Replenishing Groundwater in the San Joaquin Valley: 2024 Update

Technical Appendix

CONTENTS

Supported with funding from the S. D. Bechtel, Jr. Foundation, the Kingfisher Foundation, the Laural Foundation, Sustainable Conservation, and the Water Foundation

Appendix A. PPIC's 2023 Groundwater Recharge Survey

Introduction

This appendix describes the design and deployment of PPIC's 2023 Groundwater Recharge Survey, a follow up to a similar survey conducted by the PPIC Water Policy Center in the fall of 2017 (Hanak et al. 2018, *Replenishing Groundwater in the San Joaquin Valley*). The survey covered groundwater recharge practices, volumes of water applied, barriers and enablers, and local manager priorities for expanding recharge in California's San Joaquin Valley. Here we provide information on the characteristics and representativeness of the survey respondents according to key variables, including region, surface water availability, presence or absence of recharge basins, and size of the responding organizations. We then discuss estimation of groundwater recharge volumes for the region as a whole, building on survey results. The full list of survey questions can be found at the end of the appendix. The main report accompanying this appendix, *Replenishing Groundwater in the San Joaquin Valley: 2024 Update*, summarizes the survey results.

Survey Design and Deployment

Survey Design

The 2023 survey was designed to replicate PPIC's 2017 Groundwater Recharge Survey (described in technical appendix B to Hanak et al. 2018), with a few modifications and additions to capture changes in the context for recharge since 2017. As in 2017, the 2023 survey instrument was developed with input from water managers, state agency staff, growers, NGO partners, and other experts in the field.

We again used Qualtrics, an online survey platform, to host the survey instrument. The survey included 24 questions, both multiple choice and free response, and took anywhere from 10-20 minutes to complete.

Distribution was conducted via emails containing individualized links from October–December 2023. The emails were sent to official points of contact for the region's groundwater sustainability agencies (GSAs), with an invitation to either complete the survey themselves or to forward the links to the appropriate staff person or—in the case of multi-party GSAs—member water agency for completion. Respondents also had the option to fill out a PDF version of the survey instead of the online version. Respondents were asked to specify the name of the organization(s) on whose behalf they were answering the survey, but were informed that individual survey responses would remain confidential and anonymous. Several rounds of follow-ups were conducted from December 2023 through January 2024 to encourage responses and clarify some answers before the survey was officially closed out at the end of January 2024.

The survey asked respondents to indicate whether they would be interested in participating in a focus group to discuss initial findings, and those expressing interest were invited to an online meeting on April 24, 2024. A dozen water managers from across the valley joined this meeting.

Sampling Frame

As in 2017, we sought to send the survey to all agricultural and urban water agencies on the San Joaquin Valley floor—the region that includes 15 groundwater sub-basins that are subject to the Sustainable Groundwater Management Act (SGMA). We compiled the list of agricultural water agencies from a variety of sources, and identified agencies classified as urban (those submitting urban water management plans, generally serving at least 3,000 connections or delivering at least 10,000 acre-feet of water) with information from the Department of Water Resources (for more details see Technical Appendix B to Hanak et al. 2018, *Replenishing Groundwater in the San*

Joaquin Valley). The sampling frame that received the survey in 2017 included 202 local water agencies—151 agricultural agencies and 51 urban agencies.

Between the 2017 and 2023 surveys, new groundwater sustainability agencies (GSAs) had begun overseeing groundwater management across all the lands within groundwater basins subject to SGMA—including the entire valley floor. The fall 2017 survey took place just after the summer 2017 deadline for GSA formation, and many of these new agencies were still in early formation stages. By fall 2023 they were fully operational. They had already prepared and submitted their groundwater sustainability plans (January 2020 for the region's 11 critically overdrafted basins and January 2022 for the four other priority basins), and they had begun plan implementation, in some cases taking on coordination roles over groundwater recharge activities. Whereas some GSAs cover an individual agricultural or urban water agency, others cover multiple agencies. GSAs now also cover lands not previously covered by local water agencies. These "undistricted lands"—typically heavily or entirely reliant on groundwater—had not been covered by the 2017 survey.

Our 2023 survey again sought to include all relevant local water agencies, so we included all GSAs and their members. We built the 2023 sample frame starting with the comprehensive list of local agricultural and urban water agencies developed for the 2017 survey. To supplement the 2017 list with entities now represented by GSA membership, we consulted the California Department of Water Resources (DWR) "SGMA Portal," which provided information on GSAs, their member agencies, and points of contact. We then cross-referenced the list of GSAs and member agencies with agencies who received the 2017 survey to ensure coverage and confirm GSA membership of previously included entities.

Under SGMA, full membership in GSAs is limited to public agencies, so private entities do not appear in the list of members on the SGMA Portal. We nevertheless included private agricultural and urban water providers that operate within the valley's groundwater basins, as in 2017. We did drop several of these entities from the 2023 sample frame because we could not obtain current contact information (notably for some private ditch and canal companies). We also dropped several entities from the 2017 sample frame because we determined that they are located outside of the valley floor—our area of interest in this study.

The 2023 sample frame included 279 local agencies: 193 agricultural water agencies and 86 "urban" agencies (serving urban or smaller communities). The number of local agencies is higher than in 2017 for two primary reasons: it now includes the formerly undistricted lands (primarily agricultural) that are now covered by GSAs, and it also has a larger number of "urban" agencies because some GSAs include smaller community water systems.

In addition to an array of water districts and municipal water suppliers, local agencies now include nine county governments, most of which are members of more than one GSA.[1] Sometimes counties serve as the lead agency for undistricted lands, and in other cases they represent community water suppliers (e.g., community service districts) or other lands within a larger GSA. For the analysis, we considered counties as agricultural or urban depending on their primary purpose in different GSAs. The sample frame tally of 279 local agencies includes other agricultural and urban agencies only once, even if they appear in multiple GSAs or basins. In contrast, counties are considered as unique agencies in each GSA and basin in which they are present (in all, a total of 37 times across all nine counties), as their coverage and role may differ in each basin.

The 279 local agencies included in the sample frame are nested within 101 GSAs, including 81 primarily agricultural GSAs and 20 urban GSAs.[2] Sixty GSAs correspond to a single agricultural or urban agency, while 41 contain

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[1] This includes all eight counties that occupy the San Joaquin Valley floor—Fresno, Kern, Kings, Madera, Merced, San Joaquin, Stanislaus, and Tulare—plus Mariposa, a small portion of which overlaps part of the Merced basin.

[2] For purposes of some analysis, we classified multi-party GSAs as agricultural if they included large agricultural entities, even if they also included some urban members. In total, 38 primarily agricultural GSAs represented some 151 agricultural agencies and 54 mostly smaller urban agencies.

anywhere from two to 15 members. We initially sent the survey to points of contact for each of the 101 GSAs. Multi-party GSAs could submit one survey response on behalf of all or some of their member agencies, or provide us with contact information for individual member agencies, whom we then invited to submit responses for themselves. Our tallies of agency response rates, described below, take into account which members were included in multi-party responses.

Representativeness of Survey Responses

We received responses covering 128 local agencies out of the 279 surveyed, a 46 percent overall response rate. This total includes individual responses for 45 agencies, and grouped responses from 14 multi-party GSAs, which represent 83 agencies. This is a higher response rate than in 2017, where we received 81 responses from individual agencies (40% of those who received the survey). Six counties appear anywhere from two to six times in the sample frame, and while a few directly supplied responses to the survey for different management areas, most either did not respond (54%) or were represented by multi-party GSA responses (35%).[3]

TABLE A1

Characterization of survey responses in 2023

2023 Survey Responses	
Local agencies in sample frame	279
Local agencies covered by responses	128
Agencies covered by individual agency responses	45
Agencies covered by 14 grouped multi-party GSA responses	83
2023 Responses Compared to 2017	
Responded in both 2023 and 2017	38
Responded only in 2023	48
New to survey in 2023	42
Total responses in 2023	**128**
Responded only in 2017	35

SOURCE: PPIC 2023 Groundwater Recharge Survey. See text for details.

Although there was overlap between the agencies covered by survey responses in the two years, there were also differences. Thirty-five agencies that responded to the 2017 survey did not respond to the 2023 survey, either individually or as members of a multi-party GSA; 38 responded in both years; 48 were surveyed in both years but only responded in 2023; and 42 agencies that were new to the sample frame in 2023 provided responses.

Most (68%) of the new responses in 2023 were from agencies represented by multi-party GSAs. New responses were more likely to come from agencies with less access to surface water: 40 percent were from agencies with access to less than 10,000 af/year, and 33 percent were from groundwater-only agencies. New responses were also more likely to come from agencies in the southeast (43%) and northeast (26%) (see Figure A5 below for a map).

