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Water and the Future of the San Joaquin Valley

Technical Appendix B: Options to Improve Water Availability in the San Joaquin Valley

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ACRONYMS

ACWA	Association of California Water Agencies
af	acre-foot (feet)
BDCP	Bay Delta Conservation Plan
CCWD	Contra Costa Water District
CPUC	California Public Utilities Commission
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CV-Salts	Central Valley Salinity Alternatives for Long-Term Sustainability
CWC	California Water Commission
DWR	California Department of Water Resources
EIR/EIS	Environmental Impact Report/Environmental Impact Statement
IPCC	International Panel on Climate Change
LVE	Los Vaqueros Reservoir Expansion Project
maf	millions of acre-feet
M&I	municipal and industrial
NID	Nevada Irrigation District
SGMA	Sustainable Groundwater Management Act
SJVWIA	San Joaquin Valley Water Infrastructure Authority
SWP	State Water Project
SWRCB	State Water Resources Control Board (“State Water Board”)
SWSD	Semitropic Water Storage District
taf	thousands of acre-feet
USBR	United States Bureau of Reclamation
WEAP	Water Evaluation and Planning Model
WSIP	Water Storage Investment Program

Introduction

Over the past three decades, nearly 2 million acre-feet (maf) per year of water use in the San Joaquin Valley came from groundwater overdraft—water pumped from the aquifers at a faster pace than it is replenished. The Sustainable Groundwater Management Act (SGMA) requires valley farms and communities to bring their groundwater basins into balance by 2040. Options to achieve sustainability include augmenting supplies and reducing water use.

This appendix explores a wide portfolio of options to increase usable water supplies in the valley. Those that augment available supplies—for instance by increasing the amount of water held in storage—are commonly classified as supply management options. We also examine the potential for some options that decrease net water use—commonly considered demand management approaches—to make water available for other uses. For each option we estimate how much "new water" is likely to be available, its costs per acre-foot, and, when possible, the uncertainty in these estimates (see Box B1). We also discuss the main trade-offs various options entail.

We provide information on data sources, methods, and assumptions used to compare the options. A big challenge was reporting data consistently, as the different source studies vary widely in their assumptions.

In the following sections we first provide an overview of options under consideration. We then review the methods used in this analysis. The next sections analyze in detail each supply and demand management option. Finally, we select the most likely options, summarizing the results of increased water availability and costs.

Options Considered for Increasing Water Availability

Table B1 lists most of the available options for balancing supplies and demands in the San Joaquin Valley. Options for expanding usable supplies include capturing more local inflows in above- and below-ground reservoirs, increasing local runoff by managing forests, increasing imports, decreasing water leaving the basin, and treating and reusing local water supplies. Reducing demand can also expand water availability. On the demand side, options include reducing agricultural, urban, and environmental water uses, reducing losses from water infrastructure, and trading water to reduce use in ways that are less costly.

This section provides an assessment of the amount of water available and the costs for most of the options listed in Table B1. Many available options are presented, even if some are clearly inferior, because they are commonly discussed. Options that focus on agricultural demand management are explicitly assessed in Technical Appendix C, which includes an agricultural production model. For some options, we did not explicitly assess the amount of water or costs, mostly because they have low likelihood of being implemented or there are significant limitations in estimating the potential water yield or costs.

TABLE B1

Water portfolio options for the San Joaquin Valley

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

SOURCE: Developed by the authors.

NOTES: Options denoted with * are analyzed in greater detail in this appendix. Agricultural water use reductions denoted with ** are analyzed in greater detail in Technical Appendix C. See Chapter 2 in the main report for a summary description of each option.

Box B1. What is "new water"?

Although there is not really any "new water" to be had in California, there are ways to get new uses of existing water through infrastructure, reuse, or conservation.

For instance, building a new reservoir or expanding groundwater recharge facilities can create new water because it increases the ability to capture flood flows that would otherwise flow out of the basin. Similarly, decreasing irrigation of outdoor landscaping in urban areas creates new water that would otherwise be transpired by the plants or evaporated from soils.

However, most indoor urban water returns to rivers or streams after wastewater treatment and is used downstream. Therefore, a reduction in indoor water use will not generally create much new water. An exception is when the treated wastewater cannot be used again—for instance, when it flows directly to the ocean or a salty lake. (For a more detailed description of the difference between applied and net water use, see Box 2.1 in the main report.)

Because the water cycle is a closed loop, developing new water sources may affect other components of it. For instance, building a new reservoir and making water available for surface diversions in the San Joaquin River would decrease river outflows in the Delta that serve environmental purposes.

Methods

For each option we first estimate the amount of new water that could be made available. We then estimate the cost to implement the option in terms of its incremental or marginal cost (dollars per acre-foot). We use public reports or scientific articles to support our assessments.

To represent the uncertainties, we present likely ranges for each estimate. For simplicity, estimates of new water assume current conditions. We generally also show ranges of potential yield with climate change or other conditions when these are reported in the sources used.[1]

Similarly, for the costs of the options, we include a range from the literature. In some cases marginal costs are adopted from similar cases (such as for recycled water or urban conservation). In other cases we only found the costs of the implementation (or construction). For these cases, we calculated the equivalent annual cost of owning, operating, and maintaining an asset over its lifetime.[2] When possible, we also include a range of likely costs to account for uncertainties. Finally, to obtain the range of marginal costs, we divided the range of equivalent annual costs by the new water yielded annually by the action, presenting a minimum, average or "best estimate," and maximum cost. The final cost estimates for all options are in 2016 dollars.

In some cases, implementing an option to increase water availability can provide co-benefits. For instance, a reservoir can produce hydropower, provide recreational benefits, or supply water for ecosystems. When we found economic information on the value of the potential co-benefits, we provide two estimates: the full marginal cost (accounting for the total cost of the infrastructure and the total amount of water) and net marginal cost for new water supply (accounting for the cost of the water supply benefits only, subtracting out the value of the co-benefits). This net marginal approach assumes that other sources of funding would be available to cover the costs of achieving the co-benefits. This is the case, for instance, for public benefits associated with some water storage projects, which are eligible for state general obligation funding from Proposition 1.[3] However, some options lack estimates of potential co-benefits, such as the benefit of reducing wildfire risks when forests are managed more intensively.

Although we have attempted to compare the options in similar terms, each option has its own particularities, so the comparisons are imperfect.

Finally, we discuss other relevant information such as the reliability of the estimates of water yield and costs, the feasibility of implementation given interactions between options (e.g., if different options would draw on the same sources of runoff), potential conflicts among stakeholders, potential legal and institutional barriers, and a general estimate of the time frame needed to implement the action.

Supply Management Options

Supply management options are grouped under five main categories: capture and store more local runoff, increase local runoff, increase imported water, reduce flows leaving the valley, and reuse and repurpose local supplies.

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[1] In many cases infrastructure studies (such as those related to California WaterFix and the reservoir investments included in Proposition 1) include a short-term and long-term analysis. The short-term analysis is focused either in 2025 or 2030, and the long-term in 2065 or 2070 conditions. They include climate change impacts and other assumptions for each of the scenarios.

[2] To obtain annual costs we generally used a 3.5 percent discount rate and 100-year planning horizon, as proposed in the Technical Reference of the Water Storage Investment Program (California Water Commission 2016). In some specific cases, when the documents reviewed used other parameters, we report these in the text.

[3] Proposition 1 dedicated $2.7 billion for investments in water storage projects and designated the California Water Commission (CWC) as the agency responsible for appropriately allocating these funds. Eligible water storage projects must improve the operation of the state water system, be cost effective, and provide a net improvement in ecosystem and water quality conditions. The Commission, through the Water Storage Investment Program, can fund the public benefits of the eligible projects, up to a value of 50 percent of the total cost of the project. These public benefits generally do not have a market value and require estimates using non-market valuation techniques.

Capture and Store More Local Runoff

Nearly 1,500 dams in California capture water from rivers for later use when it is most needed. Aquifers are also used as "reservoirs" in much of California. Given the water-stress situation experienced in some parts of the state, especially during droughts, many options are being explored to increase the use of both surface and groundwater storage. Updating the operating rules for surface and underground reservoirs to manage them as a system can also help expand usable supplies.

Within the San Joaquin Valley, local rivers are already intensively managed to capture and store water for local uses, with more than 130 surface reservoirs and some of the world's most advanced groundwater banks. However, there is potential to capture some extra water, especially during very wet years.

