
# At Risk: Public Supply Well Vulnerability Under California's Sustainable Groundwater Management Act

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PACIFIC INSTITUTE

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## ABOUT THE AUTHOR

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Darcy Bostic is a Research Associate at the Pacific Institute. Her work focuses on groundwater governance, climate change adaptation, and community participation in water management. Darcy holds bachelor's and master's degrees in Hydrologic Sciences from the University of California, Davis. Darcy is the lead author on a report documenting the impact of Groundwater Sustainability Plans on shallow domestic wells, and a Microsoft AI for Earth Grantee and contributor to the gspdrywells.com project. She has also published on governance challenges in sea level rise adaptation in the San Francisco Bay Area.

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# EXECUTIVE SUMMARY

Community water systems in the San Joaquin Valley face a host of challenges that threaten the safety and reliability of drinking water, including pollution, periodic drought, and chronic groundwater overdraft. About 20% of community water systems in the region currently have water quality violations (SWRCB 2021a). Hundreds more are at risk of failing to provide safe drinking water (Henrie et al. 2021). Moreover, shallow wells, some of which serve community water systems, are vulnerable to short-term and chronic declines in groundwater levels. For example, during the 2012-2016 drought, many domestic wells and some public supply wells went dry.

To that end, the state's Sustainable Groundwater Management Act was designed to prevent—among other undesirable effects—significant and unreasonable chronic lowering of groundwater levels, which would impact beneficial users of groundwater, including water systems reliant on shallow groundwater wells. Yet implementation thus far, which occurs at the local level, often does not account for shallow well protection. This threatens the realization of California's Human Right to Water, passed in 2012, which states that "every human being has the right to safe, clean, affordable, and accessible water adequate for human consumption, cooking, and sanitary purposes." (California Water Code §106.3, Chaptered 2012).

Vulnerability to declining groundwater levels is most acute for communities in critically overdrafted basins. Underfunded local agencies, poor representation of disadvantaged communities, historical groundwater overdraft, and the potential for increasingly severe droughts driven by climate change all challenge the ability of groundwater sustainability agencies to support the Human Right to Water and protect the health and security of groundwater reliant residents, particularly in rural areas.

Numerous studies have documented the impact of submitted Groundwater Sustainability Plans and groundwater decline on shallow domestic wells (Perrone and Jasechko 2017; Gailey, Lund, and Medellín-Azuara 2019; R. A. Pauloo et al. 2020; Water Foundation 2020; Bostic et al. 2020). However, none have explored impacts to public supply wells. This report examines the potential impacts of submitted Groundwater Sustainability Plans on public drinking water supply wells. Results inform the Department of Water Resources' Sustainable Groundwater Management Act review efforts and the final plans approved by Groundwater Sustainability Agencies with quantitative evidence of the likely impacts and financial costs of minimum thresholds on public supply wells.

This report focuses on the San Joaquin Valley, due to its social and economic significance, high concentration of water-related challenges, and the availability of developed Groundwater Sustainability Plans. Across the San Joaquin Valley, the average minimum threshold is 100 feet below the average 2019 water level (R. Pauloo et al. 2021). Declines of this magnitude are likely to have detrimental impacts on shallow public supply wells and costly rehabilitation or replacement to continue operating effectively.

**We find that 503 of the 1,200 public supply wells, or 42%, are likely to be partially or fully dry at minimum thresholds established in these sustainability plans.**

Of the Groundwater Sustainability Plans that have public supply wells within their boundaries, all have at least one public supply well that would be partially or fully dewatered at minimum threshold groundwater levels. Each Groundwater Sustainability Plan would impact 16 wells and 5 water systems, on average. Furthermore, about 70% of water systems in all plans will have at least one well that could be partially or fully dewatered at minimum thresholds. Nearly 120 water systems, serving 1.35 million people, will face more severe challenges, with over 30% of each system's wells impacted. **Small water systems and water systems serving populations whose households make less than $75,000 per year are more likely to face severe impacts.**

Yet some solutions are available. Consolidation between small water systems with chronic water quality challenges and large water systems that meet water quality standards can support water quality and quantity vulnerabilities. Nearly 20% of small, underperforming system wells will be fully dewatered at minimum thresholds, while only 10% of large, high-performing water system wells are likely to experience full dewatering. However, this analysis does not include domestic well users nor groundwater-dependent state small water systems, including those in Disadvantaged Unincorporated Communities that fall outside of community water systems, where there are often dense groupings of domestic wells (London et al. 2018). These communities should be involved in discussions of nearby consolidation as they too are vulnerable to changes in groundwater quantity and quality.

