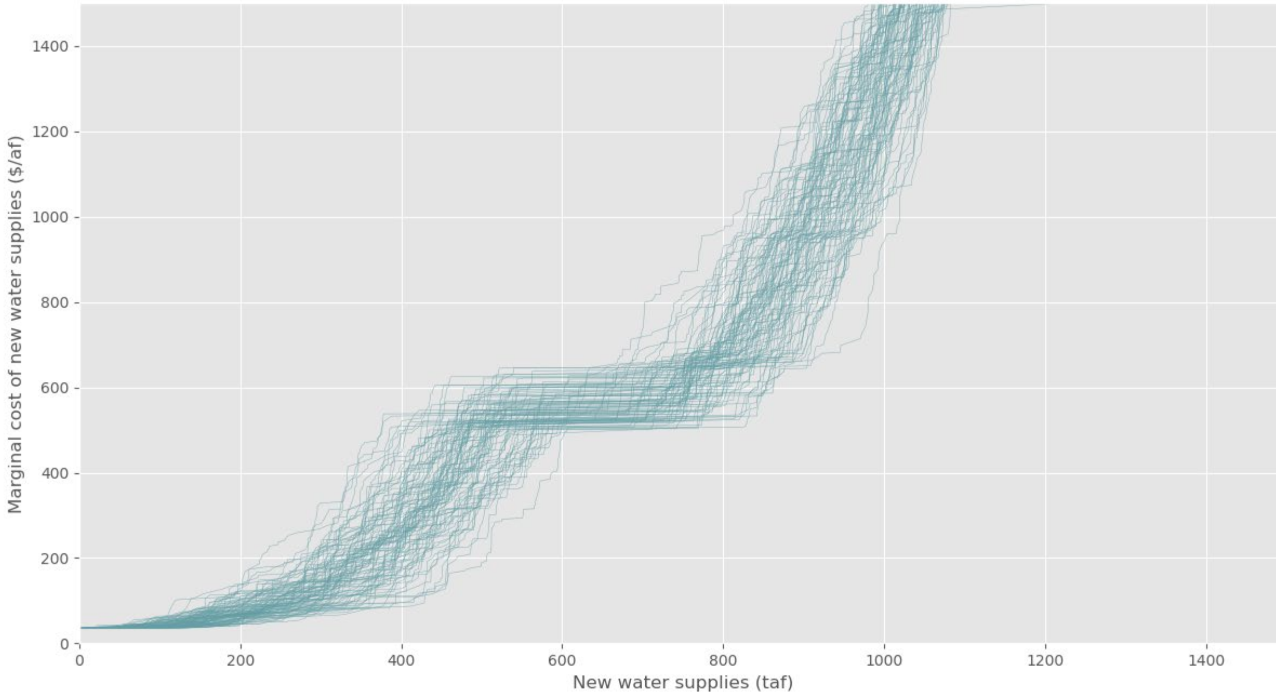
Estimates of increased water availability and costs for options to expand water supplies for agricultural use

Strategy	Action	Increased water availability (thousands of acre-feet)	Cost accounting for co-benefits ($/af)	Single-project (S) or Multiple-projects (M)
Capture and store more local runoff	Temperance Flat	197 to 257	$500 to $651	S
	Groundwater recharge	550	$36 to $1,500	M
	Reoperating surface and groundwater storage in the valley	2 to 8	$100	S
Increase local runoff	Forest management	512	$2,191 to $5,974	M
Increase imported water from the Delta	Sites Reservoir	28 to 33	$644 to $749	S
	Shasta expansion	27 to 59	$651 to $1,412	S
	San Luis expansion	7 to 43	$412 to $2,529	S
	Los Vaqueros expansion	10	$943 to $971	S
	California WaterFix	127 to 261	$1,491 to $3,076	S
	Reoperating surface and groundwater storage in the whole Central Valley	17 to 100	$100	S
Reduce exports and local non-farm water use	Urban conservation in the San Joaquin Valley	86	$137 to $4,580	M
	Urban conservation In coastal regions	144	$137 to $4,580	M
Reuse and repurpose local supplies	Urban reuse (recycling)	16	$396 to $5,800	M
	Oil and gas wells	8	$100 to $50,000	M

SOURCES: Author estimates based on the information compiled in Technical Appendix B.
NOTES: Water availability and cost estimates for many options are approximate. The value of co-benefits is deducted from the water supply cost if there are clear funding sources for these benefits.