Option 1: Expand local surface reservoirs

Much work has been done to investigate additional opportunities for above-ground storage in California. A joint federal and state effort called CALFED funded five surface storage investigations. Two of these are in the San Joaquin Valley: the Upper San Joaquin River Basin Storage Investigation, which defined different alternatives for the Temperance Flat Reservoir; and the San Luis Reservoir Expansion. Here we examine the ability of reservoirs that capture and store local runoff; we leave the expansion of San Luis and Los Vaqueros reservoirs—which store imported water from the Delta—for a later section.

Temperance Flat Reservoir. After considering 22 separate storage sites, CALFED chose the Temperance Flat Reservoir in the San Joaquin Valley. In January 2014 the US Bureau of Reclamation (USBR) published the *Upper San Joaquin River Basin Storage Investigation Feasibility Report Draft,* which assessed four alternative plans—and a no-action alternative—and determined the technical, environmental, economic, and financial feasibility of each alternative. All alternatives considered a 665-foot dam with a net additional storage capacity of 1,260 thousand acre-feet (taf). The alternative plans vary in minimum carryover storage target, beneficiaries, routing of new water supply, and intake structure type.

According to the documentation presented for Proposition 1 funding (SJVWIA 2017), the tentative present-value cost of the project is $3.9 billion, for a total equivalent annual cost of $140.6 million.[4] Average system-wide annual water deliveries would increase from 197 taf for the 2030 scenario to 257 taf for the 2070 scenario compared to no-project conditions. This implies a total cost of $559 to $730, averaging $633 per acre-feet (af) in 2016 dollars.

In addition to supply benefits, the proposal presents some potential economic and environmental co-benefits, including benefits for water quality, hydropower benefits, recreation, and flood damage reduction. As an example, ecosystem benefits are valued as a willingness-to-pay of households to reduce the risk of extinction of the San Joaquin River Chinook salmon assumed to be present in the no-action alternative.

To obtain the annual costs for *new water* from Temperance Flat, accounting for the potential co-benefits, we subtracted from the total costs the public benefits and hydropower benefits of the proposal.[5] The hydropower benefits amount to $1.2 million for the 2030 scenario and $1.1 for the 2070 scenario. The California Water Commission (CWC) has determined that the total public benefits amount to $400.7 million (in 2015 dollars).[6]

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[4] These costs are reported in 2015 dollars, for a 100-year period analysis and a 3.5% interest rate. They include capital cost, interest during construction, operations, maintenance and replacement, and future monitoring/adaptive management. The information was obtained from the *Temperance Flat Reservoir Project. Chapter 5: Benefit Cost Analysis*.

[5] Proposition 1 lists 5 eligible public benefits: ecosystem improvements, water quality improvements, flood control benefits, emergency response, and recreational benefits. We consider that all of them are co-benefits, and if paid for by Proposition 1 funds, they will be subtracted to the full cost.

[6] Water Storage Investment Program: Public Benefit Ratio Appeal Response for Temperance Flat Project (California Water Commission 2018)

Using these assumptions, the marginal cost of new water supply would range from $500 to $651 per acre-foot, averaging $565/af.

The proposal's timeline states that the project could be operating 15 years after receiving approval, making it unlikely that Temperance Flat would be operational before 2030.

Legal permitting might also be a significant barrier to make this water available, because new surface storage can interfere with water rights and environmental claims downstream.

Surface reservoirs in other regions. Surface reservoirs in other regions could also increase water availability in the valley. Here, surface reservoirs in other regions are treated as imported water and are described in a section below.

Option 2: Expand groundwater storage

Interest in recharge has increased greatly with the implementation of the Sustainable Groundwater Management Act (SGMA) and the availability of water for replenishment seen in the wet 2017, especially for critically overdrafted basins. In the San Joaquin Valley, the Kern Water Bank Authority and the Semitropic Water Storage District are good examples of using managed aquifer recharge as a hedge against drought.

Two recent studies estimate the potential availability of high-flow river water for recharge:

- The California Department of Water Resources published "Water Available for Replenishment. Final Report" (DWR 2018) providing estimates of water available for recharge in each hydrologic region, using a hydrologic model based on monthly outflows. The results presented best estimates of average annual new water availability (using current infrastructure capacity), including lower and upper uncertainty ranges (using half and twice the maximum capacity of existing infrastructure), and a maximum project estimate (assuming unlimited infrastructure capacity). For the San Joaquin River hydrologic region, the best estimate was 190 taf/year, with a feasible range of 100–290 taf/year, and a maximum with unlimited infrastructure of 550 taf/year. For the Tulare Basin hydrologic region, the report's best estimate was 30 taf/year, on average, within a feasible range from 20–60 taf/year, and 140 taf/year with unlimited infrastructure. As the outflows from the Tulare Basin hydrologic region are included in the estimates for the San Joaquin River hydrologic region, we will use the estimates for the San Joaquin River hydrologic region.[7] The methodology uses historical daily gage data (1930 through 2015 for the San Joaquin River) to develop an initial set of estimates of available water. It then adjusts these using a simulation model (Water Evaluation and Planning [WEAP]) to account for changes in outflows reflecting current water demands and operations. For the San Joaquin Valley, the WEAP adjustment reduces the volume available for recharge significantly—to 45 percent of the unadjusted volumes.
- A different approach to estimating water available for groundwater recharge was published by researchers at the University of California, Davis (Kocis and Dahlke 2017). This study presented a comprehensive analysis of high-magnitude streamflows—those above the 90th percentile—in the Central Valley, which could be available for groundwater recharge. The authors used a daily analysis of high-magnitude flows at Vernalis at the outlet of the San Joaquin River into the Delta. Without accounting for infrastructure limitations for recharge, they determined that flows available for recharge would average 455 taf/year.[8]

We discussed these approaches in Escriva-Bou and Hanak (2018). One of the conclusions we drew is that although DWR's adjustments to account for current demands and operations makes sense when using gage data over a very long timeframe, it might be unnecessary for recent years. That means the amount potentially available

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[7] Excess flows from the Tulare Basin that are not already captured and stored locally flow into the San Joaquin River—something that generally only occurs in very wet years.

[8] In the paper they obtain an average availability of 1.3 maf for years with high magnitude flows (36% of the years in the San Joaquin River). So over the long term, considering both years with high magnitude flows and without them, the average is roughly 455 taf/year. Water flowing in the San Joaquin River at Vernalis includes outflows from both the San Joaquin River and Tulare Lake hydrologic regions.

using DWR's approach could be much larger, up to 1.2 maf per year. On the other hand, these flows are concentrated in specific locations where conveyance limits are likely to be a challenge (for more details see Escriva-Bou and Hanak 2018). Therefore it is reasonable to use DWR's maximum estimate (550 taf/year)—similar to Kocis and Dahlke—as the maximum amount for recharge.[9]

It is important to stress that although these studies focused on water available for recharge, it is more appropriate to think of it as water available for capture and storage by any method. Thus, expanding surface storage—as at Temperance Flat Reservoir—would tap the same flows. For this reason, estimates of the potential supplies from Temperance Flat and from groundwater recharge are not additive. However, as discussed below, operating surface and groundwater storage facilities in a coordinated manner can increase overall volumes stored within a given storage capacity.

The DWR and Kocis and Dahlke studies only assessed available water, not methods to recharge it. Methods to artificially recharge aquifers include: dedicated recharge basins (or infiltration basins), injection wells, on-farm flood capture, urban stormwater capture, etc. (Hanak et al. 2018). Costs to recharge groundwater can vary greatly depending on the recharge method, water source, and level of treatment needed (if any). Perrone and Merri Rohde (2016) reviewed bond-funding applications to identify anticipated recharge benefits and proposed costs from these projects. They compared these costs with actual project costs collected from a survey. Their analysis indicates a median cost for managed aquifer recharge of $320/af when recharge is the primary goal, varying from $80 to $960/af (25 and 75 percentiles).[10] Bachand et al. (2016) reported that costs for on-farm flood capture were as low as $36/af in a pilot study in the Kings River Basin. The Semitropic Water Storage District also proposed the "Tulare Lake Storage and Floodwater Protection Project" for Proposition 1 funding. The project's average yield would be up to 117 taf/year, with an estimated capital cost of $603 million. Amortizing the project over 30 years at a discount rate of 5 percent (as included in the proposal), the marginal cost of the new water (including O&M) would total $435/af (SWSD 2017).

Considering that the maximum amount of water is 550 taf/year, which corresponds to DWR's maximum estimate, we assume that costs range from $36/af to $1,500/af, with a median cost of $327/af. Note that the upper range is larger than the maximum estimate reported by Perrone and Merri Rohde (2016). This is because we assume that for the upper range of the water estimates, new conveyance infrastructure would be needed to move water to recharge locations (Escriva-Bou and Hanak 2018).