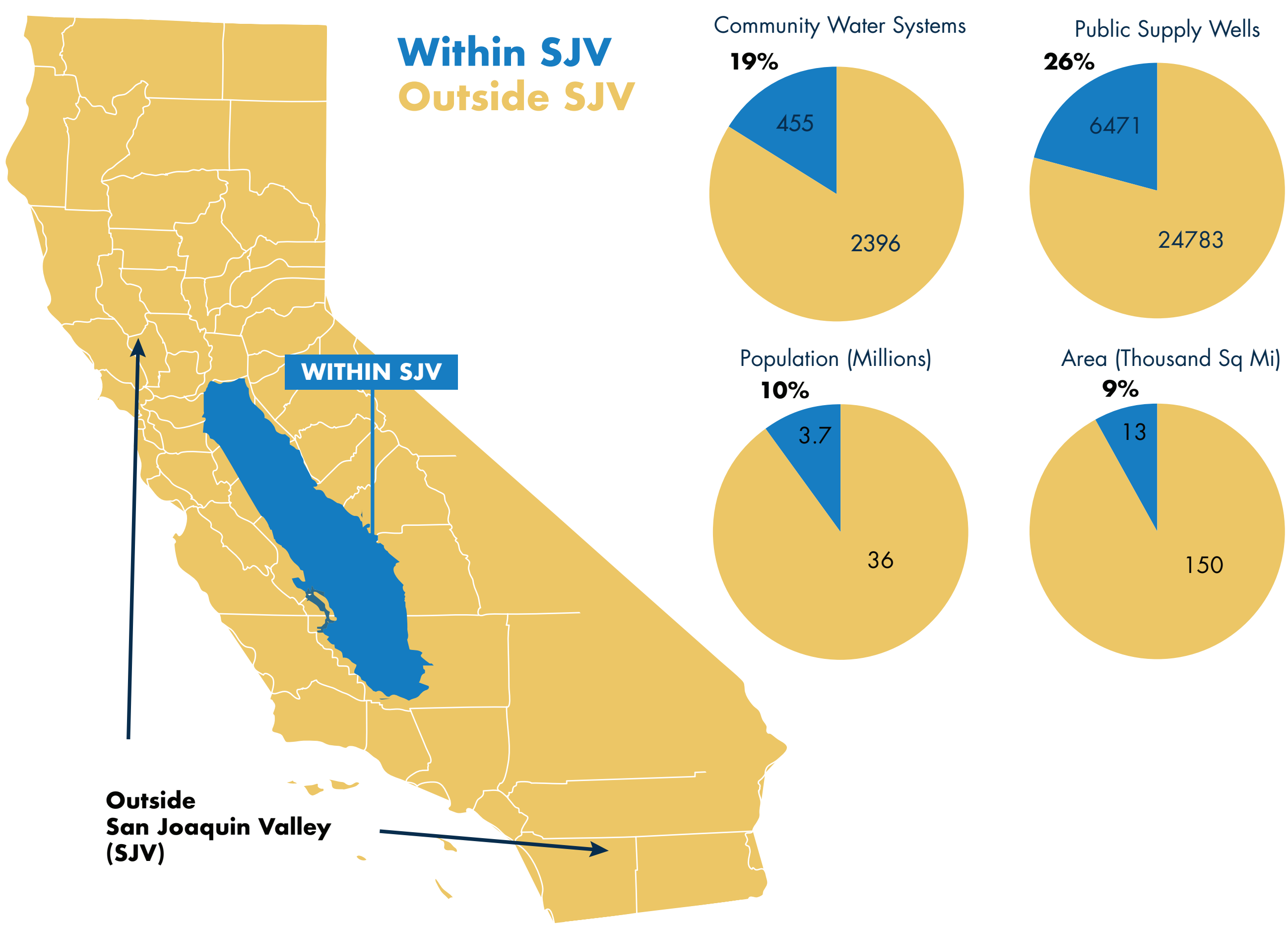
As a result of the vulnerability of public supply wells, water systems, and their customers reflected in this analysis, we recommend the Department of Water Resources examines how Groundwater Sustainability Plans consider the Human Right to Water in their minimum thresholds and mitigation plans. Furthermore, Groundwater Sustainability Agencies need to prepare to support small systems and domestic wells with additional data collection on who is vulnerable, robust mitigation frameworks, support in searching for alternative water supplies, and consolidation efforts. Finally, data and methods for assessing the impacts of a range of minimum threshold options on groundwater wells should be made accessible through a centralized, standardized, and publicly available format.

## SECTION 1. INTRODUCTION

Across the arid western United States, groundwater is a key component of drinking water supply. This is especially true in California's San Joaquin Valley (SJV). Although the SJV is home to about 10% of the state's population, it has about 60% of all groundwater wells, 25% of public supply wells (PSWs), and 16% of community water systems in California (Figure 1). Nearly 90% of water systems in the SJV are groundwater dependent, while only 36 of the 455 SJV water systems (8%) are not reliant on groundwater at all (Pace et al. 2019).

As a result of the large role groundwater plays in drinking water access, it is important to assess the vulnerability of the resource. Groundwater-dependent public water systems are critical to drinking water access and security for millions of residents in the SJV and thus should be the focus of special attention in state water management and planning. California's Human Right to Water supports this focus, requiring consideration of drinking water access, affordability, and quality in governmental programs. Yet groundwater dependent water systems remain vulnerable to declining groundwater levels.