The relatively small number of overlapping responses between the two survey years makes it difficult to make precise comparisons of responses between 2017 and 2023—especially since some agencies' responses in 2023 are grouped in

[3] Counties appearing multiple times in the sampling frame include Fresno, Kings, Madera, Merced, San Joaquin, and Stanislaus.

multi-party GSA responses, which further lowers the response count. We do know, however, that we received responses in both years from many of the valley's large groundwater rechargers.[4] This gives us confidence that we are capturing most significant recharge activity. More generally, the survey's broad coverage of suppliers of different types in different parts of the valley in both years provides a window into how other local agencies are engaging in—or thinking about—this water management practice. Overall, the recharge volumes reported by survey respondents accounted for about 70% of the total estimated valley-wide recharge volumes in 2023, as compared to 63% in 2017 (see below for calculation of valley-wide recharge estimates).

Below we review the representativeness of 2023 responses according to five different variables: 1) supplier type classification (agricultural vs. urban), 2) size, including service area (for agricultural agencies) and population served (for urban agencies), 3) surface water availability, 4) existence of recharge basins, and 5) subregion. In general, we compare the distribution of agencies included in the sample frame and agencies included in responses, with the latter broken into those that responded individually or as part of multi-party GSAs.

For the analysis of survey results presented in the main report, we typically use the number of responses—rather than the number of agencies represented—as the unit of analysis. This approach avoids weighting multi-party responses by their agency count—which could bias results if not all agency members are engaging in a particular recharge-related practice, for instance. But it does mean that agencies that replied individually are weighted the same as each multi-party group that replied.[5] In the discussion of two key variables used in the analysis—surface water availability (Figure A3) and subregion (Figure A6)—we show how this affects agency representation, by displaying the distribution of responses alongside the distribution of agencies included therein.

Supplier Type Classification

As in 2017, response rates were higher for agricultural than urban water agencies: of 193 agricultural agencies surveyed, 51 percent responded; of the 86 urban agencies surveyed, 38 percent responded. In both cases, these rates were up slightly from the 2017 survey. Urban and agricultural agencies tend to have different patterns of recharge activity, so we sometimes discuss results separately for these two groups.

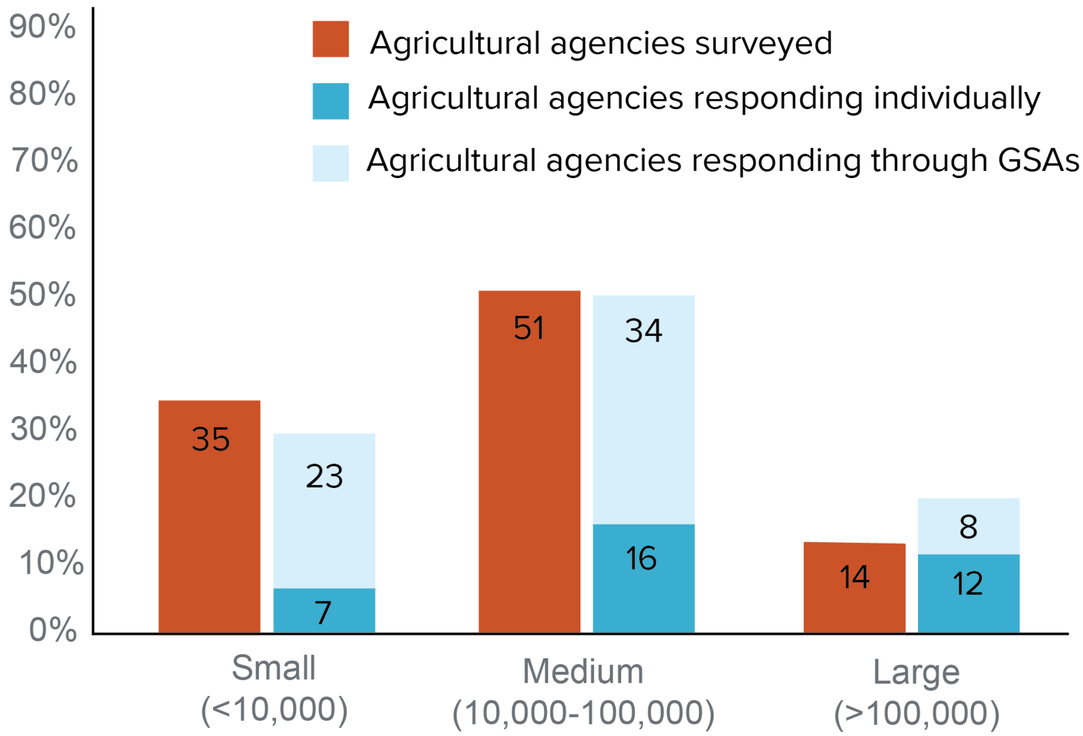
Size

One way of gauging the representativeness of agricultural suppliers' responses is by service area acreage—a metric we developed using information from GIS files, agency planning documents, and groundwater sustainability plans (Figure A1). As in 2017, suppliers with larger service areas are slightly overrepresented in the survey responses, as indicated by the greater height of the stacked blue bar compared with the corresponding orange bar. The opposite is true for underrepresented smaller agencies, where the orange bar is taller than the blue bar. A higher proportion of responses from larger suppliers came from individual agencies, rather than multi-party GSAs responding on behalf of their members.

[4] The agencies who responded to the survey in both years accounted for roughly 90 percent of onsite recharge volumes reported in 2017, and 65 percent of volumes reported in 2023.
[5] In the data analysis, we aggregate relevant information for multi-party responses—for instance, we use the aggregate volume of surface water for the group. But the group's response counts as a single response.

FIGURE A1

Comparison of agricultural agencies surveyed and respondents by service area size (acres)



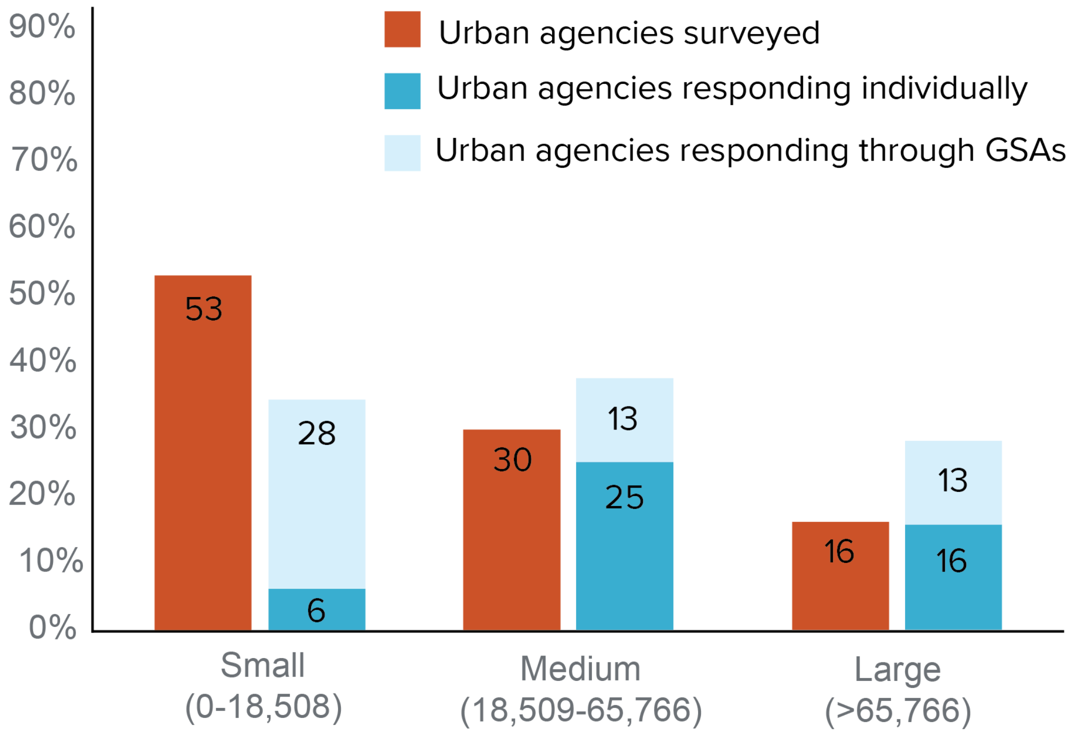
SOURCE: PPIC 2023 Groundwater Recharge Survey.

NOTES: The orange bars show the distribution of service area size (in acres) for 180 of the 193 agricultural water agencies that were surveyed (area data were not available for the other 13). The blue bars show the corresponding distribution of the 91 agencies for whom we received responses, either from individual agencies (darker blue) or as part of multi-party GSA responses (lighter blue). For counties appearing in multiple basins and GSAs, service area was calculated as the amount of undistricted land corresponding to that county within a given basin's and GSA's boundaries. Orange bars representing surveyed agencies sum to 100 percent. Stacked blue bars representing agencies covered by individual and multi-party GSA responses also sum to 100 percent.