Legal permitting might also be a significant barrier to make this water available, because recharge, like new surface storage, can interfere with water rights and environmental claims downstream.

Option 3: Reoperate surface and groundwater storage in the San Joaquin Valley

The opportunity to "re-operate existing reservoirs, flood facilities, and other water facilities in conjunction with groundwater storage to improve water supply reliability" was recognized by the California Legislature in Senate Bill X2 1 (Perata 2008). Releasing more water from surface reservoirs during the fall to replenish aquifers increases these reservoirs' capacity to capture water from winter storms. Climate change is expected to increase the importance of reoperation, because warming temperatures and changing precipitation patterns will increase winter run-off, putting added stress on surface reservoirs.

The Department of Water Resources' System Reoperation Study (DWR 2017) looks at conjunctive operation of surface and groundwater resources. The reservoirs considered are Shasta, Oroville and Folsom in the Sacramento

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[9] In Technical Appendix D we perform a sensitivity analysis of the optimal supply and demand options for valley agriculture with respect to the volume of water available for recharge, also allowing for scenarios where less water is available.

[10] In 2015 dollars.

Valley and Lake McClure in the San Joaquin Valley. They use a trade-off analysis that seeks to maximize multiple benefits such as improving the reliability of municipal and irrigation water supply, reducing flood hazards, restoring and protecting ecosystems, adapting to climate change impacts, and improving water quality. The analysis also includes forecast-based operations: incorporating weather forecasts into reservoir operations to enhance flexibility in managing the flood and conservation pools in reservoirs.[11]

This study shows that reoperating Lake McClure conjunctively with groundwater storage and using forecast-based operations could yield 8 taf/year, although with climate change (and assumed decrease in available runoff in this watershed) this amount would be reduced, yielding from 2 to 4 taf/year.[12] These estimates likely understate the amount of water that could be obtained from reoperation within the San Joaquin Valley, given that the analysis only included one reservoir, of many that could be reoperated.

DWR's analysis does not include the costs of reoperation. Although institutional inertia can be a challenge for reoperation, it remains a potential solution, and to some degree is inevitable with implementation of the Sustainable Groundwater Management Act and if other major infrastructure and regulatory changes occur. We assume that the costs to provide this water would be low, perhaps under $100 per acre-foot.[13]

Increase Local Runoff

Other tools are also being analyzed that could increase runoff from the upper watersheds to expand water availability in the valley. One prominent proposal is to do this by using a variety of methods to reduce tree density in these forests, which have become too dense as a result of poor management practices over the past decades Butsic et al. (2017).

Option 4: Increase inflows by managing forests in the upper watersheds

The headwaters—or upper watersheds—of the Sierra Nevada supply most water used by California's farms, cities, and aquatic ecosystems. A growing body of scientific literature examines the potential for managing forests to increase runoff from mountain forests and augment water supply. Although the estimates have large uncertainties, we try to assess potential water yield and costs from forest management for the San Joaquin Valley.

Synthesizing the results of more than 150 studies on forest thinning and runoff, Podolak et al. (2015) estimated potential water yield impacts from mechanical thinning for 11 watersheds in the northern Sierra Nevada. They obtained economic costs and benefits. The results show a potential increase in mean streamflow of 0–6 percent, depending mostly on the area of forest in the watershed and the size of the area that can be practically thinned. The costs per acre-foot (without accounting for other potential benefits) range from $2,251 to $5,974/af, averaging $4,635/af across basins.

Forest thinning is primarily done to reduce the risk and magnitude of wildfires, but potential co-benefits also include increased hydropower generation and water quality improvements (due to a decrease in pulses of

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[11] Many of California's large reservoirs are used both for storing water for dry seasons and dry years and for protecting downstream areas from flooding. Flood control operations dominate fall and winter seasons, obligating reservoir managers to partially empty reservoirs to have space available to capture floodwaters from winter storms. These "flood control rule curves" are defined for each reservoir. They have been criticized for being too inflexible. Beyond the seasonal reoperation approaches discussed in the text, whereby some water stored for droughts is moved from these reservoirs to groundwater storage to free up room, there is interest in adjusting the operating rules to allow more water to be kept in reservoirs, and using improved weather forecasting to make additional, "just in time" releases in advance of storms.

[12] Climate change scenarios were modeled for two 30-year future climate periods: (1) 2011–2040 as Early Long-Term (ELT), with the approximate midrange being 2025; and (2) 2046–2075 as Late Long-Term (LLT), with the approximate midrange being 2060. A total of 112 future climate projections from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report were considered with subsequent bias correction and statistical downscales to derive future Central Valley climate change. For the ELT, a midrange climate change scenario of projected temperature and precipitation was used (ELT Q5). For the LLT, three scenarios were used: LLT Q2, for drier more warming conditions; LLT Q4 for wetter less warming conditions, and LLT Q5 for midrange projections.

[13] The total yield that reoperation could provide within the Central Valley according to DWR's study could be near 100 taf per year. A cost of $100/af means a potential annual budget of $10 million for the federal, state, and local agencies involved in coordinating operations.

sediment, ash, and fire debris caused by catastrophic wildfires). Unfortunately, these other benefits involve significant uncertainties (Butsic et al. 2017). The only co-benefit that we could quantify is additional hydropower: according to Bales et al. (2011) hydropower in many watersheds along the crest of the Sierra Nevada could provide up to $75 per acre-foot, averaging $36 and $17 in the San Joaquin and Tulare Lake Basins respectively (in 1996 dollars). Accounting for this co-benefit, the cost per acre-foot would range from $2,191 to $5,915, averaging $4,515 (in 2016 dollars and simplifying across the whole San Joaquin Basin).

To estimate the additional water available from managing headwater forests, we apply Podolak et al. estimates to the San Joaquin Valley. According to our estimates presented in Technical Appendix A, the total runoff into the San Joaquin Valley floor for the period 1988–2017 averaged 8.5 taf/year. Therefore, a maximum of 512 taf per year (6% of total runoff) could be obtained in the best case, at a total cost of $4,635/af or $4,515 accounting for hydropower co-benefits.

The reliability of the estimates is very low, because they are not based on large-scale management experiences in the Sierras, but on assumptions and extrapolations from pilot projects and other studies. The timeframe and the legal and institutional barriers to provide this water supply are also uncertain, and as Butsic et al. (2017) pointed out, continued research across spatial scales and locations is needed to improve these estimates.

Increase Imported Water

On average, 4.9 maf/year of Delta imports enter the San Joaquin Valley through the Central Valley Water Project (CVP) and State Water Project (SWP) pumps in the south Delta near Tracy during 1988-2017. On average, 3.2 maf/year remained in the San Joaquin Valley—which was 19 percent of total water used in the valley. The rest is sent to the Bay Area, the Central Coast, and Southern California. Most imports come from the Sacramento River, a much larger river than the San Joaquin.

One way to increase water availability for the San Joaquin Valley is to increase water imported from the Delta. (Another is to reduce water exported, considered in a section below.) Some different options include: increase storage and water available in the Sacramento River Basin to supply water to pumps in the Delta; increase the capacity of existing storage facilities in or south of the Delta—specifically San Luis Reservoir and Los Vaqueros Reservoir; improve conveyance capacity across the Delta (i.e., California WaterFix); and reoperate the entire Central Valley storage and conveyance system to maximize Delta imports.

Option 5: Expand Sacramento Valley storage

The most significant proposals are to build Sites and Centennial Reservoirs and to expand Shasta Reservoir.

Sites Reservoir. Sites Reservoir is a proposed off-stream storage facility on the west side of the Sacramento Valley, about 10 miles west of Maxwell, in Colusa County. It could improve the operations of the main reservoirs of the Sacramento River Basin by stabilizing Sacramento River fall flows for salmon, conserving cold water pools in existing reservoirs, and increasing water supplies for agricultural and urban customers (Sites Project Authority 2017a).

Sites would deliver up to 441 taf/year on average for multiple purposes, including environmental benefits that would be funded under Proposition 1. Non-Proposition 1 benefits would include a long-term average of 286 taf/year for additional water supply (254 taf/year in the simulations for 2030 modeling results, and 295 taf/yr for 2070) (Sites Project Authority, 2017b). Most of the 32 project partners are from the Sacramento Valley, with others from Southern California and the Bay Area. As of September 2018, only 2 partners are from the San Joaquin Valley. We therefore assume that of projected new water supplies from Sites, only south-of-Delta deliveries with agricultural purposes would stay in the valley, bringing to the San Joaquin Valley an additional 28 taf/year for the 2030 scenario, 33 taf/year for the 2070 scenario, averaging 31 taf/year over the long term.