**Figure 1. Number of Wells, Water Systems, and Populations Served in California**

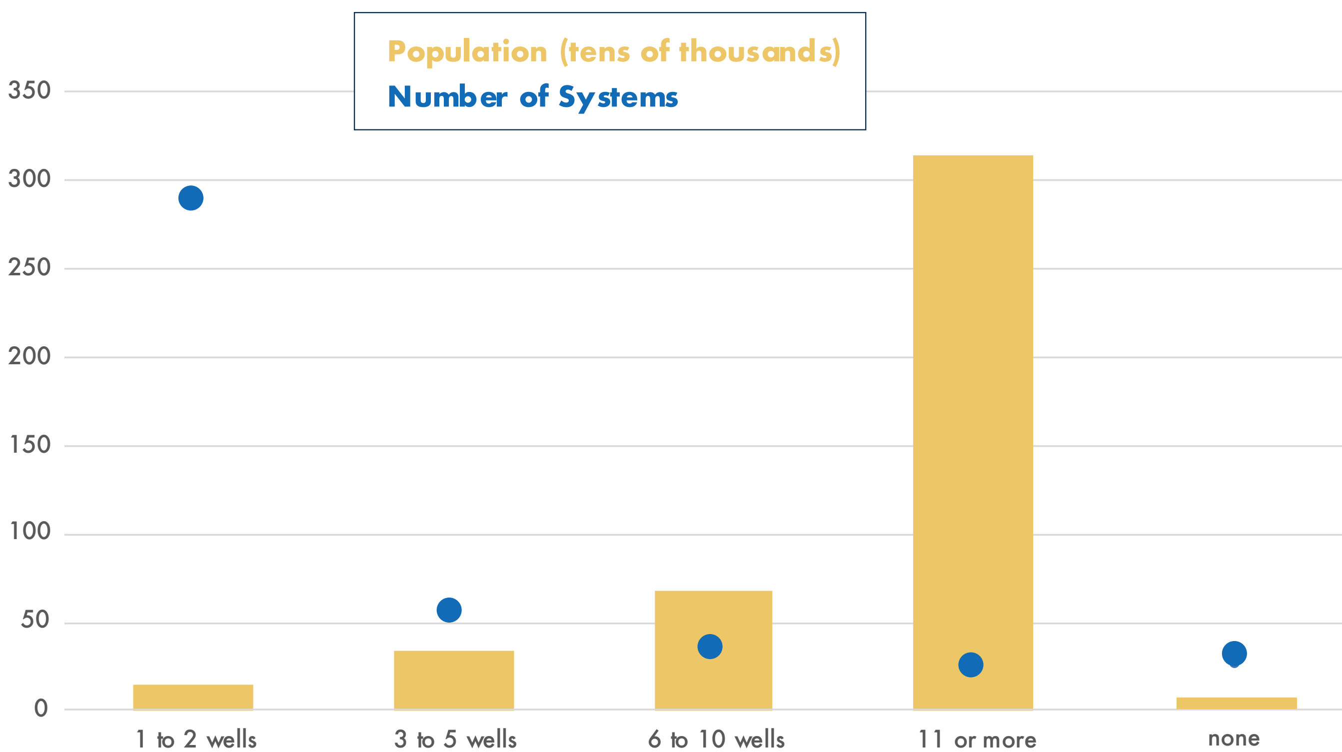



*Data Source: CA SDWIS Drinking Water Watch (California SWRCB 2021b)*

Historical patterns in California groundwater use demonstrate that dry years encourage more groundwater pumping to augment lost surface water supply (Hanak 2011; Medellín-Azuara et al., n.d.). Thus, as surface water supplies become more variable and uncertain under climate change, groundwater use may increase to compensate, creating more demand for already overdrafted aquifers. When groundwater levels decline during periods of intense use, the shallowest wells are generally the first to be impacted. Even if a well maintains access to groundwater, as water levels decline, it become increasingly energy intensive and costly to pump water from greater depths, although the relative costs of increased lift are a fraction of the cost to replace or refurbish impacted wells (Water Foundation 2020)[1]. In particular, small, rural communities are more likely to rely exclusively on groundwater and have high proportions of low-income residents unable to afford increases in water bills to support searches for alternative supplies or purchasing of alternative water during drought (Perrone and Jasechko 2017).

Water systems in the SJV are especially vulnerable because they rely on historically unmanaged groundwater and compete for water with other users (e.g. agriculture). Moreover, SJV water systems are likely to provide water to low-income and disenfranchised communities. Most water systems do not have alternative surface water supplies and are dependent on only one or two wells. According to data from SWRCB (2021c), in the SJV, 288 systems reliant on one or two wells serve about 40,000 people (Figure 2). Just over half, or 161 systems, have only one active well (SWRCB 2021b). Furthermore, water systems with fewer wells serve less people, and thus have fewer ratepayers to support infrastructure upgrades. On average, water systems with one or two wells serve about 500 people each.