For urban entities, we used population served as a metric of agency size. Compared to 2017, when we surveyed 51 urban agencies, our sample frame was larger in 2023 (86 agencies)—and it included many smaller drinking water providers that are part of multi-party GSAs. The higher share of small agencies surveyed in 2023 can be seen in Figure A2, which uses size categories representing quartiles of the population served by urban agencies surveyed in 2017: small is the smallest quartile, medium is the two middle quartiles, and large is the largest quartile. Whereas only one-quarter of the urban agencies surveyed in 2017 were in the small population bin (those with a population served of 18,509 or less), over half of all suppliers surveyed in 2023 were in this bin. Relative to the share of agencies surveyed (orange bars), larger urban agencies (those with a population served of more than 65,766) were more likely to respond to the survey than smaller agencies, and more likely to do so through individual responses (dark blue bars)—rather than multi-party GSA responses (light blue bars). The reverse is true for the smallest agencies.

FIGURE A2

Comparison of urban agencies surveyed and respondents by population served



SOURCE: PPIC 2023 Groundwater Recharge Survey.

NOTES: The population categories are those used in the 2017 survey to show quartiles of the 51 urban agencies included in that sample frame: small was the first quartile, medium was the two middle quartiles, and large was the largest quartile. The 2023 sample frame includes more agencies that supply drinking water to communities (86)—including many that are smaller than the threshold to be considered an urban water supplier under California law. In 2023, we received responses for 33 agencies (38%). Orange bars representing surveyed agencies sum to 100 percent. Stacked blue bars representing agencies covered by individual and multi-party GSA responses also sum to 100 percent.

Surface Water Availability

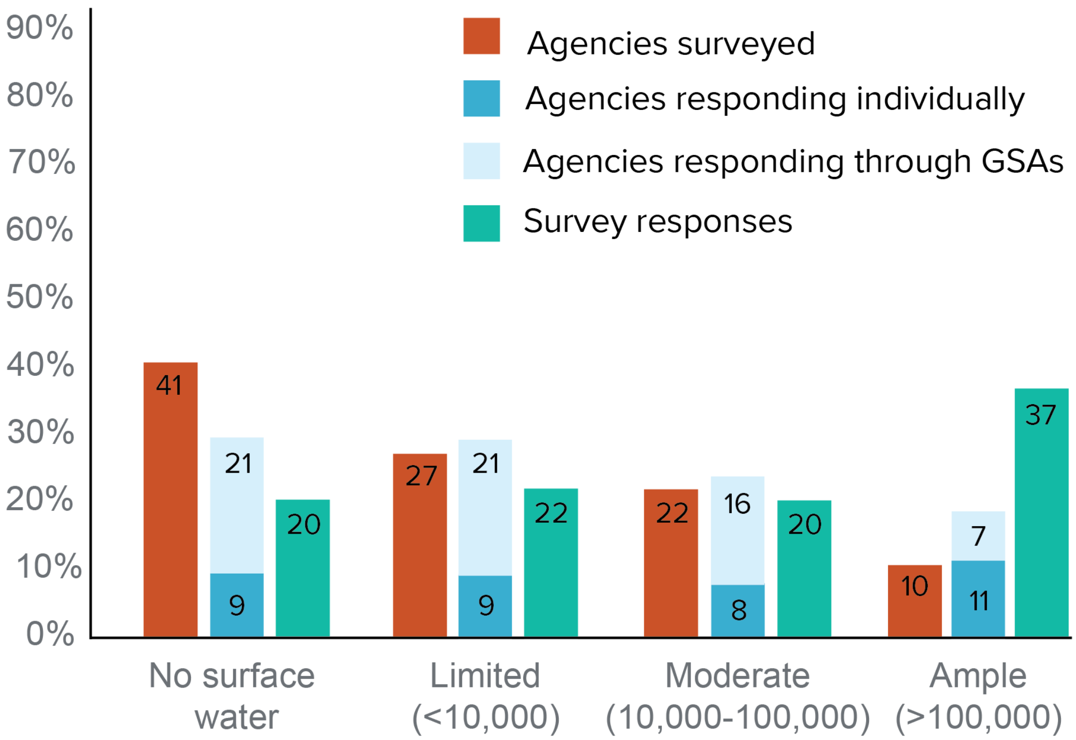
The amount of surface water that an agency has access to can be an important factor in the volumes it is able to apply towards recharge. For agencies surveyed in 2017, we used information on average water deliveries during the 2005–08 period—which includes a mix of wet, dry, and normal years—to categorize them by surface water availability in terms of acre-feet (af) of deliveries per year. This information was sourced from Central Valley Project, State Water Project, and local water agency and river association records. For agencies that are new to the 2023 sample frame, we sought to provide comparable information, drawing from groundwater sustainability plans and other public sources, including agency websites. As noted above, many of these new agencies have little or no access to surface water.

As in the earlier figures, Figure A3 presents information on the distribution of the agencies included in the sample frame (orange bars) and agencies providing responses individually (dark blue bars) or as part of multi-party GSAs (light blue bars) for different levels of surface water availability. Because surface water access is a key variable for the analysis of survey responses, we also show the distribution of survey responses—i.e., how the 59 individual and multi-party responses are distributed across the three size categories (green bars).

In general, agencies with access to large volumes (>100,000 af/yr) of surface water were overrepresented in the 2023 survey responses, while entities with no access to surface water (groundwater-only entities) were underrepresented (Figure A3). This roughly mirrors the patterns of responses in the 2017 survey. The survey is now capturing more agencies with little or no surface water: groundwater-only agencies make up a higher share of the agencies surveyed in 2023 (41%, up from 32% in 2017), and a higher share of agencies represented in responses (30% compared to 22% in 2017). The proportion of agencies with small volumes of surface water (<10,000 af/yr) has also gone up slightly (27% of those surveyed, up from 24%; 30% of agencies responding, up from 25%). Because agencies in these two groups are more likely to be represented by multi-party GSAs, however, their share in the survey response count (green bars) is lower (20% and 22%, respectively)—closer to their shares in 2017.

FIGURE A3

Comparison of agencies surveyed, agencies responding, and survey responses by average yearly surface water deliveries (acre-feet)



SOURCE: PPIC 2023 Groundwater Recharge Survey.

NOTES: The figure shows the distribution by four categories of average surface water availability (in acre-feet/year) of the 279 agencies included in the sample frame (orange bars), the 128 agencies included in survey responses either through individual responses or multi-party GSA responses (dark and light blue bars, respectively), and the 59 survey responses (green bars). Orange bars representing surveyed agencies sum to 100 percent, as do stacked blue bars representing agencies included in single-agency and multi-party GSA responses, and green bars representing survey responses.

Operation of recharge basins

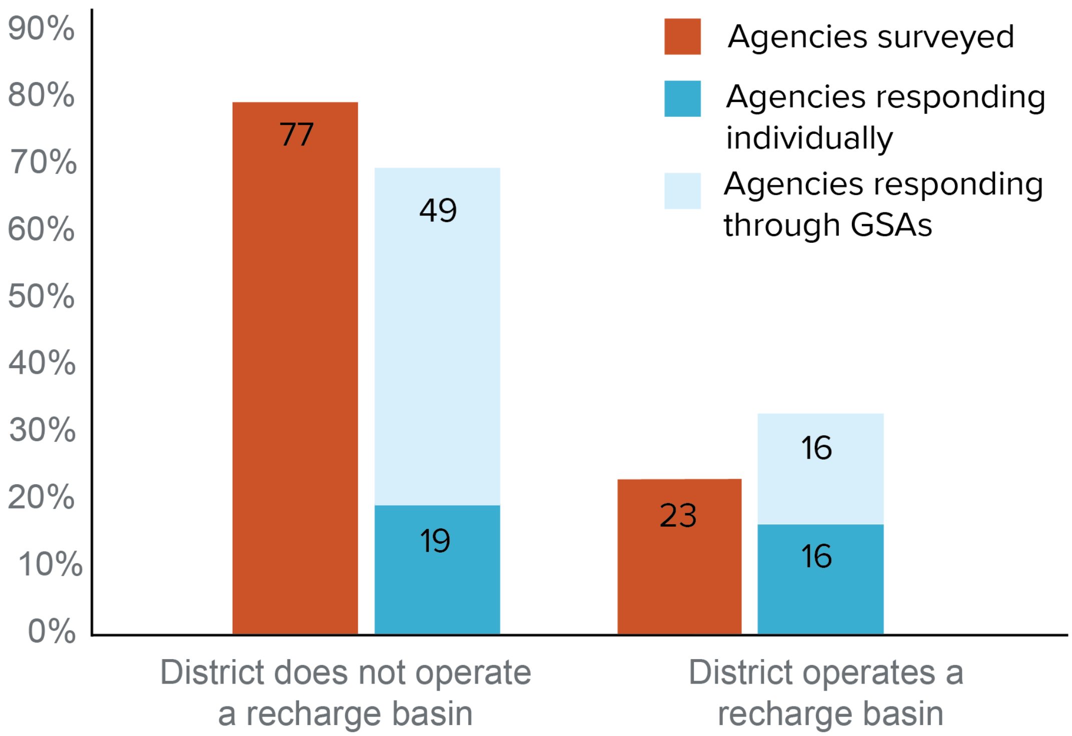
Local agencies' recharge programs are in various stages of development across the valley. Agencies with more informal programs tend to use recharge methods that leverage existing infrastructure, such as in-lieu recharge or recharge via unlined canals and streambeds. In contrast, more formal programs are often characterized by the construction and operation of dedicated recharge basins. As described in the main report, survey results indicate that these basins were responsible for the largest share of the total volume recharged in both 2017 and 2023.