The total cost of the project (in 2015 dollars) including operations, maintenance, and repairs is $5.9 billion. The California Water Commission has determined that the value of the public benefits provided by Sites Reservoir amounts to $933 million, and the final bond funding to $816 million. The proposal also estimates a potential hydropower co-benefit of $19,483 per year.

Accounting for the total cost of the project and the new water delivered for public and non-public benefits, the incremental cost of this new water would range from $482/af to $502/af, averaging $486/af. When the non-public costs are allocated over the water supplied for non-public purposes, the incremental cost would be $665/af (ranging from $644/af to $749/af).

Centennial Reservoir. This proposed project would build an 110,000 acre-foot reservoir on the Bear River between Rollins Reservoir and Combie Reservoir. It would operate as a "fill-and-spill" project, to maximize reservoir storage during the winter and early spring runoff periods. The non-public water supply benefits would include 3.8 taf for 2030 conditions, and 11.2 taf for 2070 conditions (NID 2017).

Because of the small amount of water produced and the fact that the reservoir only involves Nevada Irrigation District, we assume that no water would go to the San Joaquin Valley.

Shasta Reservoir expansion. Shasta Dam is a federally-owned facility, and the largest surface reservoir in California, with a storage capacity of 4.55 maf. The U.S. Bureau of Reclamation is planning to enlarge the reservoir by raising the dam 18.5 feet to provide an additional 630 taf of storage capacity (USBR 2018). The objectives of the expansion are to: (1) improve anadromous fish survival in the upper Sacramento River, (2) increase water supply reliability in the Central Valley of California, and (3) address related water resource problems, needs, and opportunities (USBR 2015).

The expansion of Shasta Reservoir would increase average valley-wide CVP and SWP deliveries by 55 taf/year (ranging from 31 to 76 taf/year for different alternatives).[14] South-of-Delta deliveries would increase by 40 taf/year on average (ranging from 27 to 59 taf/year).

The total cost of the project is estimated at $1.4 billion (in 2014 dollars). The annualized costs, including capital costs and interest, would range from $56 million to $63 million. Using these figures, the marginal cost of new water would range from $834/af to $1,911/af, averaging $1,211/af.

The feasibility report also estimates the monetary value of some co-benefits: hydropower production, the improvement of anadromous fish survival, and the expanded recreation benefits. Because there is not committed funding to pay for the public benefits of this project (fish survival and recreation), we assume that the cost of the new water can be reduced by adding the private co-benefit of hydropower production. When accounting for co-

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[14] The 2015 feasibility report includes six alternatives. Four alternatives analyze an 18.5 foot raise in the height of the dam, while two other alternatives examine smaller dam expansions. These values include the four 18.5 foot raise alternatives (CP3, CP4, CP4A, and CP5).

benefits, the cost of new water delivered from the expansion of Shasta Reservoir would range from $651/af to $1,412/af, averaging $921.

Option 6: Expand Delta and South of Delta storage

San Luis Reservoir. San Luis Reservoir is on the eastern slopes of the Diablo Range in Merced County, approximately 12 miles west of Los Banos. It stores water pumped from the San Joaquin–Sacramento Delta by the CVP and the SWP, and has a capacity of 2.04 maf.

USBR generated cost estimates for raising the dam to increase reservoir capacity by approximately 130 taf (USBR 2013). The construction cost was estimated at $360 million, which would yield 7 to 43 taf/year in water supply. Two other alternatives for water yields, but not for cost, are presented in the report: a 300 taf increase in storage capacity, increasing average new water supply by 13 to 67 taf/year and a 500 taf capacity increase, increasing new water supply by 21 to 71 taf/year. These estimates come from a draft appraisal report, so we assume their uncertainty is high (as shown in the large discrepancy between scenarios).

From the construction costs, we assume a 10 percent increase in costs for design and preliminary studies. From the total investment cost we estimate the annualized cost. Finally, we add another 10 percent to account for operation, maintenance, and other costs. We also estimate costs for the second and third alternatives—not included in the report—by assuming proportional increases in construction costs relative to the first alternative.

With these assumptions, the annual cost of new water supplied from expanding San Luis Reservoir would range from $412 to $2,529 per af for the 130 taf of storage capacity (averaging $1,471/af of new water available), from $529 to $2,724 per acre feet for 300 taf of added storage capacity (averaging $1,626/af), and from $873 to $2,951 for 500 taf of additional storage capacity (averaging $1,912/af).

Given the design, permitting, and construction requirements of this project, and using as a benchmark the timeline report for the Temperance Flat reservoir, it is unlikely that the project would be operational before 2030.

Los Vaqueros Reservoir. Los Vaqueros Reservoir is an off-stream reservoir in Contra Costa County that provides water quality and supply benefits to the customers of the Contra Costa Water District, as well as providing Delta fishery benefits. The Los Vaqueros Reservoir Expansion Project (LVE Project) would enlarge the existing reservoir from 160 taf to 275 taf, making it a regional facility with additional public benefits, including ecosystem benefits for south-of-Delta wildlife refuges, drought and non-drought emergency water supply for a large number of local agency partners, and recreation. It would also provide nonpublic benefits to regional water supply agencies, integration with state water systems to increase flexibility and efficiency of operations, and enhanced opportunities for sustainable groundwater and recycled water management (CCWD 2017).

The non-public benefits of expansion would accrue to urban and agricultural partner agencies. According to Contra Costa Water District (2017), additional water supply would average 35 taf/year for 2030 conditions and 34 taf/year for 2070 conditions.[15] The project includes many urban utilities in the Bay Area and some agricultural districts in the San Joaquin Valley—principally members of the San Luis and Delta-Mendota Water Authority. Because most new water from Los Vaqueros is expected to supply urban areas in the Bay Area, the maximum amount that would go to San Joaquin Valley for agricultural supplies is about 10 taf/year.

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[15] Table 3-2.2 in Contra Costa Water District (2017) shows 2030 modeling results of 31 taf/year for municipal and industrial (M&I) and 10 taf/year for agriculture, and for the 2070 modeling results 29 taf/year for M&I and 10 taf/year for agriculture. The M&I results are for all years outside of drought emergencies, so the long-term averages are lower. The authors make this distinction because economic benefits of emergency response during droughts is considered a public benefit and can be funded under WSIP. For purposes of comparing costs across multiple projects, it is more appropriate to report the long-term average, as we did.

The net present value of the project costs is $1.3 billion, and the California Water Commission has determined that the value of the public benefits is $813 million, and that Proposition 1 can contribute $459 million. This makes the total cost per acre-foot $1,422, or $930 when accounting for public benefits funded by Proposition 1.

Option 7: Increase cross-Delta conveyance capacity

California WaterFix—formerly called Bay Delta Conservation Plan (BDCP)—would add three new water intakes in the north Delta (each with 3,000 cfs capacity and an average annual yield of 4.9 maf), and two tunnels up to 150 feet below ground to deliver this water to the south Delta pumps.

The modeling scenarios presented in the WaterFix EIR/EIS (BDCP 2016b) assume that imports through the Delta under current conditions average 5,176 taf/year. With no project, modeling assumptions show that sea level rise—which would increase salinity in the Delta—and other effects of climate change in hydrology would reduce imports to 4,728 taf/year by 2025 (a loss of 189 taf/year), and to 4,441 taf/year by 2060 (a loss of 703 taf/year). With WaterFix, in 2025 the average would be 4,917 taf (an improvement of 189 taf/year relative to the no-action alternative); in 2060 four different alternatives are considered, averaging 4,831 taf/year (an improvement of 390 taf/year relative to the no action alternative). If the San Joaquin Valley's share of Delta imports remains constant, about two-thirds of this water would stay in the valley (127 taf/year in the short term and 261 taf/year in the long term, averaging 194 taf/year).

According to the latest fact sheets, the costs of WaterFix would be $15.7 billion ($14.9 billion for tunnel design and construction and $0.8 billion for mitigation). Using a 3.75 percent discount rate and a project life of 100 years, and 10 percent of annualized costs for operations and maintenance (O&M), the equivalent annual cost would be $666 million.

The improvement in water supplies would be 289.5 taf/year (averaging short-term and long-term enhancement). So the total cost, without accounting for additional co-benefits, would be $2,301/af.

Some other studies (for example, Sunding 2015 and Michael 2016) have included in their analyses potential co-benefits from water quality improvements from exporting less-salty water through the SWP and CVP facilities, and from avoided seismic risks. The annualized co-benefits would range from $65 million (base case scenario in Michaels 2016) to $120 million (scenario in Sunding 2015). That would decrease the cost to $1,887/af (with Sunding co-benefits), and to $2,078/af (with Michael co-benefits).