**Figure 2. Population Served and Number of Water Systems by Number of Wells**

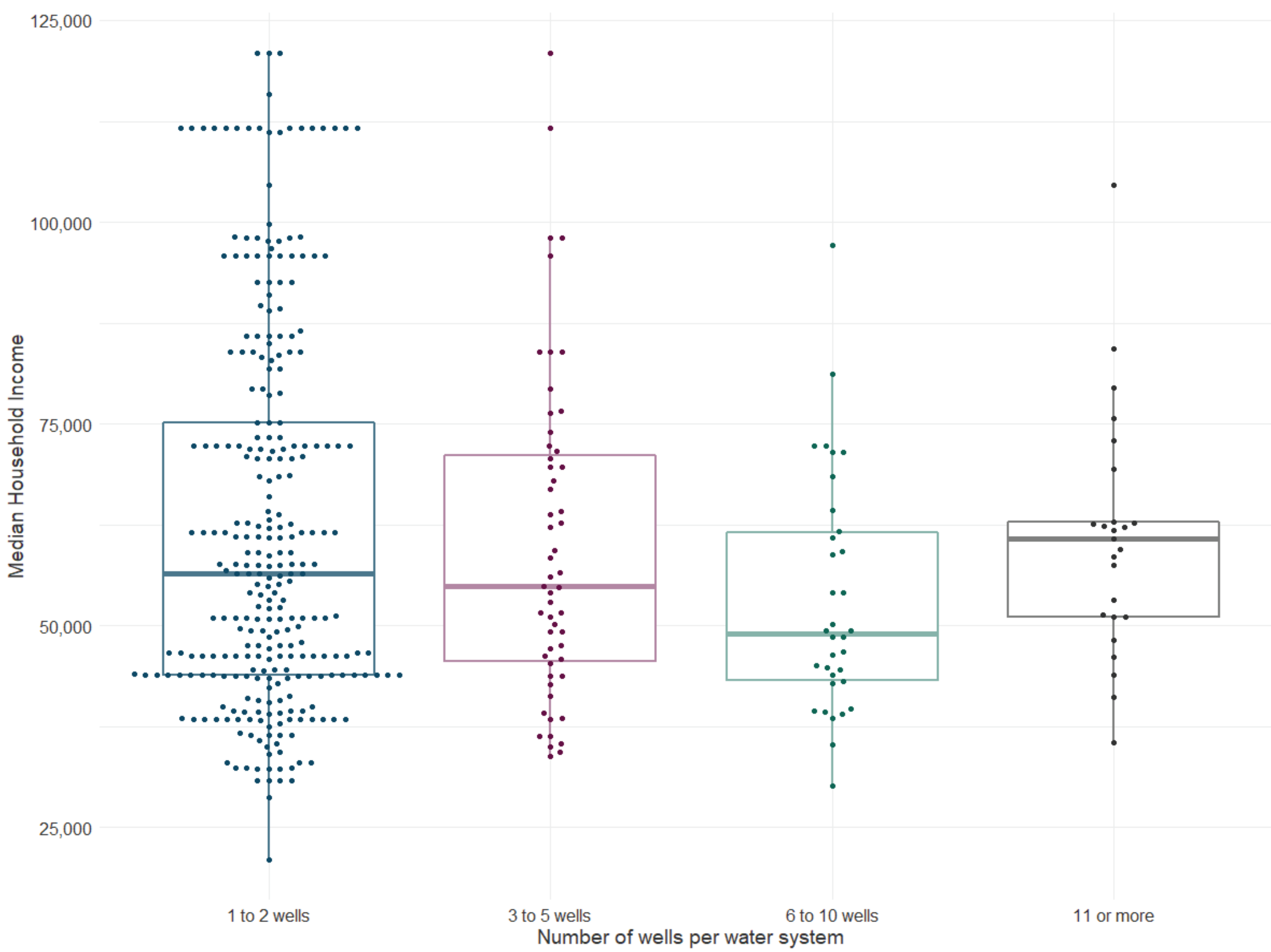



*Source: CA SDWIS Drinking Water Watch (California SWRCB 2021b)*

1 Increased lift costs were around 1.3% of well replacement and pump lowering costs associated with a scenario in which groundwater level Minimum Thresholds were reached at all domestic wells in submitted critical priority Groundwater Sustainability Plans.

In addition, most water systems with one to two wells serve communities with a median household income below 80% of the state median household income of about $75,000 (163 systems, or 57%). By contrast, 46, or 16%, of these small water systems are in relatively wealthier communities, whose median household incomes are at least 120% of the state median household income (Figure 3). Water systems that serve higher percentages of homeowners and serve communities that are higher income are also more able to provide affordable water that meets water quality standards, highlighting the resilience of water systems with more financial resources. In contrast, socioeconomically disadvantaged communities served by small water systems have disproportionate exposures to water quality violations (Balazs et al. 2012; London et al. 2018).

**Figure 3. Median Household Income by the Number of Wells per Water System**




*Source: Author's calculations using water system boundaries from Pace et al (2019), number of wells per water system from CA SDWIS Drinking Water Watch (California SWRCB 2021b), and U.S. 2019 5-year American Community Survey Census Table S1903.*

NOTE: Each dot represents a water system, the x-axis shows the number of wells the water system has, and the y-axis shows the median household income of the zip code the water system primarily intersects.

Efforts to build supply resiliency for small drinking water systems, especially those with low-income customers, have been challenged in the past. In the 2012-2016 drought, 127 small community water systems supplying 473,000 people reported either water supply outages or applied for emergency funding to prevent shortfalls. Another 3,700 domestic wells supplying an estimated 11,000 people reported shortages. The state spent $22 million a year on emergency drinking water needs for affected communities (Feinstein et al. 2017). Many public utilities in the SJV are concerned about their supply in the next drought. One water manager in Tulare County said, "if we lose our one operating well, I don't know what we'd do. We wouldn't have water to give to our customers." (Prado Sr. 2020).

Passed in response to the 2012-2016 drought, the Sustainable Groundwater Management Act (SGMA) is the first statewide law regulating groundwater access and use in California (Box 1). It establishes local agencies tasked with the prevention of "significant and unreasonable" impacts to beneficial uses and users of groundwater (CA DWR 2017). Among these significant and unreasonable impacts are significant and unreasonable chronic decline of groundwater levels, which would impact the aforementioned vulnerable water systems reliant on relatively shallow wells in areas with historic groundwater overdraft. Analyses of the early implementation of SGMA suggest that the law is unlikely to prevent a recurrence of these shortages. A 2020 review of Groundwater Sustainability Plans (GSPs) by the Water Foundation found that between 46,000 and 127,000 people could lose access to their household wells by 2040 if water is managed as outlined in the plans. Solutions for these individuals could cost $88–$359 million (Water Foundation 2020). However, less than one-third of plans submitted to the state describe how groundwater-dependent drinking water stakeholders could be impacted based on the sustainable management criteria for water quality and quantity, and do not include projects and management actions specifically designed to support drinking water or underrepresented communities (Dobbin et al. 2020).

Previous research on impacts to wells has emphasized domestic wells (Gailey, Lund, and Medellín-Azuara 2019; R. A. Pauloo et al. 2020; Bostic et al. 2020; R. Pauloo et al. 2021). This report expands on these analyses by evaluating the impact of minimum thresholds specified in GSPs on PSWs. We follow well-established methodology for well impact analyses (Gailey, Lund, and Medellín-Azuara 2019; Water Foundation 2020; Bostic et al. 2020; R. A. Pauloo et al. 2020; R. Pauloo et al. 2021). Next, we review the results for the identification of PSWs vulnerable to GSP sustainable management criteria. Finally, the report provides recommendations for local and state action.

### Water Systems and the Sustainable Groundwater Management Act

Water systems reliant on wells are beneficial users of groundwater. Therefore, their groundwater use falls under the purview of Groundwater Sustainability Agencies (GSAs). GSAs are new local agencies, formed by the SGMA, tasked with managing groundwater sustainably. The law defines sustainability as "management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results." (Sustainable Groundwater Management Act 2014). Specifically, six undesirable results should be prevented, including chronic lowering of groundwater levels and degraded water quality (Figure 4). This report focuses on the chronic lowering of groundwater levels.