[1] In some cases there are large ranges of costs or sizes of projects that are not evenly distributed (for instance, the cost of urban conservation ranges from $137/af to $4,580/af averaging $1,335/af). To deal with these asymmetries in the distributions we assumed that the variables followed a beta distribution function that is adjusted using the minimum, maximum, and average values in the range. These parameters can be found in Table B5 in Technical Appendix B.

FIGURE D4
An illustration of 50 supply curves generated with the Monte Carlo approach



SOURCE: Author estimates.

The Optimal Combination of Supply and Demand Management Actions

Farmers will be willing to pay for those supply options which cost less than the profits they can earn with that water—their willingness to pay. When the cost of new supplies exceeds famers' willingness to pay, supply options are no longer feasible and farmers must begin to fallow the less profitable lands. We also assume that the least expensive options will be developed first.

To obtain the optimal combination of supply and demand management actions we combine demand curves (farmers' willingness to pay) and supply curves (costs and increased water availability from actions to enhance supply) in the same chart. Figure D5 shows these results, using 500 different combinations to reflect uncertainty in these values. This represents a scenario in 2040 where groundwater balance is achieved with a combination of supply expansion and water use reductions from cropland fallowing.

- **The supply curve** (the red line) is the median of all potential supply options (shown with red shading). Although we show a continuous line, every supply curve included in the analysis is formed from many points, which represent all projects sorted from lower to higher cost (as shown in Figure D4). The left-most part of the curve is dominated by cheaper groundwater recharge options, reoperation of surface and groundwater storage, and some lower-cost urban conservation and water reuse. The right-most part is dominated by more expensive options, mainly from forest management. In the middle part are many different options, including new reservoirs and water provided by improving through-Delta conveyance (California WaterFix).
- **On the demand side** (shown in blue), the top of the shaded area represents the highest willingness to pay, where we assumed an increased farm profitability relative to current conditions. The bottom part of the shading shows the scenario with valley-wide trading—where all surface water in the valley is available for the highest bidders. The blue line shows the median of all demand options. Note the significantly higher willingness to pay to avoid the first 600 taf of demand reduction (the top of the blue shaded area): this is the

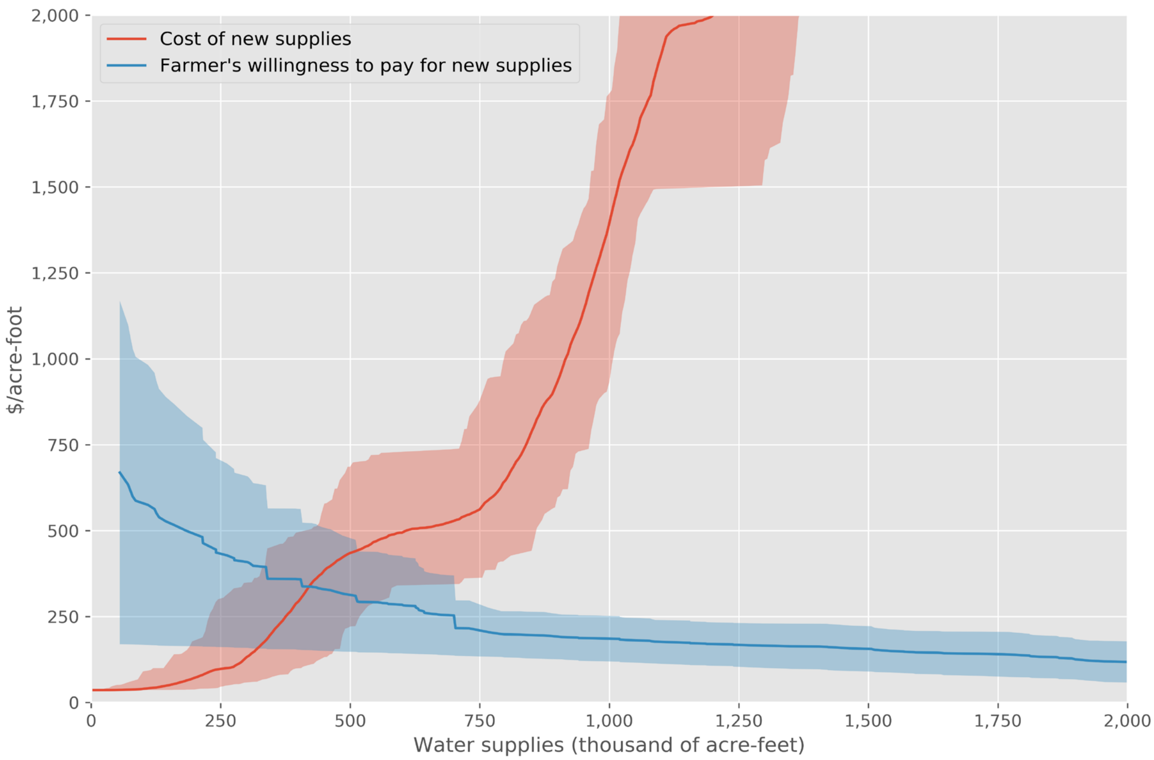
water demand of the orchards and vines that would be fallowed to end overdraft if new supplies were not available and valley-wide trading were not possible.