There are high uncertainties for the new water available from this project, so we consider these estimates to have low reliability. It is also unlikely to operate before 2030.

Option 8: Reoperate the whole Central Valley system

If the operation of Central Valley surface and groundwater reservoirs were fully coordinated, water availability in different parts of the entire region and other areas dependent on Delta imports could be significantly expanded. This might include increased Delta imports that could benefit the San Joaquin Valley.

Some studies have looked at the potential water resources that could be yielded by reoperation in the Central Valley:

- Lund et al. (2014) concluded that "the benefits and cost-effectiveness of coordinating surface and groundwater storage and conveyance operations greatly surpass the benefits of expanding storage capacity alone." For each additional maf of conjunctively managed surface and groundwater storage, water deliveries would increase to as much as 200 taf. When operated alone, the increased yield by each additional maf of storage would be only 50–150 taf.
- The Association of California Water Agencies (ACWA) published a report about the benefits of expanding storage and integrating operations (ACWA 2017). The study assumes that all the potential storage projects

are already in operation (construction of Centennial, Sites, and Temperance Flat reservoirs and expansion of Los Vaqueros and San Luis reservoirs, American River conjunctive management, and new groundwater storage in the Kern Fan Area and Tulare Lake). Under this scenario, south of Delta deliveries to the valley would increase by 404 taf/year with existing Delta conveyance, and up to 816 taf/year with improved Delta conveyance (i.e. WaterFix). The study also gives the following values for improved deliveries by individual projects with the existing Delta conveyance: 254 taf/year from Sites, 51 taf/year from Los Vaqueros, 8 taf/year from San Luis, and 81 taf/year from integration of operations. Like Lund et al. (2014), this study does not present the results of integration of operations with current infrastructure.

- As described above (option 3), the Department of Water Resources has also released a System Reoperation Study (DWR 2017). This study looks at operating Shasta and Oroville reservoirs in the Sacramento Valley conjunctively with Lake McClure in the San Joaquin Valley, using a trade-off analysis that tries to maximize multiple benefits. It also includes forecast-based operations, incorporating weather forecasts into reservoir operations to enhance flexibility in management of the flood and conservation pools. The study looks at many different strategies, including future uncertainties about hydrology and salinity in the Delta caused by climate change.

We focus on the results of the DWR study to assess the expanded potential yield of Delta imports from reoperation.[16] Two results of this study are significant for our purposes:

1. A new operation strategy for the Shasta, Oroville, and Folsom reservoirs would yield 26 taf/year of water from Jones and Banks pumping plants into the San Joaquin Valley, which would increase to up to 82 taf/year with improved Delta conveyance (WaterFix). Considering climate change, for the early long-term scenario (2025) the increase would be 43 taf/year, and for the late long-term (2060) from 39 to 72 taf/year, depending on the scenario considered.[17] This is water that would be available for the whole CVP and SWP system, so accounting for the share of imports that remain in the San Joaquin Valley (about two thirds for the last three decades) the increased imports to the valley would be between 17 and 37 taf/year without WaterFix, and between 34 and 54 taf/year with WaterFix.
2. A second analysis in the study concludes that "operating the CVP and SWP as a single project increases operational flexibility, allowing operators to more easily rebalance system benefits (…). Depending on hedging assumptions, average annual water supply benefits ranged from about 100 to 150 taf/year." Again, assuming that two thirds of this water would go to the San Joaquin Valley, the final amount would range from 67 to 100 taf/year.

From these two assessments, we estimate that the increased water availability in the San Joaquin Valley from reoperation of the system without expanding reservoir capacity or new Delta conveyance would range from 17 taf/year (lowest estimate when reoperating the system, but maintaining CVP and SWP as separated projects) to 100 taf/year (highest estimate when operating CVP and SWP as a single project).

As noted above (option 3), there are no cost estimates for this reoperation study.[18] We assume that the cost would be low—less than $100/af.

Reduce Outflows and Exports

Reducing the flows that leave the valley is another general strategy to increase water availability in the San Joaquin Valley. In this section we discuss two such options: reducing San Joaquin River flows into the Delta, and reducing exports from the valley to other regions.

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[16] We are interested in the benefits of the expanded yield of reoperation with current infrastructure to show what is potentially available without new investments. The increase in Delta exports from other investments are already accounted in their options (see for instance options 5 and 7).

[17] See footnote 12 for the details on the assumptions for climate change.

[18] Lund et al. (2014) and ACWA (2017) do not provide cost estimates for reoperation either.

Option 9: Reduce San Joaquin River outflow

This option is equivalent to capturing and storing more local runoff (options 1, 2, and 3, described above).

Because capturing and storing more local runoff reduces river flows, the State Water Board will generally need to authorize these actions—after ensuring that the new diversions do not harm downstream water-right holders or the environment. The board's new environmental flow regulations to protect endangered salmon on three San Joaquin River tributaries—the Merced, Stanislaus, and Tuolumne—could reduce the amount available (SWRCB 2018a). We consider this possibility when assessing the costs of adaptation to a larger future water supply deficit (Technical Appendix C and Chapter 2 of main report).

The new environmental flow order would require unimpaired flows ranging from 30 to 50 percent, with a starting flow of 40 percent, for February to June for the Stanislaus, Tuolumne, and Merced Rivers through to the San Joaquin River near Vernalis. The long-term mean annual reduction in surface water supplies with 40 percent unimpaired flows would be 293 taf/yr, a 14 percent reduction relative to current diversions from these tributaries by agricultural and urban water users in the northeastern part of the San Joaquin Valley. The reductions have also the potential to affect areas out of the San Joaquin Valley, especially the city and county of San Francisco, which rely on water exported from the Tuolumne River. The board left open the possibility of approving a negotiated settlement, rather than these flow levels, as part of a comprehensive agreement on flow management in the Sacramento–San Joaquin Delta watersheds in 2019 (SWRCB 2018b).

Option 10: Reduce exports to other regions

For the period 1988–2017, an average of 1.9 million acre feet per year were exported from the San Joaquin Valley to Southern California, Central Coast, and the Bay Area hydrologic regions (see Technical Appendix A and related dataset). Southern California received the lion's share (65%), followed by the Bay Area (24%), and the Central Coast (12%). Most of this water (89%) consists of Delta imports, conveyed through the valley by the SWP and CVP. Just over 200 taf/year (11%) is from the Tuolumne River (a tributary of the San Joaquin River), exported to communities in the Bay Area by the San Francisco Public Utilities Commission.[19] This water primarily serves urban areas.

As described in Technical Appendix A, the share of Delta imports that stays in the San Joaquin Valley has declined over time as Southern California's share has increased. Southern California's average imports increased by more than 500 taf/year from 2000 onwards, as the region began using more of its SWP contracts to increase local storage. Some Southern California communities also purchased long-term contracts from irrigation districts in the valley. Other regions' exports from the valley have remained fairly stable.

Assuming that these urban areas could reduce their imported water by reducing demand and that this water would be re-allocated in the San Joaquin Valley, there is a potential increase in water availability from reducing exports. However, both the amount of this increase and its costs are highly uncertain.

Under legislation enacted in 2018, urban areas across California will be required to make long-term reductions in water use. To estimate the maximum amount of water that could remain in the valley, we assume that valley users could pay urban customers in the Bay Area, Central Coast, and Southern California to reduce their outdoor water use by 50 percent relative to 2013 levels.[20] First we obtain the total amount of water exported to these urban areas

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[19] The East Bay Municipal Utilities District also imports an average of nearly 160 taf/year from the Mokelumne River, an east side river that flows directly into the Delta from the northeastern corner of the San Joaquin River hydrologic region. We do not include this river's flows in our regional water balance, because it lies within the Delta portion of the San Joaquin River hydrologic region (see Technical Appendix A).

[20] We focus on outdoor water use because this is the best way to obtain net water savings statewide. In coastal areas, reductions in indoor water use could also reduce the demand for imports (see Box 2.1 in main report). Other options, such as more investments in recycled water and stormwater capture, could also reduce the demand for imports in these regions. We used data from 2013 as the baseline because it was unaffected by emergency conservation policies implemented during the drought.

from our estimates detailed in Technical Appendix A. Then we estimate baseline outdoor water use in 2013 by assuming that per capita indoor use is 55 gpcd of total urban water use, using data from the State Water Board's conservation reporting (SWRCB 2017). Urban agencies might reserve this saved water to accommodate population growth, so we also calculate the water savings that would remain available after accounting for this growth. This results in a maximum of 144 taf/year for potential use in the valley. Table B2 shows the details of the assessment.