**Figure 4.** **Undesirable Results Groundwater Sustainability Agencies Are Required to Avoid Through the Establishment of Minimum Thresholds and Measurable Objective Metrics**

| Sustainability Indicators | Lowering GW Levels | Reduction of Storage | Seawater Intrusion | Degraded Quality | Land Subsidence | Surface Water Depletion |
|---|---|---|---|---|---|---|
| Metric(s) Defined in GSP Regulations | • Groundwater Elevation | • Extraction Volume | • Chloride concentration isocontour | • Migration of Plumes<br>• Number of supply wells<br>• Volume<br>• Location of isocontour | • Rate and Extent of Land Subsidence | • Volume or rate of surface water depletion |

*Source: Austin (2019) and California DWR (2017).*

In critically overdrafted groundwater basins, which are primarily located in the SJV, sustainability must be achieved by 2040, according to SGMA. GSPs in these basins further specify when the six undesirable results occur. These values are set through two criteria: measurable objectives and minimum thresholds. Measurable objectives are sustainability goals where the balance between users of groundwater can be maintained over time. Minimum thresholds outline the minimum conditions required to avoid significant and unreasonable impacts. Measurable objectives and minimum thresholds are provided at specific locations throughout a GSP area, identifying groundwater levels that delineate sustainability. This report focuses on the impacts of minimum thresholds specified for the lowering of groundwater levels in 31 GSPs. These minimum thresholds identify the deepest groundwater level allowable for the basin to be considered sustainable and to avoid undesirable results. In other words, if groundwater levels drop below minimum thresholds for more than several years, the GSA will likely need implement mitigation measures to raise the groundwater level.

# SECTION 2. METHODS

In this study, we examine the vulnerability of wells serving community water systems to minimum thresholds established in 31 GSPs in the SJV. First, we identified active wells within the study region. Second, we compared the depths of active wells with projected minimum threshold groundwater levels from Pauloo et al. (2021) and determined whether wells are active, partially dewatered, or fully dewatered. Third, we associated the PSWs with community water systems. Finally, we conducted a first-order analysis of the demographic characteristics of community water systems with impacted wells. Additional detail on each of these steps is provided in the following sections.

## GROUNDWATER LEVELS

Current groundwater levels and minimum threshold levels are downloaded from gspdrywells.com (R. Pauloo et al. 2021). Current groundwater levels are derived from CASGEM 2019 groundwater level measurements and minimum threshold levels were created by compiling all minimum thresholds set in the 31 GSPs and interpolating between points, as described in gspdrywells.com/#methodology.

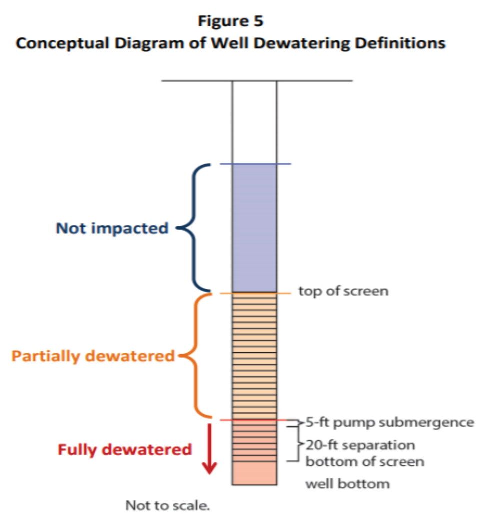
## WELL FAILURE ANALYSIS

We use a State Water Resources Control Board PSW dataset to identify the number and location of active wells impacted by minimum thresholds. To identify active PSWs, we removed wells labeled as destroyed, inactive, or abandoned. Some wells lack construction information, and those wells are also not analyzed, as described in Appendix A; this reduced the number of analyzable wells to 1,737. We also assumed that wells shallower than current groundwater levels are no longer active and removed wells if current groundwater levels (2019 average) were less than 25 feet above the bottom of the well screen. To do so, we intersected the remaining PSWs with the interpolated current groundwater levels and compared groundwater level at each well location to the well's construction information.

About 30% of the 1,737 wells have a top of the screened interval above 2019 groundwater levels, reducing the number of analyzable wells to 1,198.

These final 1,200 wells are analyzed for their vulnerability to minimum threshold water levels. Wells are assumed to be partially dewatered if the minimum threshold water level is between the top of the well screen and the 25 feet operating margin above the bottom of the well (Figure 5). When the minimum threshold water level is below the 25 feet operating margin, the well is considered fully dewatered (Water Foundation 2020). A well is considered impacted if it is either partially or fully dewatered at the minimum thresholds.

**Figure 5. Conceptual Model of Well Failure**




*Source: Water Foundation 2020*

## CONNECTING WATER SYSTEMS TO WELLS

To understand which water systems are most vulnerable to minimum thresholds, the wells analyzed must be connected to their corresponding water system. Three steps were undertaken to connect water systems to their wells. First, some wells include the water system ID (formally called Public Supply Well IDs, or PWSIDs) in their unique ID. These wells are matched to their water system by their unique IDs. Second, for wells whose

IDs had no corresponding PWSID, we performed an intersection between water systems and PSWs. Finally, we assigned wells with no PWSID that fall outside of water system boundaries to the nearest water system. The accuracy of this method is discussed in Appendix A. Once water systems are connected with wells, estimates of the number of people reliant on vulnerable wells can be made as well, using the population served by each water system (derived from SWRCB (2021c)).

## ASSESSING IMPACTS BY SYSTEM SIZE AND DEMOGRAPHICS

To understand which community water systems and demographics are most vulnerable, systems were categorized according to the percent of impacted wells, or partially and fully dewatered wells (Table 1). Both partially and fully dry wells are included because both categories of wells are likely to need rehabilitation or replacement, and thus add financial obligations to and increase vulnerability of a water system. Because PSWs were connected to water systems using the above methods, the uncertainty in the number of wells per water system permeates into the categories of impact. As such, these remain coarse approximations of vulnerability.