As in 2017, we used a variety of public data sources to identify whether agencies in the sample frame had dedicated recharge basins in 2023. The share with recharge basins was similar in both years (23% in 2023, versus 22% in 2017) (Figure A4). And in both years, agencies that own/operate a recharge basin were somewhat more likely to be represented in survey responses. A larger proportion of survey respondents that do not own/operate a recharge basin were part of a multi-party GSA response.

Our updated data on recharge basins are consistent with other information pointing to an increase in the availability of this infrastructure in the valley since 2017. Although the share of valley agencies with recharge basins was similar across the two survey years, the larger number of agencies surveyed in 2023 points to a larger number of agencies with this capability: 64 agencies in our 2023 sample frame, versus 44 agencies in 2017. As described in the main report, responses to the 2023 survey provide other indications of capacity expansion: over half of all rechargers reported that they had increased their recharge capacity since 2017; a larger share of respondents reported using recharge basins in 2023 than in 2017; and the reported volumes of recharge using this method were up.

FIGURE A4

Comparison of agencies surveyed and respondents by operation of recharge basins



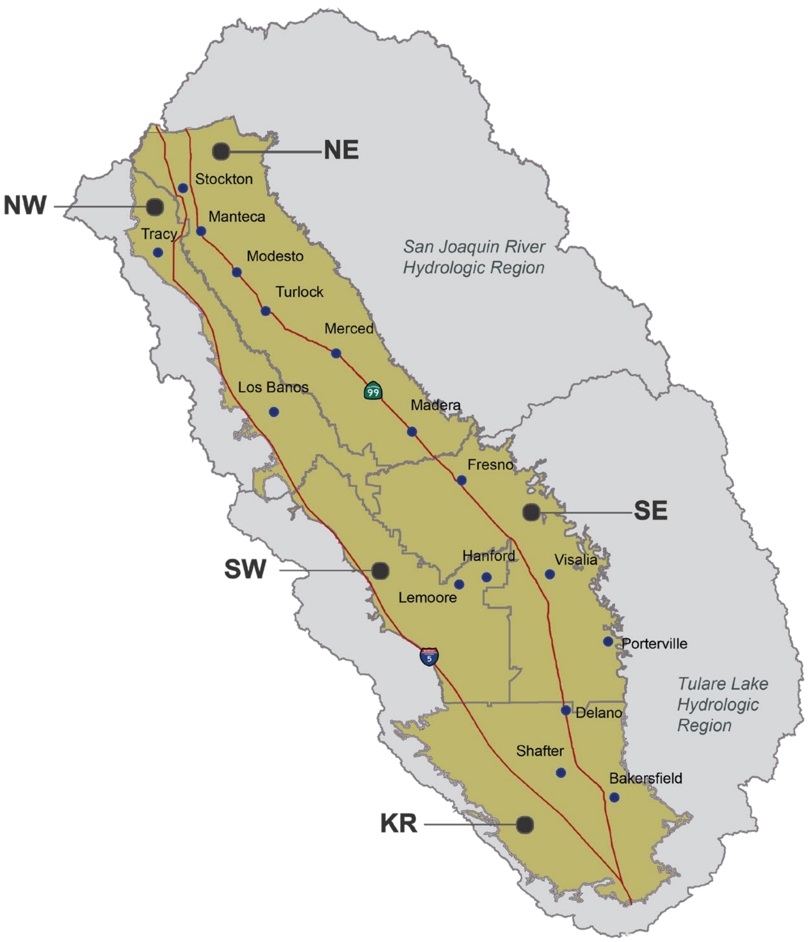
SOURCE: PPIC 2023 Groundwater Recharge Survey.

NOTES: The figure shows the distribution of the 279 agencies included in the sample frame (orange) and the 128 agencies included in survey responses (blue) in the 2023 survey. Orange bars representing surveyed agencies sum to 100 percent. Stacked blue bars representing agencies covered by individual and multi-party GSA responses also sum to 100 percent.

Subregion

To protect the confidentiality of agencies responding to the survey, we only report geographic results by five subregions—two in the San Joaquin River hydrologic region (northwest and northeast) and three in the Tulare Lake hydrologic region (southwest, southeast, and Kern) (Figure A5). Figure 1 in the main report shows summary measures of annual groundwater overdraft and soil suitability for recharge for each of these subregions.

FIGURE A5
Subregions used for reporting and analysis



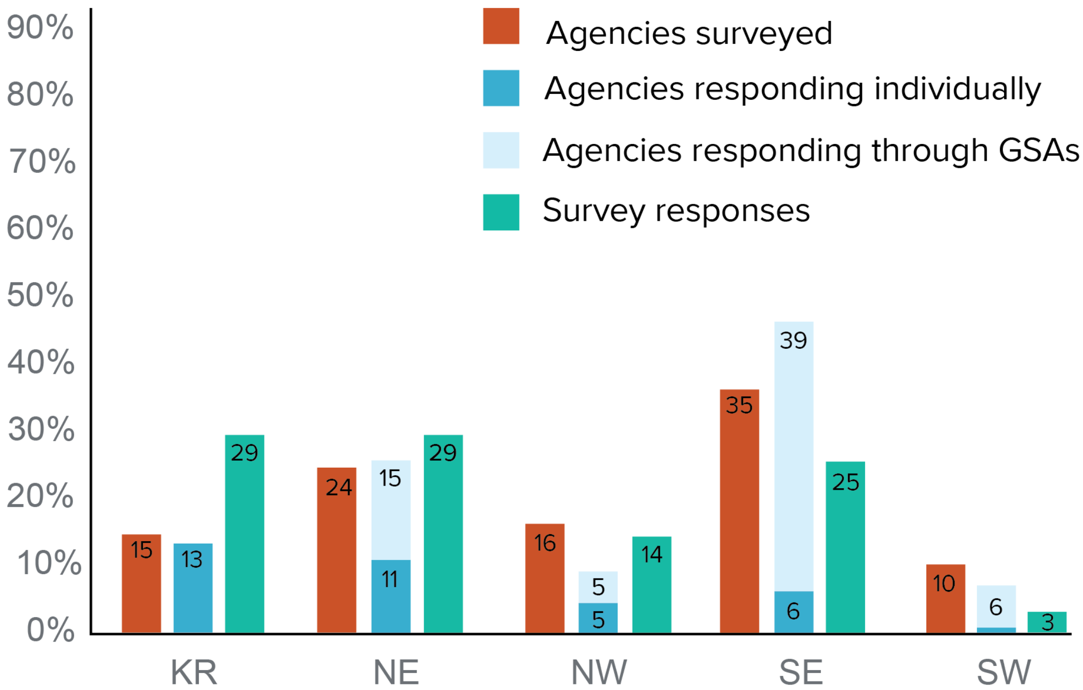
SOURCE: PPIC 2023 Groundwater Recharge Survey

NOTES: The map depicts the San Joaquin Valley's two hydrologic regions, including headwaters (gray) and valley floor (tan), and divides the region's 15 groundwater basins on the valley floor into five subregions: the northeast (NE) includes Eastern San Joaquin, Modesto, Turlock, Merced, Chowchilla, and Madera basins; the southeast (SE) contains Kings, Kaweah, and Tule groundwater basins; Kern (KR) contains the Kern and White Wolf basins; the southwest (SW) contains Tulare Lake and Westside basins; and the northwest (NW) contains the Delta-Mendota and Tracy basins.