TABLE B2

Reductions in San Joaquin Valley water exports from a 50 percent cut in urban outdoor water use in other regions

Region	Average exports from San Joaquin Valley (taf/yr)	Population Growth (2015–40)	Outdoor share in 2013	Maximum reduction of SJV exports (taf/yr)	Maximum reduction of SJV exports with population growth (taf/yr)
South Coast Delta imports	1,254	16%	45%	285	131
Central Coast Delta imports	227	17%	38%	43	13
SF Bay Delta imports	237	24%	35%	41	-6
SF Bay Tuolumne River imports**	219	24%	35%	38	-6
Total	1,937	-	-	408	144*

SOURCES: Average exports: Technical Appendix A; 2013 water use: SWRCB (2017); population growth: Department of Finance Population Projections.

NOTES: *Means the sum does not take into account negative numbers in the SF Bay region.

For costs of this water, we rely on a report published by California Public Utilities Commission (2016). Their survey found that the cost per acre-foot for water conservation ranges from $137 to $4,580, averaging $1,335.

If Central Valley users could get water from decreased exports, the time frame to implement the actions could be quite fast, because these are local investments that usually need little time to implement, potentially less than five years. However, the likelihood of obtaining water from existing water rights or contracts in other regions is low. As an example, Table B2 shows that potential reductions of exports from the San Joaquin Valley would actually be negative in the San Francisco Bay Area after accounting for population growth—meaning that this region will need to find additional ways to meet their project demands, beyond these assumed water savings. It is also unlikely that Southern California or the Central Coast will be willing to sell conserved water, which is often cheaper than other sources of new water. That said, water savings in coastal areas will, at a minimum, reduce pressures to increase water imports in these regions, such as occurred in Southern California from 2000 onwards.

Reusing and Repurposing Local Water Supplies

In some parts of the valley, recycled urban wastewater is being developed as an irrigation water supply, and there is growing interest in such projects. There is also interest in desalting brackish groundwater and expanding the use of water produced by oil and gas mining.

Option 11: Expand recycled water reuse

The importance of recycled water in meeting future water demands is enshrined in state law: "It is hereby declared that the people of the state have a primary interest in the development of facilities to recycle water containing waste to supplement existing surface and underground water supplies and to assist in meeting the future water requirements of the state" (California Water Code Section 13510).

The State Water Board's Recycled Water Policy, adopted in 2009 and updated in 2013, mandates an increase in the use of recycled water by 200,000 af/year by 2020 and an additional 300,000 af/year by 2030 (SWRCB 2013). This means going from 669 taf/yr in 2009, to 889 taf/yr in 2020, and 1,169 taf/yr in 2030. Using data from the 2009 Municipal Wastewater Recycling Survey and the Urban Water Management Plans, the Department of Water Resources estimates in the 2013 California Water Plan (DWR 2013) that the 2020 and 2030 targets for statewide municipal water recycling should be slightly higher—at 1 maf and 1.3 maf, respectively.

The 2015 Municipal Wastewater Recycling Survey (SWRCB 2015) found that 714 taf of recycled water was used for other beneficial reuses in that calendar year. This is just 45 taf more than in 2009, and far below the board's 2020 target. The survey results also show that in the San Joaquin Valley, a total of 117 taf were recycled in 2015, with most used by agriculture, and almost half (54 taf) used in Kern County. If the board's targets for 2030 are met, and the San Joaquin Valley's share remains similar to its share in 2015 (about 16%), the San Joaquin Valley would recycle 191 taf/yr by 2030, an increase of 75 taf over 2015 levels.

However, most inland wastewater reuse cannot be considered new water because most of the water recycled in the San Joaquin Valley would already be used with further treatment by downstream users or the environment, including water recaptured by the south Delta pumps that contributes to SWP and CVP imports.[21] So the only recycled water that can increase actual water availability in the basin is wastewater that exits the basin at times when the San Joaquin River is contributing to Delta outflows that exceed volumes required by water quality and environmental regulations.[22] This would most likely be possible at some times from communities in the San Joaquin River hydrologic region (Madera, Merced, San Joaquin, and Stanislaus counties), whose treated wastewater flows into the San Joaquin River and the Delta.

As a rough estimate of what might be possible, we assume that new water from reuse of recycled water in the valley might be as high as 13 to 16 taf/year.[23] The costs of recycled water, according to a report on non-traditional water sources, would range from $396 to $5,800, averaging $2,898 per acre-foot (CPUC 2016).

This water will likely not be available before 2030, given the time needed to implement these projects.

Option 12: Desalinate brackish groundwater

Salinity accumulation in soils harms agricultural productivity in the San Joaquin Valley, and several options are being studied to reduce salt loading (for a discussion, see Chapter 3 in the main report and CV-Salts 2016a and 2016b). One of the management strategies being pursued is to desalinate brackish groundwater. Although this could increase usable supplies, it would not help achieve groundwater balance because pumping this groundwater would add to extraction from the aquifer.

Option 13: Reuse water produced in oil and gas wells

California is the nation's third largest oil-producing state, with 6 percent of US production in 2015. It also produces 0.7 percent of US natural gas output. As part of the extraction process, water is injected into more than 55,000 wells around the state. During extraction, many wells also produce water mixed with oil and drilling fluids. This water must be disposed of or treated. A 2014 law—SB1281—requires well owners to report water volumes used and

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[21] For a discussion of this issue, see Box 2.1 in the main report. It arose in a recent sale of recycled water from the City of Modesto to the Del Puerto Water District. Some other valley water users dependent on Delta imports charged that the sale reduced the normal outflows from the San Joaquin River and would reduce normal Delta imports, and Del Puerto settled the claim (Morain 2015).

[22] As Gartrell et al. (2017) show, periods with "uncaptured outflow" from the Delta—in excess of regulatory requirements—occur even in dry years, but are most common in wetter years.

[23] This estimate assumes that San Joaquin, Stanislaus, Merced and Madera counties attain the State Water Board mandate for 2030, or the slightly higher goal DWR set in its 2013 update of the California Water Plan, and that three-quarters of this amount might be used without compromising downstream users or Delta conditions.

produced. Following the reporting data, in 2015 and 2016 they produced 12,896 and 8,514 af of water suitable for domestic or irrigation purposes statewide, respectively (Department of Conservation 2017).[24] According to another publication that reported well counts and production of oil, gas, and water by county in 2012, the eight San Joaquin Valley counties were responsible for 62 percent of total statewide oil well-related water production, and Kern is the main producer, with 78 percent of the statewide total. Assuming that this share remained unchanged, 7,971 and 5,262 af produced in the San Joaquin Valley would have been available for treatment in 2015 and 2016, respectively. We assume that most of this water could be available for reuse after treatment.

The water produced by the oil and gas industry processes varies greatly in quality, and treatment costs vary greatly. According to the literature reviewed, the costs can vary from less than $100 to nearly $50,000 af depending on the treatment needed for the end use of the water (Arthur et al. 2005, Fakhru'l-Razi et al. 2009, Meng et al. 2016). Assuming a log-normal distribution of the costs, the average cost would be $1,196 per af of treated wastewater.

Although the costs of treatment can limit its use, such projects could be implemented in the short-term.

Demand Management Options

Options examined include methods to reduce net water use and losses, and approaches to increase flexibility, primarily through water trading.

Reduce Water Use and Losses

Option 14: Reduce agricultural water use

The valley has over 5 million acres of irrigated cropland. Here we briefly review potential water savings and costs of two approaches to reducing agricultural water use: increasing irrigation efficiency and reducing crop evapotranspiration (or net water use).

Increase irrigation efficiency. It is commonly thought that increasing irrigation efficiency is an important way to save water. Although it has other benefits, greater irrigation efficiency often just reduces applied—not net—water use, because most irrigation water not consumed by plants returns to rivers or recharges aquifers where it is available for reuse (see Box 2.1 in main report). Irrigation efficiency is usually defined as the fraction of water consumed by the plants divided by the water applied through the irrigation system (field application efficiency) or the water diverted from rivers or pumped from the aquifers (scheme irrigation efficiency). The remaining water—evaporation from soils and water bodies, and transpiration from weeds—are considered "water losses" while water percolated to soil layers below the root zone and surface runoff are defined as "return flows."