**Table 1. Water System Vulnerability Categories by Percent of Wells Impacted**

| Category | Percent of Wells Impacted |
|---|---|
| Sustainable | 0 |
| Moderate Vulnerability | 1-30% |
| High Vulnerability | 31-70% |
| Extreme Vulnerability | 71-100% |

*Source: Author's categories based on distribution of well impacts across water systems and categories from Feinstein et al (2020).*

We then categorized water systems by the number of customers they serve (system size) and the demographics of the population served. This kind of analysis helps us understand what kinds of systems are most impacted and where to efficiently allocate assistance for the most vulnerable systems. Small systems serve less than 10,000 people, while medium and large systems serve more than 10,000 people (Dobbin and Fencl 2019). For a finer resolution, population was further broken down by EPA system size classifications: <500 customers, 501-3,300, 3,301-10,000, 10,001 – 100,000, and >100,000 (US EPA n.d.).

There is no public information that provides the demographics of the populations served by the water systems assessed in this study. As such, we completed a first-order analysis to understand the attributes of customers likely to be impacted by water systems with vulnerable wells. Water system boundaries from Pace et al. (2019) were intersected with 2019 Census American Community Survey 5-year Zip Code Tabulation Area (ZCTA) Tables S1903 (Median Income by Household and Individual) and B03002 (Hispanic or Latino Origin by Race). The attributes of the largest intersecting ZCTA are assigned to each water system, providing percentages of the population by race and ethnicity, as well as by income. ZCTAs are smaller than some census block groups in the SJV, thus allowing for finer resolution of race and income data.

## UNDERSTANDING THE VULNERABILITY OF SYSTEMS THAT ARE CANDIDATES FOR REGIONALIZATION

Feinstein et al. (2020) outlines preliminary partnership zones between large water systems that consistently meet water quality standards (high performing) and small water systems who chronically violate water quality standards (underperforming). Twenty-five large water systems reach 80% of the population served by small water systems struggling to meet water quality standards across California. These systems may be able to provide technical assistance or clean water to small, underperforming systems, thus reducing their vulnerability to declining groundwater levels and degrading water quality.

Here, the high and under-performing water systems are examined for their vulnerability to minimum thresholds. Only a subset of the water systems assessed in this report fall into the categories of “large, high performing” or “small, underperforming.” Specifically, 63 of the 214 systems assessed for vulnerability to minimum thresholds are examined.

This analysis does not consider domestic well users, nor state small water systems, including those in Disadvantaged Unincorporated Communities that fall outside of community water systems, where there are often dense groupings of domestic wells (London et al. 2018). These communities should be involved in discussions of nearby physical or managerial consolidation as they too are vulnerable to changes in groundwater quantity and quality.

# SECTION 3. RESULTS

## IMPACTS TO PUBLIC SUPPLY WELLS

Across the SJV, the average minimum threshold is 100 feet below the average 2019 water level (R. Pauloo et al. 2021). Declines of this magnitude are likely to have detrimental impacts on shallow PSWs. We find that 503 of the 1,200 wells, or 42%, are likely to be partially or fully dry at minimum thresholds established in GSPs (Table 2). These impacted wells will need rehabilitation or replacement to continue operating effectively.

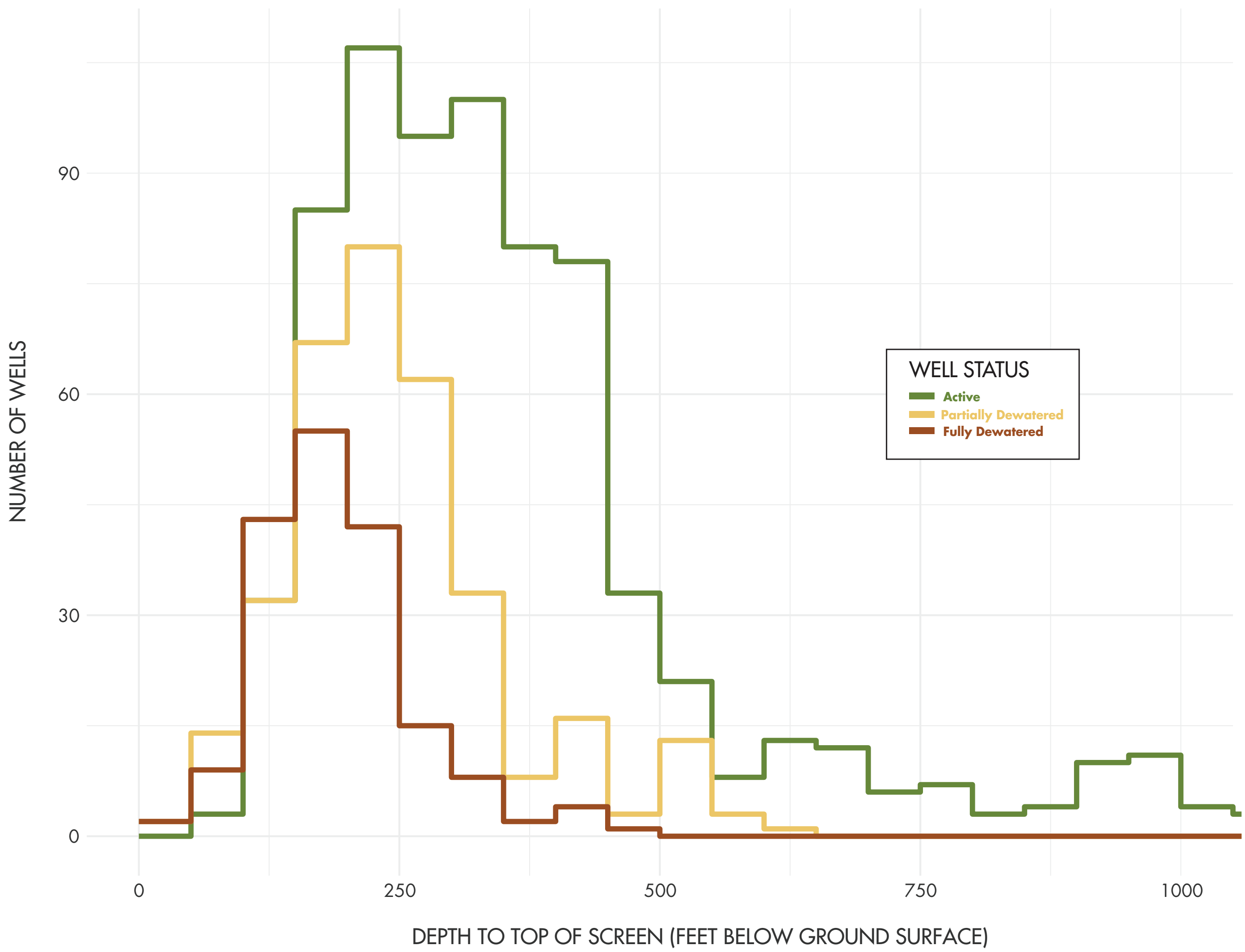
**Table 2. Active and Dewatered Wells at GSP Minimum Thresholds**