As in Figure A3, Figure A6 reports the distribution of agencies surveyed (orange) and agencies represented in responses (blue), as well as the distribution of the 59 individual and multi-party survey responses (green). Compared to 2017, the 2023 sample frame (orange) includes a slightly larger share of agencies in the northeast (+3%), northwest (+3%), and southeast (+5%), and a smaller share of agencies in the southwest (–10%). Across regions, the proportion of agencies represented in responses (blue) was fairly similar to their proportion of agencies surveyed (orange), although agencies in the southeast (SE) were slightly overrepresented and those in the northwest (NW) and southwest (SW) were slightly underrepresented. Looking just at survey responses (green), Kern plays an outsized role, given the larger number of individual responses there. Compared to our 2017 survey responses, the most striking differences are relatively stronger representation of agencies in Kern and the northeast (NE), and a corresponding drop in the southwest.

FIGURE A6

Comparison of agencies surveyed, agencies responding, and survey respondents by subregion



SOURCE: PPIC 2023 Groundwater Recharge Survey

NOTES: The figure shows the distribution of the 279 agencies included in the sample frame (orange), the 128 agencies included in survey responses (blue), and the 59 survey responses from individual agencies and multi-party GSAs (green). Orange bars representing surveyed agencies sum to 100 percent, as do stacked blue bars representing agencies included in single-agency and multi-party GSA responses, and green bars representing survey responses.

Estimates of Valley-Wide Recharge Volumes in 2023

We asked water managers to supply estimates of the volumes of water they applied for recharge in 2023, along with the methods used. Total on-site active recharge reported was 5.3 maf.[6] Of 59 total survey responses, 33 respondents provided non-zero volumes of recharge, and another 11 reported no recharge activity; the balance (15) indicted some recharge activity, but did not report volumes.

Although we captured most of the known major rechargers in the valley, we missed activity from rechargers who did not report volumes or did not respond to the survey. As in 2017, we did a simple regression analysis to provide a rough estimate of the total volume of active on-site recharge in the valley. This section describes data and methods used in this analysis, presents results, and discusses how these estimates compare with our estimates for 2017.

Regression method for predicting recharge volumes

To estimate valley-wide recharge volumes, we applied a linear regression to the characteristics of survey respondents that provided volumes and used the results to predict estimated volumes for the 148 agencies that either did not report recharge volumes or did not respond to our survey.

We ran regressions using the natural log of on-site recharge volume as the dependent variable. We used four predictor variables that were available for the entire sample frame: subregion, average yearly surface water deliveries (scaled to natural logs), supplier type (agricultural or urban), and whether the entity owns or operates a recharge basin (Table

[6] This total likely includes most of the 0.5 maf that some agencies reported storing off-site through partnerships with other agencies.

A2). To allow use of natural log scales, we set zero levels of recharge volume and surface water availability to 1 acre-foot. Table A3 provides descriptive statistics for all variables included in the regressions.

TABLE A2

Predictor variables used in regression analysis

Variable	Description
Average surface water supply	Natural log of average annual surface water supply available to local agency from all sources
Agency has recharge basin(s)	Binary variable that equals 1 if the agency owns and operates one or more recharge basins
Type of water supplier	Binary variable that equals 1 if the agency serves urban (or smaller) communities, and 0 if it serves agricultural customers
Subregion	Binary variables for four of the five subregions: Southeast, Southwest, Northeast, Northwest (with Kern as the baseline category)

TABLE A3

Regression sample descriptive statistics

	Mean	Standard deviation
On-site recharge volume (acre-feet)	120,241	162,419
Average surface water supply (acre-feet)	126,494	163,633
Agency has recharge basin(s)	0.57	0.50
Urban water supplier	0.2	0.4
Kern basin (baseline subregion)	0.34	0.47
Southeast	0.25	0.43
Southwest	0.02	0.15
Northeast	0.25	0.43
Northwest	0.14	0.34

SOURCE: PPIC 2023 Groundwater Recharge Survey. See text for details.

NOTES: The regression sample includes 44 observations from agencies that reported positive or zero recharge volumes. For categorical variables, means correspond to the proportion of the sample in each category.

Results and comparison with 2017

Table A4 presents the results of the regression analysis. Regression coefficients indicated that higher volumes of recharge were associated with agencies that have recharge basins, agricultural agencies (the baseline agency type for the regression formula), and agencies in Kern (the baseline region). The coefficient on surface water availability is also positive—indicating association with higher recharge volumes—though not statistically significant. The overall fit for the regression was good for cross-sectional analysis, with adjusted $R^2=0.49$ and $p<0.001$.

TABLE A4

Regression analysis estimating the volume of on-site recharge in 2023

Predictor variable	Estimate (SE)
Ln average surface water supply	0.141 (0.174)
Supplier type	
Agricultural	-----
Urban	-3.488 (1.727)**
Subregion	
Kern	-----
Southeast	-3.467 (1.510)**
Southwest	-0.816 (3.819)
Northeast	-1.749 (1.559)
Northwest	-7.010 (2.065)***
Recharge basin	
Responder does not have recharge basin	-----
Responder has recharge basin	3.055 (1.373)**
N	44
Adj R^2	0.49

SOURCE: Author estimates (see text).

NOTES: The table reports regression coefficients for each variable, with standard errors in parentheses. Statistical significance at the 99 and 95 percent levels are represented by ** and *, respectively.

To estimate predicted recharge volumes for the 148 agencies for which we do not have recharge volumes, we applied the coefficients in Table A4 to these agencies' characteristics, summarized in Table A5.

TABLE A5

Extrapolation sample descriptive statistics

	Mean	Standard deviation
Average surface water supply (acre-feet)	15,750	38,008
Agency has recharge basin(s)	0.15	0.36
Urban water supplier	0.36	0.48
Kern basin (baseline subregion)	0.14	0.35
Southeast	0.28	0.45
Southwest	0.13	0.33
Northeast	0.23	0.42
Northwest	0.22	0.42

SOURCE: PPIC 2023 Groundwater Recharge Survey. See text for details.

NOTES: The extrapolation sample includes 148 observations from agencies that recharged but did not provide information on amounts and agencies that did not respond to the survey. For categorical variables, means correspond to the proportion of the sample in each category.

Aggregating the reported and predicted recharge volumes, this suggests that total valley-wide on-site recharge in 2023 was roughly 7.6 maf. Based on our earlier estimates of recharge in 2017, this also suggests that valley-wide recharge may be up by 17 percent. In that year, we estimated total on-site recharge to be 6.5 maf, including reported volumes of 4.1 maf.[7]

The estimated increase of valley-wide recharge by 17 percent between 2017 and 2023 falls within the range of estimates obtained from other results from the 2023 survey. We asked respondents how their recharge activity in 2023 compared with 2017, with possible answers including: much more this year (>25%), a little more this year (10–25% more), about the same (+/- 10%), a little less this year (10–25% less), and much less this year (more than 25% less). We estimated the change in recharge for survey respondents by applying their answers to this question (using upper and lower bounds for each range)[8] to the volumes they reported for 2023. This method suggests that overall recharge between the two years increased by at least 12 and as much as 23 percent.[9]

[7] The volumes reported in 2023 were a slightly higher share of the estimated total (69%, versus 63% in 2017), which is consistent with the higher overall survey response rate in 2023 (46%) than in 2017 (40%).

[8] We used a range of 30–45 percent for the "much more" category in these calculations. No one responded that they recharged "much less."

[9] To estimate these ranges, we took into account the volume of recharge by those who did not recharge in 2017, treating their recharge in 2017 as zero. The total increase compared to 2017 would be higher than 23 percent if survey responses underrepresent new rechargers and if those who responded that they recharged "much more" in 2017 increased recharge by more than 45 percent on average.

2023 Survey Questionnaire

SAN JOAQUIN VALLEY GROUNDWATER RECHARGE SURVEY

Thank you for agreeing to participate in this survey, which aims to obtain first-hand input from San Joaquin Valley water managers regarding groundwater recharge challenges, practices, and opportunities. A similar PPIC survey was conducted in 2017. The results will inform a public document that identifies policies, regulations, and funding tools to support groundwater recharge activities in the region. We have developed the questions in consultation with water managers from across the Valley.

The survey is designed to take about 10-15 minutes to complete, and it covers the following topics:

1. Current and potential groundwater recharge methods in your service area,
2. Groundwater recharge activities this year (e.g., recharge volumes),
3. Barriers to groundwater recharge (e.g., infrastructure, regulatory, financial issues), and
4. Priorities for expanding your system's potential to engage in groundwater recharge.

At the end of the survey, we also ask you to indicate if you would be interested in participating in a focus group discussions of preliminary results, to inform conclusions and recommendations in our report. **We will maintain confidentiality of individual responses, and present results such that no organization-specific identifiers will be publicly available.**

A printable PDF version of the survey is available upon request by emailing morales@ppic.org. If you prefer, you may print and complete a hard copy of the survey and return by:

- Sending a scanned copy to morales@ppic.org OR
- Mailing a paper copy to Zaira Joaquín Morales, PPIC;
  1121 L St., Unit 801; Sacramento CA 95814

What organization(s) are you answering this survey on behalf of?