The intersection of both curves shows a potential outcome of about 410 taf of new supplies being developed; the remaining amount needed to end overdraft would be obtained by reducing agricultural water use.

The main conclusion of this analysis is that only a fraction of the 1.8 maf/year of estimated groundwater overdraft might be mitigated by investments in new water supplies. This likely range of supply expansion is between 220 and 580 taf, at most 30 percent of the total overdraft.

FIGURE D5

Less than half a million acre-feet of new supplies are affordable for farmers



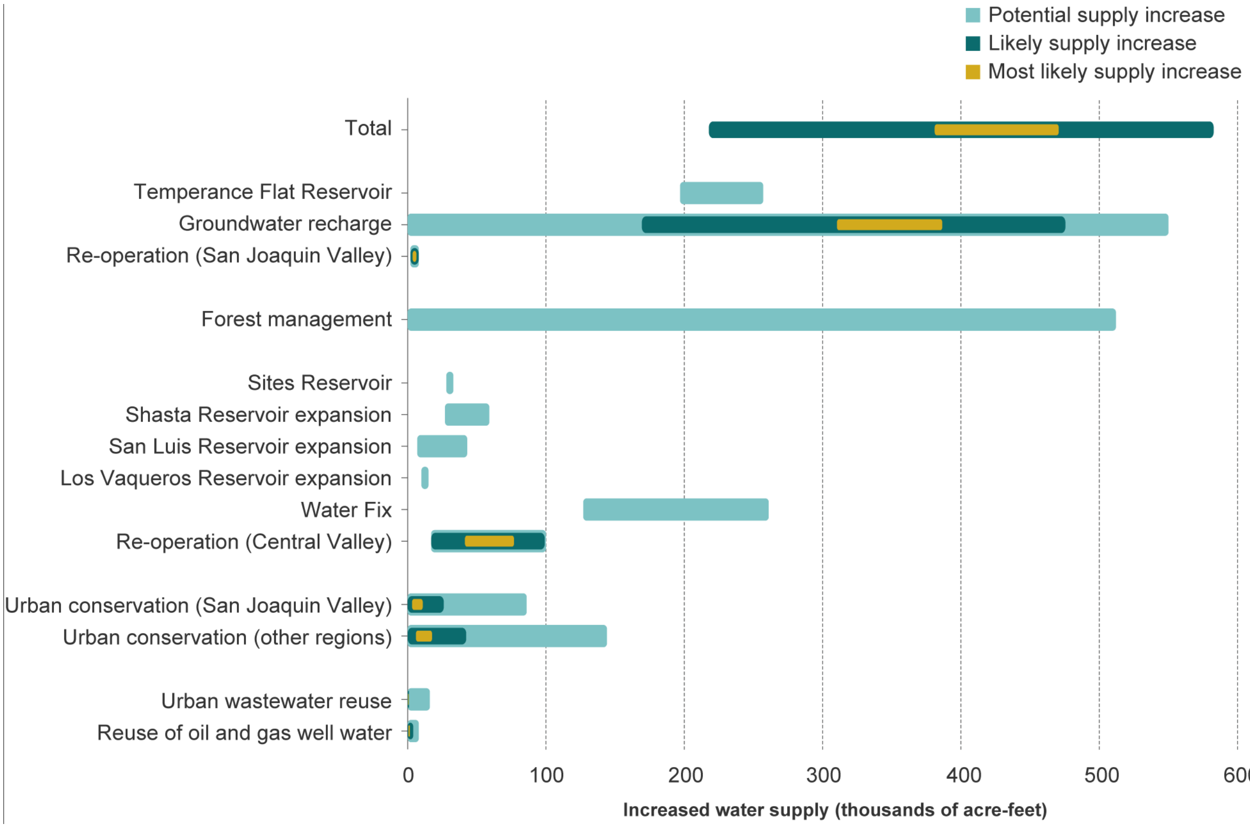
SOURCE: Author estimates.