Although converting to more efficient irrigation systems does reduce the application of water to the plants—as well as reducing labor costs, pollution from fertilizers and other chemicals, and energy consumption—many studies have shown that increased irrigation efficiency can actually increase net water use.[25] This is because the plants are more efficient when water is applied with improved technologies, thus increasing the water consumed per unit of land, and also because the area irrigated might be expanded using water savings from the irrigation efficiency intervention (Ward and Pulido-Velazquez 2008).

A recent review of irrigation technology interventions by Perry et al. (2017) concludes that "there are rather few examples of carefully documented impacts of hi-tech irrigation […] and more often these studies as do exist show that water consumption actually increased (as science would predict)." This study cites a case from the San Joaquin

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[24] Untreated water extracted from oil or gas wells that has a number of total dissolved solids (TDS) lower than 10,000 parts per million (ppm).

[25] Energy consumption might actually increase because there is a need to pressurize the system when converting from flood irrigation into drip or sprinkler.

Valley, where water consumption (evapotranspiration) was lower in fields irrigated with drip/micro than in fields with surface irrigation methods in 13 of 25 crop-irrigation methods (Thoreson et al. 2013). But a previous statewide study by Burt et al. (2002) on evaporation from irrigated agricultural land concluded that "the estimated evapotranspiration from crops on drip/micro is 6 to 10 percent higher than under surface or sprinkler irrigation."

Water that percolates to soil layers below the root zone or escapes as runoff from inefficient irrigation is not lost. Indeed, such surface water is often vital for recharging aquifers. And since consumptive water savings from irrigation efficiency is not evident, we assume that irrigation efficiency does not save water or make new water at the basin scale.

Reduce crop evapotranspiration. To reduce net agricultural water use, it is necessary to reduce crop evapotranspiration. This can be achieved by shifting to less water-intensive crops, reducing water consumption using deficit irrigation, or fallowing agricultural land. The net water savings are from the difference between the water consumption of the original and new land use. The costs to farmers of reducing net agricultural water use when shifting to less water-intensive crops or fallowing agricultural lands are the decrease in farm profits; and there are other potential costs to the regional economy from the decline in output and employment. We used a model of the valley's agricultural economy to estimate changes in water consumption and costs to bring groundwater basins into long-term balance, as described in Technical Appendix C.

Option 15: Reduce urban use in the San Joaquin Valley

To estimate the water supplies that could be obtained from urban water conservation within the San Joaquin Valley, we followed the approach used in Option 10, with the only difference being that the "saved" water stays in the valley.

We assume urban customers could reduce their outdoor water use by 50 percent, but that urban water agencies would want to retain the portion of savings needed to accommodate projected population growth (Table B3). Reductions in indoor urban water use in the San Joaquin Valley would produce very little net water savings as this use almost entirely returns to rivers or aquifers after treatment.

The maximum amount of water that could be obtained from local urban water conservation, after subtracting the amount needed to accommodate population growth, is 86 taf/year. To obtain the costs of this water, we rely on a report published by California Public Utilities Commission (CPUC 2016), which found a cost range from $137/af to $4,580/af, with an average cost of $1,335/af. Implementation could be quite fast.

TABLE B3

Increased water availability resulting from a 50 percent cut in urban outdoor use in the San Joaquin Valley

Region	Total Urban Use (taf)	Population Growth (2015–40)	Outdoor share in 2013	Maximum reduction of outdoor conservation (taf)	Increased water available for re-allocation considering population growth (taf)
San Joaquin Valley	868	32%	63%	274	86

SOURCES: Water use from SWRCB (2017), population projections from the California Department of Finance.

Option 16: Reduce net water use on non-irrigated lands and managed wetlands

On average, roughly one-tenth of net water use in the valley is on non-irrigated lands and managed wetlands. The largest portion is for natural vegetation on unirrigated lands, which occupy more than 3 million acres on the valley floor. The main water source is precipitation, and both vegetation growth and net water use vary substantially between wet and dry years. These landscapes already provide an array of services, including rangeland for livestock grazing and habitat for an array of species. And as described in chapter 4 in the main report, there is potential for enhancing these benefits as part of a coordinated strategy for managing the valley's drylands. Reducing water use from native vegetation in the valley floor is not an option that has been considered in the literature reviewed.

The other environmental use is the roughly 130,000 acres of wildlife refuges—a network of federal, state, and private wetlands managed to support waterbirds of the Pacific Flyway. As described in Chapter 4 in the main report, these refuges are allocated water through the Central Valley Project under a 1992 federal law, the Central Valley Project Improvement Act (CVPIA). A 2009 study estimated that average water deliveries to the refuges increased by about 21,000 acre-feet (up from 422,000 acre-feet) after the enactment of the CVPIA, and that reliability of these deliveries improved (Central Valley Project Improvement Act Refuge Water Supply Program 2009). However, actual deliveries have averaged only 80 percent of full mandated annual water supply under the CVPIA. Although there is little potential to generate net water savings from these refuges without harming wildlife, there are opportunities for cooperative water management projects that can improve the timing and availability of water for the refuges and neighboring irrigation districts.

Option 17: Reduce losses in water infrastructure

From 1998–2010, roughly 720 taf per year evaporated from reservoirs, natural lakes, and ponds within the region, and roughly 550 taf per year were lost from evaporation during the water delivery process.[26] Controlling these losses seems unlikely, although there might be some scope for using solar panels to reduce evaporation on canals. The distribution system also loses water to seepage—around 460 taf annually over this same period. Lining canals and making other investments to reduce leaks are sometimes employed to reduce seepage losses. But this approach has similar limitations to irrigation efficiency for achieving net water savings, because it reduces return flows and the recharge of aquifers.[27]

We could not find any studies that analyze potential water savings and costs of enhancing infrastructure to avoid these losses. That might be a signal that these costs are too high relative to the potential benefits, because many evaporation and evapotranspiration processes are practically unavoidable. Therefore, we did not estimate potential supply increases from this option.

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[26] These estimates are from regional water balances in the California Water Plan Update (Department of Water Resources 2013). About 97 percent of total conveyance losses are apportioned to agriculture, and the remainder to the urban sector.

[27] Our 2017 survey of water managers found that unlined canals were a major tool for capturing and recharging high flows for irrigation districts in some parts of the valley (Hanak et al. 2018).

Improve Flexibility of Demand Management

Option 18: Expand water trading

Water markets enable the temporary, long-term, or permanent transfer of water to another user in exchange for compensation. The ability to transfer water adds flexibility to the water system—helping address temporary drought conditions or accommodate longer-term changes in water demands (Hanak and Stryjewski 2012). Given the physical, financial, and environmental limits on expanding overall water supplies in the San Joaquin Valley and the prospect of supply reductions, water markets—including local trading of groundwater allocations within overdrafted basins—are likely to become more important.

Water markets will not make new water supply available, but rather can help water users adapt to using less water more economically. If water is reallocated to higher-value water uses, the economic costs of adapting to future conditions—including the need to bring groundwater basins into long-term balance—will be lower. Technical Appendix C shows how regional water trading strategies can reduce the costs of ending overdraft in the valley.

Summary of Increased Water Availability and Costs for Likely Options

This section reviews the results for those options more likely to be implemented. We exclude options that reduce environmental flows in rivers or wetlands as unlikely. Other options—such as reducing losses in water infrastructure or desalinating brackish groundwater—are dropped either because there are no reliable estimates for them or because they do not increase water availability at the basin scale. For options involving urban water conservation in coastal regions or the San Joaquin Valley, we focus on the amount that could be available for agriculture in the valley, after subtracting the amount that would be needed to support urban water demands from population growth. Options including reducing agricultural water use and water trading are analyzed in Technical Appendix C. We have grouped the options under five strategies, as presented in Table B4. Table B5 summarizes the likely new water availability, total cost, cost with co-benefits, and sources of information for each option.