CURRENT AND POTENTIAL GROUNDWATER RECHARGE METHODS

[Q1] What methods of active groundwater recharge does your organization currently practice—or envision practicing or expanding in the future? (Please check all that apply.)

	Currently Used	*Potential to expand*
Dedicated recharge basins	☐	☐
In-lieu recharge (i.e., using surface water instead of groundwater in wetter years)	☐	☐
Recharge in stormwater basins	☐	☐
Recharge on cropland (e.g., extra irrigation, winter flooding)	☐	☐
Recharge on fallowed farmland	☐	☐
Recharge on floodplains, open space, or other natural lands	☐	☐
Recharge via unlined canals / stream beds	☐	☐
Injection wells / ASR (aquifer storage and recovery)	☐	☐
Recharge under cropland (e.g., reverse tile drainage)	☐	☐
None	☐	☐

[Q1.1] Please feel free to list other recharge methods we've overlooked, and/or elaborate on any of the answers above.

[Q1.2] Does your organization currently engage in partnerships to bank groundwater with off-site partners?

- ○ Yes, we bank water for our customers off site in other districts
- ○ Yes, we bank water locally on behalf of off-site partners
- ○ No

ACTIVE GROUNDWATER RECHARGE THIS YEAR

[Q2] Has your organization actively recharged groundwater this calendar year (starting January 2023 through the end of 2023)?

- ○ Yes
- ○ No

[Q3] Please provide the estimated volume of water applied for recharge in 2023 (January 2023 through the end of 2023):

Recharge to date (*acre-feet*): ______

Additional recharge expected (*acre-feet*): ______

[Q4] Please provide the approximate percentage of total recharge in 2023 by method:

	Percentage %
Dedicated recharge basins	
In-lieu recharge (i.e., using surface water instead of groundwater in wetter years)	
Recharge in stormwater basins	
Recharge on cropland (e.g., extra irrigation, winter flooding)	
Recharge on fallowed farmland	
Recharge on floodplains, open space, or other natural lands	
Recharge via unlined canals / stream beds	
Injection wells / ASR (aquifer storage and recovery)	
Recharge under cropland (e.g., reverse tile drainage)	
Total	

[Q4.1] If you are banking groundwater in 2023 through off-site partnerships, please provide the estimated volume:

For your customers off site (*acre-feet*): ______

Within your district for off-site parties (*acre-feet*): ______

[Q4.2] Please list any recharge methods and approximate percentage(s) that were not mentioned above:

[Q5] What were the sources of water for recharge this year?

	Please check all that apply
CVP water (including Section 215 and Recovered Water Account)	☐
SWP water (including Article 21 water)	☐
Local district water	☐
Other local supplies (including flood flows)	☐
Recycled wastewater	☐
Urban stormwater runoff	☐
Water purchased from another party	☐
Not Applicable	☐

[Q5.1] Were any sources used for recharge this year not listed above? Also, please feel free to elaborate on any of the answers regarding water sources.

[Q6] Which of the following statements is most accurate for your system's physical capacity this calendar year (starting January 2023 through the end of 2023)?

- ◯ We could have recharged more water with our existing capacity
- ◯ We will have used all of our existing capacity
- ◯ Unsure
- ◯ Not Applicable

[Q7] Did you recharge groundwater in calendar year 2017 (the last time this survey was administered)?

- ◯ Yes
- ◯ No

[Q7.1] How did your recharge this calendar year compare to your recharge in 2017?

- ◯ Much more this year (>25% more)
- ◯ A little more this year (10-25% more)
- ◯ About the same (+/- 10%)
- ◯ A little less this year (10-25% less)
- ◯ Much less this year (more than 25% less)

[Q8] Has your physical capacity to recharge increased since 2017?

- ◯ Yes
- ◯ No
- ◯ Unsure
- ◯ Not Applicable

ACCOUNTING AND CREDITS

[Q9] Which accounting methods are you employing to quantify and manage the groundwater recharge process in your area?

	Please check all that apply
Water balance method (input and output tracking)	☐
Direct measurement at the district level (e.g., headgate flow meter, water level monitoring)	☐
Direct measurement at the field level (e.g., flowmeter at turnout)	☐
Remote sensing (e.g., evapotranspiration)	☐
Groundwater modeling and simulation	☐
We do not have a specific accounting method for groundwater recharge	☐

[Q9.1] Please feel free to list other accounting methods you are using below:

[Q10] Is your organization implementing any incentives or credit systems to encourage groundwater recharge by local landowners?

	Please check all that apply
Price reductions for recharge water	☐
Surface water bill reductions to incentivize in-lieu recharge	☐
Groundwater pumping / allocation credits	☐
Lease payments to use landowner's lands for recharge	☐
Flood easement agreements with landowners	☐

[Q10.1] Please feel free to list other incentives or credit systems you use below:

BARRIERS AND ENABLERS TO GROUNDWATER RECHARGE THIS YEAR

[Q11] Did you encounter any barriers to recharging groundwater this year?

	Please check all that apply
Physical barriers	
Capacity constraints in district-level recharge basins	☐
Other district-level capacity issues (e.g., conveyance to recharge locations)	☐
Capacity constraints in system-wide conveyance (e.g., CVP or SWP canals)	☐
Permitting and regulatory barriers	
Challenges obtaining new or expanded water diversion permits	☐
Regulatory issues related to project operation	☐
Regulatory issues related to project construction	☐
Issues related to groundwater quality	☐
Concerns about water migrating to neighboring areas	☐

Please check all that apply

Implementation barriers

- Irrigation constraints (e.g., inability to spread water on drip-irrigated fields) ☐
- Limited farmer knowledge on how to perform recharge ☐
- Farmer concerns about getting credited adequately for on-farm recharge ☐
- Farmer concerns about crop yields ☐
- Costs to farmers for field preparation and monitoring ☐

Cost and funding barriers

- Proposition 218-related difficulties raising local funds to support recharge ☐
- Difficulty accessing state grants to support recharge ☐
- Difficulty accessing federal grants to support recharge ☐
- Price of recharge water too high ☐

No barriers

- None - we did not encounter any barriers ☐

[Q11.1] Please feel free to specify any barriers not listed above and elaborate on any of the selected answers.

[Q12] If you recharged in 2023, did any of the following enabling factors contribute to this activity?

Please check all that apply

- District-level planning/preparation ☐
- District-level incentives or credits for landowners ☐
- Temporary recharge permits from the State Water Board ☐
- Executive orders allowing flood water diversions for recharge ☐
- Technical assistance ☐
- Availability of temporary pumps and siphons ☐
- Local funding (e.g., Proposition-218 approved fees) ☐
- State funding ☐
- Federal funding ☐

[Q12.1] Please feel free to specify enablers not listed above that contributed to your recharge activities and to elaborate on any of the selected answers.

[Q13] In your opinion, what are the top two to three priorities that need to be addressed to expand the potential of your organization or those you serve to engage in groundwater recharge activities in the future? (You can refer to barriers listed above or other issues.)

1

2

3

CONTACT INFORMATION

Thank you very much for your participation.

So that we can contact you for follow-up questions or clarifications, please provide your name and contact information. This information is optional and **will remain confidential.**

Name:

Position:

Phone:

Email:

Would you be interested in participating in a focus group discussion of preliminary survey results with other water managers?

- Yes
- No

We welcome your comments on these topics, as well as comments regarding the questionnaire itself or clarifications of your responses. You may include any written comments in the space below.

Thank you for taking the time to fill out this survey. We greatly appreciate your input, and will send you a copy of the final report when it is released.

Please check below if you would like to subscribe to our publication alerts and blog:

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Appendix B. Estimating Water Available for Recharge in 2017 and 2023

Introduction

In this appendix, we provide estimates of water available for recharge in the San Joaquin Valley in two recent wet years—2017 and 2023—to contextualize the results of our surveys of groundwater recharge in the San Joaquin Valley. To recap, based on our survey results we estimate that managed aquifer recharge amounted to 6.5 million acre-feet (maf) in 2017, and 7.6 maf in 2023 (see appendix A for details). The estimates here provide insights on how much additional water might have been available for capture. We first describe our methodology for calculating uncaptured water that might be available for recharge. We then discuss our findings.

Methodology for Estimating Water Available for Recharge

Our methodology for estimating water available for aquifer replenishment is an update to the approach detailed in technical appendix A of our 2018 report *Replenishing Groundwater in the San Joaquin Valley* (Escriva Bou and Hanak 2018). To estimate Delta outflows originating as runoff from San Joaquin Valley (SJV) watersheds that could have been available for recharge, we consider total daily outflows from the Delta and the San Joaquin River at Vernalis—the only major outlet through which water leaves the valley. We obtained flow data for both stations from the California Department of Water Resources' (DWR's) Dayflow, which is a program for estimating average Delta inflows and outflows.