Figure D6 summarizes our findings about the likely supply portfolio. The light blue bars show the range of potential increase in water availability within the San Joaquin Valley from each option—*without* considering affordability. The dark blue bars show the *likely* increase in supplies—and the yellow bars the *most likely* increase—taking into account supply costs and farmers' willingness to pay.[2] The low end of the range shows the amount of new supplies farmers would invest in even when they have low willingness to pay and the supply costs are high. The high end shows the other extreme: investments that would be worth making when supply costs are low and the profits farmers could earn with the additional water are high.

[2] The likely increased water availability range includes supplies with costs that farmers are willing to pay for in at least one combination. The most likely water availability range includes options that appear feasible in at least half of all combinations.

FIGURE D6

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



SOURCE: Author estimates using multiple sources (see Technical Appendix B for supply and cost ranges).
NOTES: "Potential" supply increase is the additional water that might be available in the San Joaquin Valley, not accounting for cost. For options that can be implemented through many small projects, the minimum potential increase starts at zero and goes up to the highest amount that might be available by combining all possible projects. For options that involve large investments, such as new reservoirs, the bar shows the range of potential yield from the project. "Likely" and "most likely" supply increase are the amount valley farmers may be able to afford, taking into account costs, yield, and farm-level profitability of additional supplies. See text for details.

Sensitivity Analysis of the Results to the Amount of Water Available for Recharge

The results show that most of the affordable water available for increasing supplies is likely to come from groundwater recharge. As with any other option considered, these results depend on the values used for the cost of the projects and the maximum amount of water potentially available.

Using values from the literature (detailed in Technical Appendix B), we assumed that the cost of each project would range from $36 to $1,500 per af, with a median cost of $327 per af. We fixed the maximum water availability at 550 taf, which is the similar to the maximum estimate obtained by two recent studies on water available for recharge (California Department of Water Resources 2018, Kocis and Dahlke 2017).[3] Yet there is some uncertainty in these estimates.

To test the consistency of the main results against the potential water available for recharge in the San Joaquin Valley, we ran our model three times with different maximum potential recharge as follows:

- Scenario 1: Maximum recharge is limited to 190 taf per year, which is the Department of Water Resources (DWR) study's "best estimate" using current infrastructure.

[3] We discussed these approaches in Escriva-Bou and Hanak (2018) and a more detailed explanation is included in Technical Appendix B.

- Scenario 2: Maximum recharge is randomly selected in each of the 500 simulations from 190–550 taf, with a median value of 290 taf per year (these values are, respectively, the best estimate, the maximum estimate without infrastructure limitations, and the upper sensitivity range estimate under current infrastructure obtained by DWR).
- Scenario 3: Maximum recharge is limited to 550 taf per year, DWR's maximum estimate without infrastructure limitations.

TABLE D2

Sensitivity analysis of supply options under different assumptions about the maximum water available for recharge

Strategy	Action	Potential Increase (taf)	Likely increase			Most likely increase		
			Sc. 1 Recharge 190 taf	Sc. 2 Recharge 190–550 taf	Sc. 1 Recharge 550 taf	Sc. 1 Recharge 190 taf	Sc. 2 Recharge 190–550 taf	Sc. 1 Recharge 550 taf
Capture and store more local runoff	Temperance Flat	197–257	0–0	0–0	0–0	0–0	0–0	0–0
	Groundwater recharge	0–550	47–190	80–419	184–492	106–143	152–231	303–376
	Reoperating surface and groundwater storage in the valley	2–8	2–8	2–8	2–8	4–6	4–6	4–6
Increase local runoff	Forest management	0–512	0–0	0–0	0–0	0–0	0–0	0–0
Increase imported water from the Delta	Sites Reservoir	28–33	0–0	0–0	0–0	0–0	0–0	0–0
	Shasta expansion	27–59	0–0	0–0	0–0	0–0	0–0	0–0
	San Luis expansion	7–43	0–0	0–0	0–0	0–0	0–0	0–0
	Los Vaqueros expansion	7.5–12.5	0–0	0–0	0–0	0–0	0–0	0–0
	California WaterFix	127–261	0–0	0–0	0–0	0–0	0–0	0–0
	Reoperating surface and groundwater storage in the whole Central Valley	17–100	18–100	17–100	17–100	42–77	43–79	43–77
Reduce exports and local non-farm water use	Urban conservation in the San Joaquin Valley	0–86	0–25	0–28	0–24	5–13	4–13	4–10
	Urban conservation in coastal regions	0–144	0–43	0–43	0–34	8–22	8–21	5–17
Reuse and repurpose local supplies	Urban reuse (recycling)	0–16	0–2	0–2	0–2	0–1	0–1	0–1
	Oil and gas wells	0–8	0–4	0–4	0–4	1–2	1–2	1–2
Total		–	**82–317**	**135–542**	**247–570**	**185–243**	**236–336**	**380–467**
Cost of most expensive supply ($/af)		–	**162–629**	**164–600**	**152–504**	**284–470**	**285–468**	**245–402**