TABLE B4

Management options considered to increase water availability in the valley for farming purposes

Management options
Capture and store more local runoff - Expand local surface reservoirs o Temperance Flat Reservoir - Expand groundwater storage - Reoperate surface and groundwater storage in the San Joaquin Valley
Increase local runoff - Increase inflows by managing forests in upper watersheds
Increase imported water from the Delta - Expand Sacramento Valley storage o Sites Reservoir o Shasta Reservoir expansion - Expand Delta and south of Delta storage o San Luis Reservoir expansion o Los Vaqueros Reservoir expansion - Increase cross-Delta conveyance capacity o California WaterFix - Reoperate the whole Central Valley system
Reduce exports and increase non-farm water use within the valley - Urban conservation in the valley - Urban conservation in coastal regions*
Reuse and repurpose local water supplies - Urban reuse - Reuse water produced in oil and gas wells

NOTE: * This option is a way to reduce exports from the valley to coastal regions (Table B1)

TABLE B5

Range estimates of increased water availability, costs, and sources for each option considered

Actions		Increased water availability (taf)			Total Cost ($/af)			Cost with Co-Benefits ($/af)			Source and comments
		Min	Average or best estimate	Max	Min	Average	Max	Min	Average	Max	
Capture and store more local runoff	Temperance Flat Reservoir	197	227	257	$559	$633	$730	$500	$565	$651	CWC Water Storage Investment Program
	Groundwater recharge	0	190	550	$36	$327	$1,500	$36	*$360*	$1,500	DWR (2017a), Perrone and Merri Rohde (2016), Bachand et al. (2016)
	Re-operating surface and groundwater resources in the valley	2	5	8	$50	$100	–	–	$100	–	DWR (2017b). There are no cost estimates in the literature, so it is just an assumption.
Increase local runoff	Forest management	0	N/A	512	$2,251	$4,635	$5,974	$2,191	$4,515	$5,915	Podolak et al. (2015) for potential increase of runoff and costs; Technical Appendix A for total runoff.
Increase imported water from the Delta	Sites Reservoir	28	31	33	$482	$486	$502	$644	$665	$749	CWC Water Storage Investment Program
	Shasta Reservoir Expansion	27	40	59	$834	$1,211	$1,911	$651	$921	$1,412	USBR (2015). Assuming only 18.5-feet raise scenarios are considered.
	San Luis Expansion	7	25	43	$412	$1,471	$2,529	$412	$1,471	$2,529	USBR (2013). Costs are obtained using the average yield of two models with large differences.
	Los Vaqueros Expansion	10	10	10	$1,402	$1,422	$1,443	$943	$957	$971	CWC Water Storage Investment Program
	WaterFix	127	194	261	$1,708	$2,301	$3,524	$1,491	$2,008	$3,076	Bay Delta Water Conservation Plan
	Re-operating the whole Central Valley system	17	59	100	–	$100	–	–	$100	–	DWR (2017b). There are no cost estimates in the literature, so it is just an assumption.
Reduce exports & local non-farm water	Urban conservation in coastal regions	0	N/A	86	$137	$1,335	$4,580	$137	$1,335	$4,580	Own calculation for availability and CPUC (2016) for costs
	Urban conservation in the SJ Valley	0	N/A	144	$137	$1,335	$4,580	$137	$1,335	$4,580	Own calculation for availability and CPUC (2016) for costs
Reuse local supplies	Urban reuse (recycling)	0	N/A	16	$396	$2,898	$5,800	$396	$2,898	$5,800	SWRCB (2015) and own calculation for availability and CPUC (2016) for costs
	Oil and gas wells	0	N/A	8	$100	$1,196	$50,000	$100	$1,196	$50,000	Department of Conservation (2017) for availability and Arthur et al. (2005) and Fakhru'l-Razi et al. (2009) for costs

Figure B2 highlights the ranges of increased water availability and presents costs with different colors. For options that can be built as single projects (such as reservoirs), the color represents the total cost per acre-foot, accounting for co-benefits. For options that involve multiple small projects (such as groundwater recharge or urban conservation), we assume the total amount of water available will be provided by multiple projects with different costs from the range provided in the literature review.[28] Estimates for options where the ranges appear in a lined pattern have high uncertainty.

The potential new water that is least expensive mostly comes from capturing local runoff, especially with groundwater recharge and reoperating reservoirs. Temperance Flat might provide a significant amount of water to the valley, but has uncertainties on increased water availability and costs that might make the project uneconomical. Forest management is expensive if considered only for water supply.

Most options for expanding water imports will be expensive and unlikely to provide much additional water. WaterFix, as a single option, could significantly increase water availability, but with potentially prohibitive costs for farmers in the valley. Only reoperation of Central Valley surface and groundwater resources (including the optimization of operations of the Central Valley Project and State Water Project) seems affordable for farmers.

Urban conservation, both to reduce local demands in the San Joaquin Valley and exports to coastal regions, could provide some affordable water. But relatively little of this water would be available for valley farms if cities reserve most of these savings for future urban population growth—and cities may wish to hold on to these incremental supplies as a hedge against drought and future growth. Urban wastewater reuse in the valley would not provide sizable new water to the basin.

Some increases in water supply availability for the San Joaquin Valley are possible and affordable, but a balance of water use and supplies for the valley will also require considerable reductions in agricultural water use. Technical Appendix C examines the costs of this water use reduction, and Technical Appendix D examines the likely portfolio of supply and demand options that will minimize costs for the regional economy.

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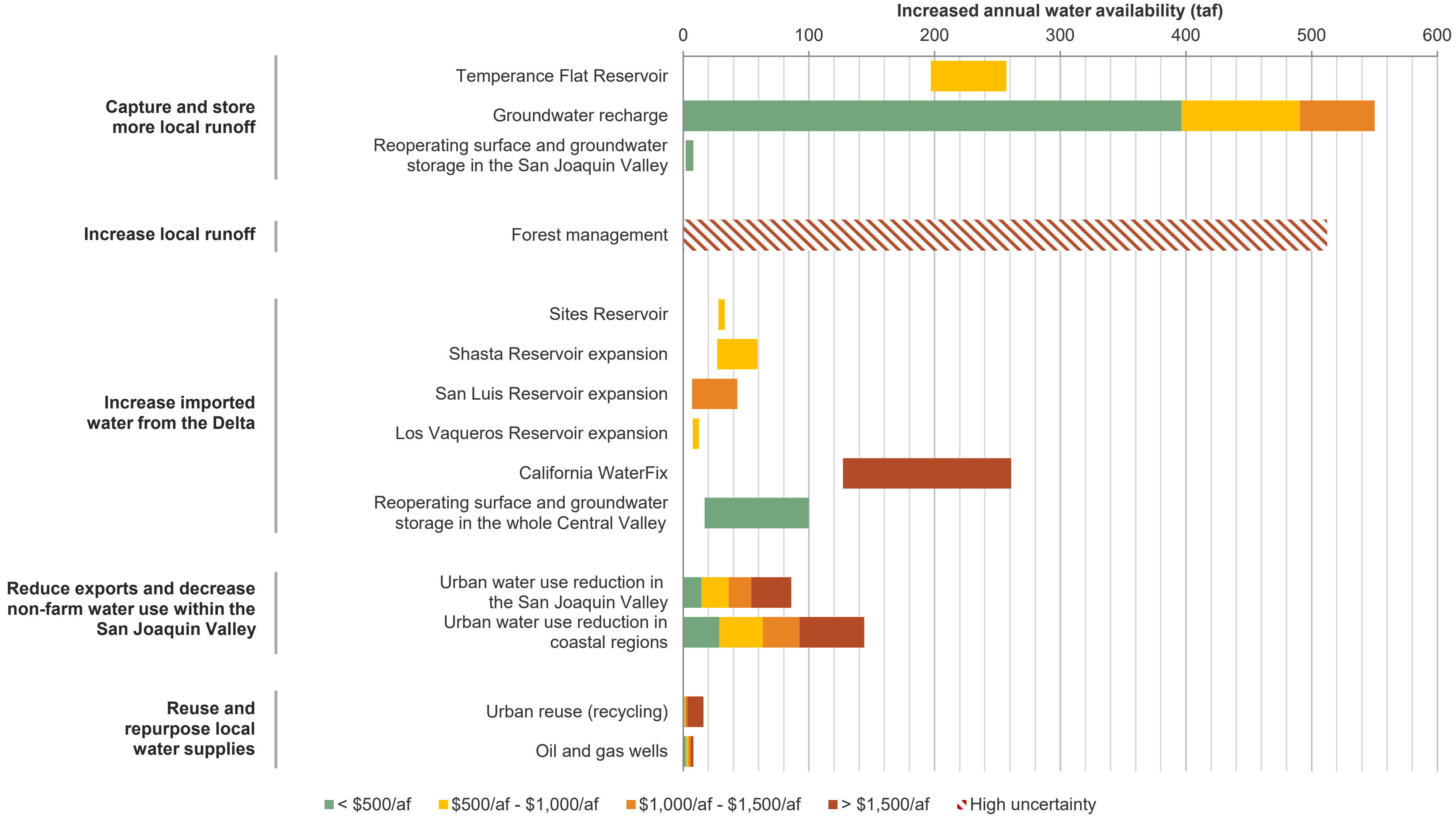
[28] Technical Appendix D describes in more detail the specifics of single project and multiple project cost estimates.

FIGURE B2

Supply ranges and costs of the water supply options considered



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