First, we obtained Delta outflows required to meet water quality standards and other regulations (e.g., maintaining sufficiently low levels of salinity). In our earlier report (Escriva Bou and Hanak 2018), we used a fixed required outflow value 10,000 cubic feet per second (cfs), which was calibrated to match DWR's estimates for water available for replenishment (California Department of Water Resources 2018). Here, we instead use a tiered required outflow value depending on the time of year and conditions, based on the approach for Delta water accounting in Gartrell et al. (2022), *Tracking Where Water Goes in a Changing Sacramento–San Joaquin Delta*.[10] This approach results in a more conservative estimate of water available for recharge in 2017.

During the months of February through June, we used several levels, depending on outflows:

- For outflows between 7,500 cfs and 11,000 cfs, we used a required outflow value of 7,500 cfs;
- For outflows between 11,500 cfs and 29,000 cfs, we used a required outflow value of 11,500 cfs;
- And for outflows above 29,000 cfs, we used a required outflow value of 29,000 cfs.

For the other months, we used the following values for required outflows:

- 8,000 cfs in January;
- 9,000 cfs in July;
- 8,000 cfs in August; and
- 5,000 cfs for September through December.

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[10] This is a simplified approach relative to the one used by Gartrell et al. (2022). We thank Greg Gartrell for suggesting this approach as a way to approximate regulatory requirements.

Lastly, we assumed that water would be available only when the Delta was considered to be in "excess conditions," based on a list of days in excess provided by DWR.[11] There were 285 days in excess in water year (WY) 2017 and 195 days in excess in WY 2023.[12] With these rules of thumb for regulatory outflow requirements, this method likely overestimates minimum regulatory outflows and underestimates the water available for recharge.

We then estimated daily uncaptured water leaving the Delta after accounting for these required outflows. Because water entering the Delta can come from either the Sacramento River or San Joaquin River hydrologic regions, we calculated outflow relevant for the SJV based on the share of total inflow from the San Joaquin River system to the Delta. Following this approach, we estimate outflow that could have been diverted from points upstream of the Delta within the San Joaquin Valley prior to reaching the Delta without violating environmental regulations or impacting downstream water users in the Delta.

Whether water users in the region would actually be able to use this additional water for recharge would depend on capacity issues—that is, whether the region's water agencies and landowners have sufficient capacity to move, divert, and capture this water. It would also depend on regulatory issues—notably whether the State Water Board would grant permits to divert the water for recharge. The board's current default "90/20 rule" for permitting diversions for recharge is generally more restrictive than the rules used in our calculations, which correspond to meeting Delta outflow requirements.[13]

Results and Discussion

Total Delta outflow was significantly higher during WY 2017 than in WY 2023 (Figure B1). In particular, surge flows in mid-January and from February through March were much higher in 2017. Smaller peaks occurred in mid-December 2016 and late April 2017, during which 2023 flows were substantially lower. Outflows totaled 48.6 maf in WY 2017, versus 24.5 maf in WY 2023. These differences in outflow are primarily driven by differences in Delta inflow from the Sacramento River and Yolo Bypass, which were substantially higher in WY 2017. While 2017 and 2023 brought roughly similar levels of precipitation to the San Joaquin Valley, 2017 was much wetter in the Sacramento Valley.[14] In addition, the 2023 water year started out with reservoirs emptier than in water year 2017, so more runoff was retained in surface reservoirs in 2023.

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[11] This corresponds to days when the Central Valley Project and the State Water Project—which are jointly responsible for meeting Delta water quality standards—are not releasing water from their upstream reservoirs to help maintain these standards and outflow exceeds the minimum required. Nearly all Delta outflow during both 2017 and 2023 occurred during days when the Delta was in excess. For WY 2017, about 83,000 acre-feet (af) of additional water would have been available if days in excess conditions were ignored. The corresponding volume in WY 2023 is about 48,000 af.

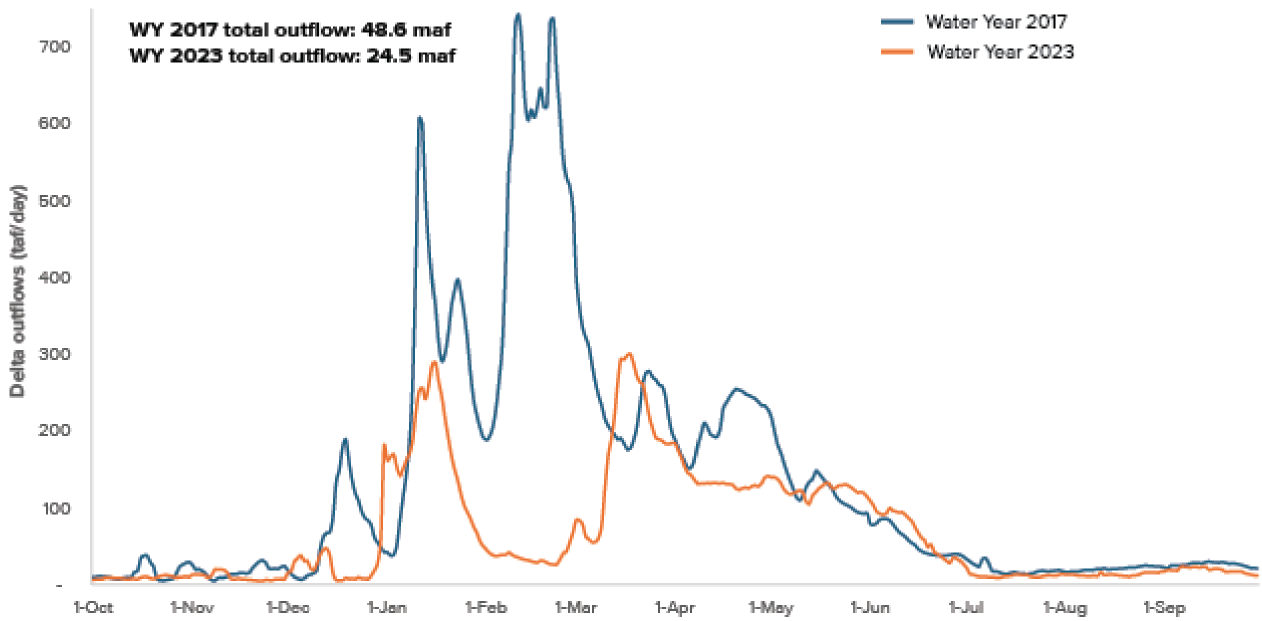
[12] Water years run from October 1st of the prior year to September 30th of the named year.

[13] Under this rule, water can be diverted for recharge if instream flows exceed the 90th percentile for that calendar day, *and* if the diversion would amount to less than 20 percent of the flow at that point in time.

[14] Data from the National Centers for Environmental Information at NOAA show total precipitation for the valley and its headwaters (California region 5) at 32.9 inches for the 2017 water year and 33.1 inches for the 2023 water year. As data from the California Data Exchange Center (CDEC) show, 2017 was the wettest year on record in the Sacramento River hydrologic region; the eight-station Northern Sierra index reported 94.7 inches of precipitation in 2017, versus just 66.6 inches in 2023.