SOURCE: Author estimates using multiple sources.
NOTES: See notes to Figure D6 for definitions of potential, likely, and most likely supply increases. "Sc" stands for Scenario.

The results of the sensitivity analysis (Table D2) show that the final amount of supply expansion will depend on the amount that can be obtained from recharging groundwater. Scenario 1 is clearly a lower bound, given that DWR's best estimate, which we used in this scenario, assumes only current infrastructure. The total supply expansion is much more likely to be between the second and third scenarios, given that some investments in new infrastructure will be developed to adapt to increasing water scarcity in the valley. As we discussed in Technical Appendix B, we think that the third scenario—which assumes a maximum amount of 550 taf per year—might be achievable. In Escriva-Bou and Hanak (2018) we found that over a million acre-feet of water could be available for recharge while meeting environmental constraints and the demands of downstream water users. But given timing and location constraints, it may only be feasible to capture this lower amount.

Main Findings

This analysis supports several conclusions about new supply investments:

- **Capturing more local runoff is the most promising way to augment valley water supplies.** In particular, recharging groundwater could deliver significant new supplies at a cost farmers can afford (likely increase of 170–475 taf/year). Limited studies done to date on reoperating surface and groundwater reservoirs in the valley also show small additional increases are possible (less than 10 taf/year)—and the potential is likely greater.[4] In contrast, investing in the Temperance Flat reservoir appears too costly. Although this project could capture more than 200 taf/year of local runoff, the cost (averaging $565/af) is more than farmers would likely be willing to pay.
- **Forest management could significantly increase local runoff, but at a very high cost.** The potential yield of forest management is very uncertain, but could reach more than 500 taf/year. However, this water would be much too expensive (generally more than $4,500/af) if the costs had to be covered solely by water users. Co-funding partnerships would be needed to make this a feasible water supply option, with most costs covered by entities seeking to reap other benefits of forest management, including timber harvest and reduced cost of firefighting and air quality risks from wildfires.
- **Projects to increase imports will likely be too costly, but re-operating the system could pay off.** Most additional imports from expanding surface storage (Los Vaqueros, San Luis, and Sites Reservoirs) would go to parties in the Bay Area and Southern California. Projected increases in imports from California WaterFix would also be small for the valley. These options are also relatively expensive for valley agriculture, as reflected in limited local interest to invest in them. Expanding Shasta Reservoir would principally benefit valley farmers, but it is likely too costly for them without federal or state financial support. The best option appears to lie in re-operating the entire Central Valley network of surface and groundwater reservoirs, which could augment imports by up to 90 taf/year. This would yield nearly half as much new water as building a new reservoir at Temperance Flat, at a much lower cost.
- **Water reuse provides little additional water supply.** Although urban wastewater reuse projects can increase deliveries to some water users, this does not generally result in net water savings for the valley, since most wastewater is already reused for aquifer recharge or streamflow. The potential for increasing usable water from oil and gas wells also appears to be very limited.
- **Greater urban conservation would mainly support population growth.** Population is expected to increase 32 percent in the valley from 2015 to 2040, 24 percent in the Bay Area, 17 percent in the Central Coast, and 16 percent in the South Coast. Even if 50 percent of current outdoor use is conserved—a significant goal—most of these savings will support urban population growth. Costs can also be an issue. Although some conservation is low-cost, reports from conservation programs show that the median cost of savings can exceed $1,000 per acre-foot. On balance, a small amount of urban savings (10–30 taf/year) is likely to be available and affordable for valley agriculture.

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

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[4] DWR's analysis only focuses on re-operating reservoirs on the Merced River.

On balance, the amount of new water available to valley agriculture will be much less than the region's 1.8 maf/year long-term groundwater imbalance. Combining various feasible options, the likely total increase is 220–580 taf/year, and the most likely range is 380–470 taf/year. This means that reductions in agricultural water use will have to cover most of the valley's groundwater deficit.

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