| | Number of Wells | Percent of Wells |
|---|---|---|
| Operational at minimum threshold | 695 | 58% |
| Partially dewatered at minimum threshold | 324 | 27% |
| Fully dewatered at minimum threshold | 179 | 15% |
| Total | 1,198 | 100% |

*Source: Author's calculations based on well depths and locations from California SWRCB (2021c), well status categories from Water Foundation (2020), and groundwater depths from Pauloo et al (2021).*

Most wells begin to draw water from depths shallower than 500 feet below the land surface. Impacted wells with screens that begin before 300 feet (Figure 6) likely draw from unconfined aquifers. Generally, shallow wells are more likely to be impacted, but this is dependent on local groundwater conditions as some deeper wells may also access unconfined aquifers with relatively deep groundwater levels. As seen in Figure 6, most dry wells are shallower than active wells but a few partially dewatered wells are deeper than 500 feet below the land surface. Because groundwater levels are deeper in some areas than in others, even some PSWs deeper than 500 feet are likely to be partially dewatered.

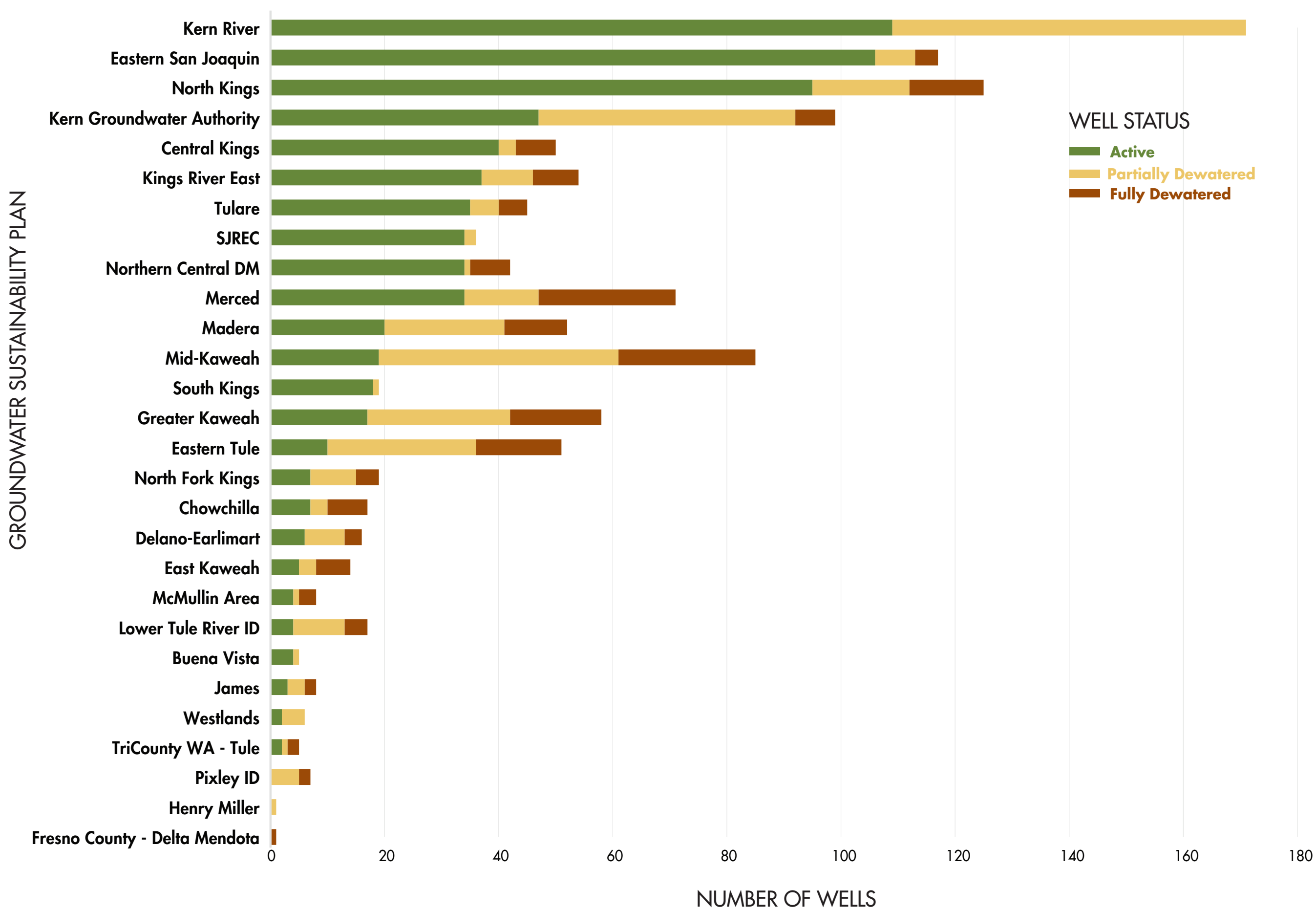
**Figure 6. Distribution of Well Depth by Well Status at Minimum Threshold Groundwater Levels**