FIGURE B1

Comparison of Delta outflow, water years 2017 and 2023

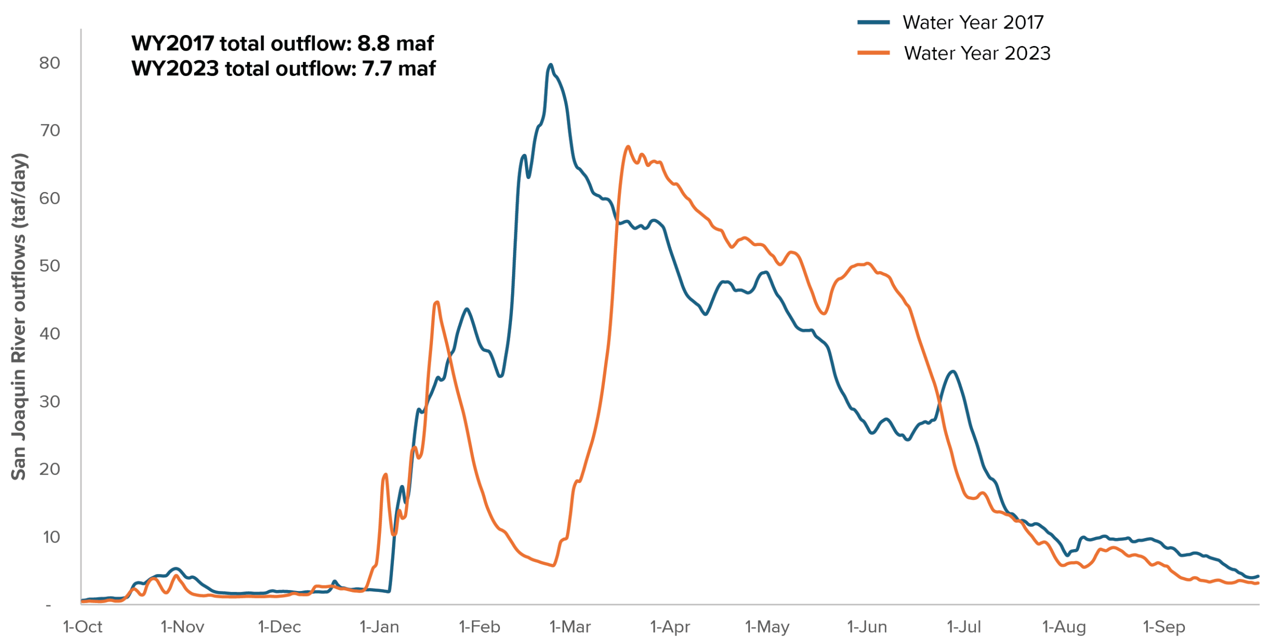


SOURCE: Calculated by the authors using information from Dayflow.

NOTES: Taf is thousands of acre-feet and maf is millions of acre-feet.

Overall San Joaquin River outflows to the Delta were roughly 1 maf higher in WY 2017 (8.8 maf) compared to WY 2023 (7.7 maf) (Figure B2). Although outflows were similar from October through January, outflows in February 2017 were roughly six times higher than during the same period in 2023. During this period, the Delta was considered in excess in both years. Even after accounting for required outflows (described below), this suggests that more water was potentially available for diversion upstream. Outflow from mid-March through the end of the water year was higher in WY 2023 than WY 2017, providing additional water that might have been used for replenishment.

FIGURE B2
Comparison of San Joaquin River outflow at Vernalis, water years 2017 and 2023



SOURCE: Calculated by the authors using information from Dayflow.
NOTES: Taf is thousands of acre-feet and maf is millions of acre-feet.

Finally, Figure B3 shows our estimates of minimum outflow requirements and additional water available for replenishment that was not captured in both years. In WY 2017, the amount potentially available for recharge totaled about 5.3 maf, and in WY 2023, somewhat less—about 3.5 maf. [15] Available water reflects similar trends as San Joaquin River outflow to the Delta; early season availability is similar but drops off sharply in February in WY 2023. Summer water available for replenishment was higher for WY 2023. However, the low flow during February drove stark differences in the total that might have been available for recharge. That said, in practice divertible water may be more comparable between the two years, because the high peak flows in February 2017 likely would have been particularly challenging to capture.[16] More generally, capacity limitations would be a consideration during most high-flow periods.

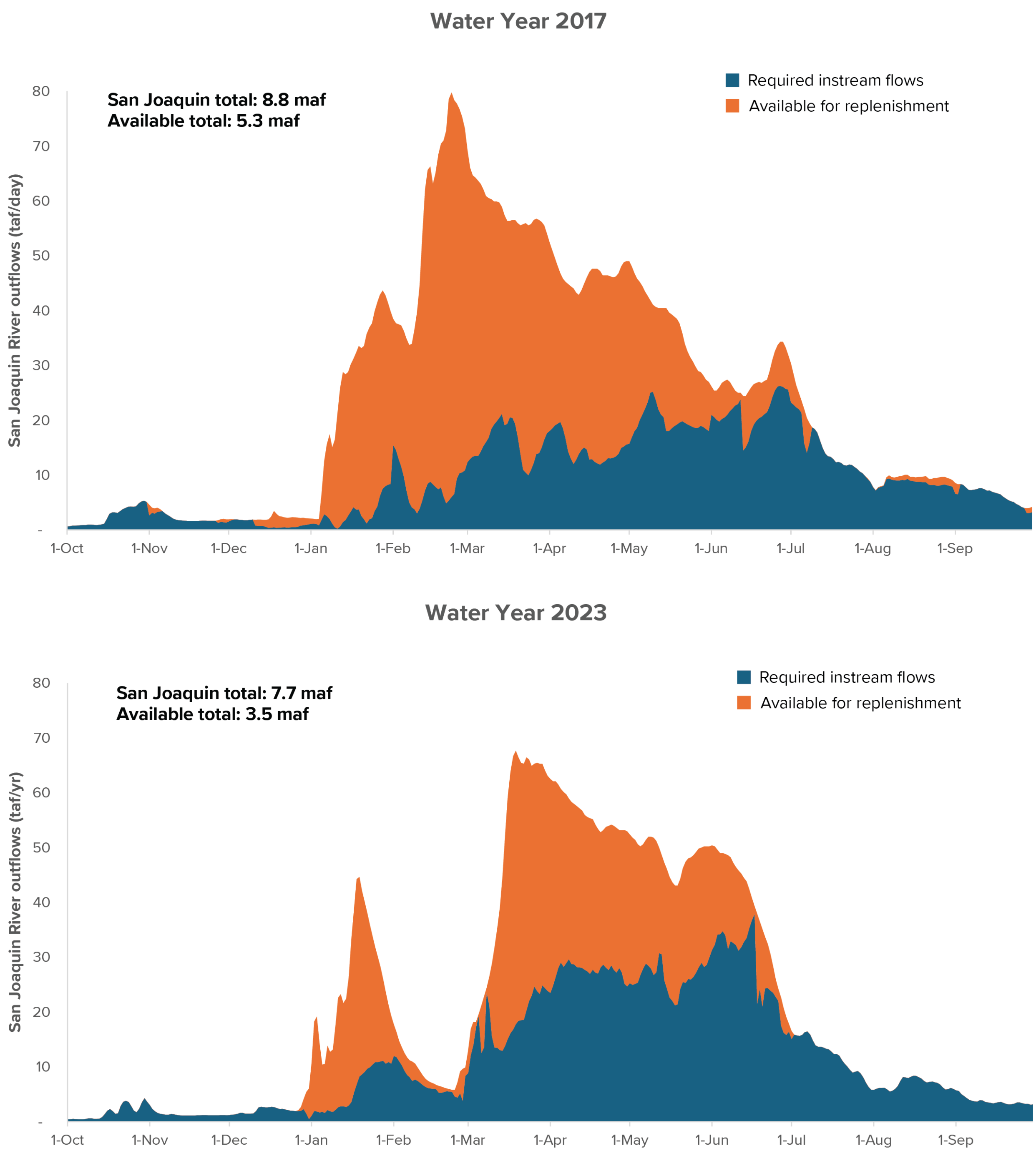
As discussed in technical appendix A, based on our surveys of water managers we estimated that managed aquifer recharge in calendar 2017 was 6.5 maf; for calendar year 2023, this estimate was about 1 maf higher at 7.6 maf. Water users tapped some water from water years 2017 and 2023 throughout the fall of both years. Based on the preceding analysis, it appears that the lower volume of water available but untapped in 2023 partly reflects higher regulatory requirements in the Delta, given the different patterns of Delta outflow across the season and the more limited contributions from the Sacramento River: in WY 2017, regulatory requirements on San Joaquin River outflow totaled just 3.5 maf, versus 4.2 maf in WY 2023. The lower volume of San Joaquin River outflow in WY 2023 is also

[15] This is somewhat lower than our earlier estimate of about 6.3 maf (Escriva-Bou and Hanak 2018) when we used a coarser method for adjusting for seasonal Delta outflow requirements, as explained above.
[16] For example, with a maximum of 2,250 cfs of additional diversion capacity, the additional amount available for recharge in 2017 was 890,000 af, versus 734,000 af in 2023. With 5,000 cfs of capacity, the corresponding volumes are 1.76 maf in 2017 and 1.47 maf in 2023.

consistent with the higher level of recharge we estimated in 2023 than in 2017—two years with similar overall precipitation levels in the region.

FIGURE B3

Additional water potentially available for recharge in the San Joaquin Valley, water years 2017 and 2023



SOURCES: Calculated by the authors using information from DWR's Dayflow (outflows at Vernalis) and data provided by DWR (days with Delta in excess).

NOTES: See text for a description of methods. An additional 83 taf and 48 taf would be available in WY2017 and WY2023, respectively, if diversions were not restricted to days when the Delta is in excess.

REFERENCES

California Department of Water Resources. 2018. *Water Available for Replenishment Information and Estimates*. California Department of Water Resources.

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Gartrell, Greg, Jeffrey Mount, and Ellen Hanak. 2022. *Policy Brief: Tracking Where Water Goes in a Changing Sacramento–San Joaquin Delta*. Public Policy Institute of California.

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