*Source: Author's calculations based on well depths and locations from California SWRCB (2021c), well status categories from Water Foundation (2020), and groundwater depths from Pauloo et al (2021).*

The impacts to PSWs vary with the location and concentration of wells and local changes in water levels. Because minimum thresholds are specified at the GSP level, impacts are assessed at the same scale. Of the GSPs that have PSWs within their boundaries, all have at least one PSW that would be partially or fully dewatered at minimum threshold groundwater levels. Each GSP would impact 16 wells and five water systems, on average. However, the distribution of impacts by GSP vary widely (Figure 7). For example, Pixley Irrigation District has seven PSWs within its boundaries, all of which are vulnerable to the minimum threshold selected. Eastern San Joaquin, in contrast, has 117 wells, yet just nine percent the wells are expected to be partially or fully dewatered. See Appendix B for a complete list of the number of wells impacted per GSP.

**Figure 7.** Number of Active and Dewatered Wells at Minimum Threshold Groundwater Levels




NOTE: DM = Delta Mendota, SJREC = San Joaquin River Exchange Contractors, ID = Irrigation District, WA = Water Authority

## IMPACTS TO WATER SYSTEMS

Declining groundwater levels affect systems of all sizes. Impacts to water systems are assessed along with the impacts to wells to outline the number of distinct entities that will be faced with restoring access to water. In addition, the GSAs will have to coordinate with water systems to provide support with remediation and calculate the populations impacted.

Nearly 70% of water systems will have wells that are partially or fully dewatered at minimum thresholds. To understand which water systems are most vulnerable, systems were categorized according to the percent of wells that would need rehabilitation or replacement (Table 3).

**Table 3.** Water Systems and Population Served by Vulnerability Categories

| Category | Percent of Wells Fully or Partially Dry | Number of Systems | Population Served |
|---|---|---|---|
| Sustainable | 0 | 70 | 227,378 |
| Moderate Vulnerability | 1-30% | 27 | 1,464,239 |
| High Vulnerability | 31-70% | 52 | 876,152 |
| Extreme Vulnerability | 71-100% | 65 | 472,931 |

*Source: Author's calculations based on well depths and locations from California SWRCB (2021c) and water system boundaries and population served from Pace et al (2019).*

Impacts to water systems were further categorized by system size. Although there are over three times as many small systems (population served <10,000) as large ones, large systems have many more wells (Table 4). Small systems, however, have a higher percentage of fully dewatered wells (19%) than large systems (12%).

### Table 4. Number of Active and Dewatered Wells Under Minimum Threshold Scenario, by System Size

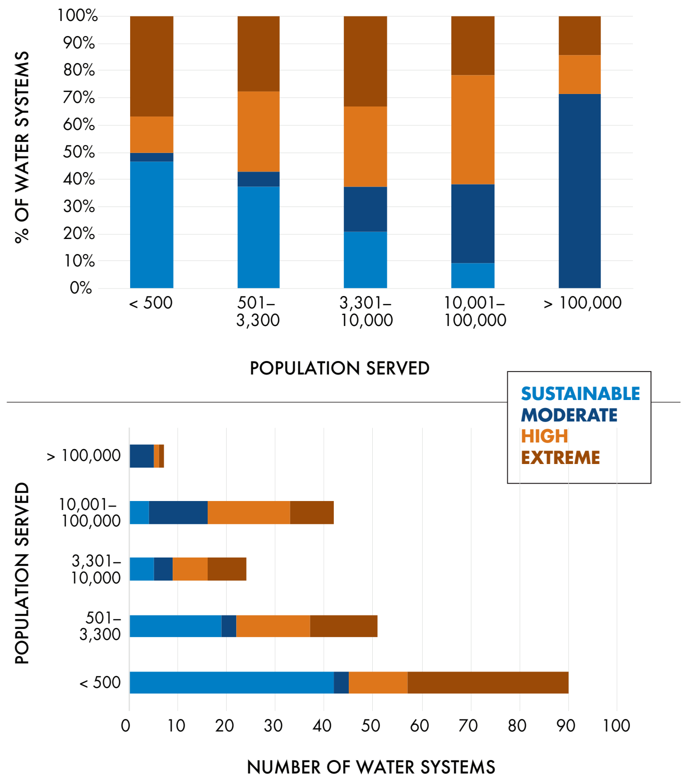
| | Small Systems | Medium/ Large Systems | Total |
|---|---|---|---|
| Water Systems | 162 | 49 | 214 |
| Active Wells | 238 | 452 | 690 |
| Partially Dewatered Wells | 108 | 216 | 324 |
| Fully Dewatered Wells | 82 | 93 | 175 |

*Source: Author's calculations based on water system boundaries from Pace et al (2019) and well depths and locations from California SWRCB (2021c).*

Minimum threshold water levels affect systems of all sizes but small systems are more vulnerable for several reasons. First, small systems typically have fewer wells, and those wells are more vulnerable to minimum thresholds than larger systems. Forty percent of water systems reliant on one well are likely to have a partially or fully dewatered well at minimum threshold water levels. Moreover, small systems may have less capacity to pay for large infrastructure projects and often do not have secondary sources of water when wells go dry. In other words, small water systems are slightly more likely to experience well failure under minimum threshold conditions than larger water systems, but will have a harder time restoring water service or affording remediation for impacted wells.

Figure 8 shows the vulnerability of water systems by system size. Although all very large water systems (>100,000 people) have at least one impacted well, these water systems have many more wells than systems serving fewer people. For systems serving less than 500 people, there are about the same number of systems with no impacted wells (42 systems) as those who fall in the extremely vulnerable category (33 systems). This understanding can narrow down which systems to aid, especially during drought or periods of rapidly declining groundwater levels.

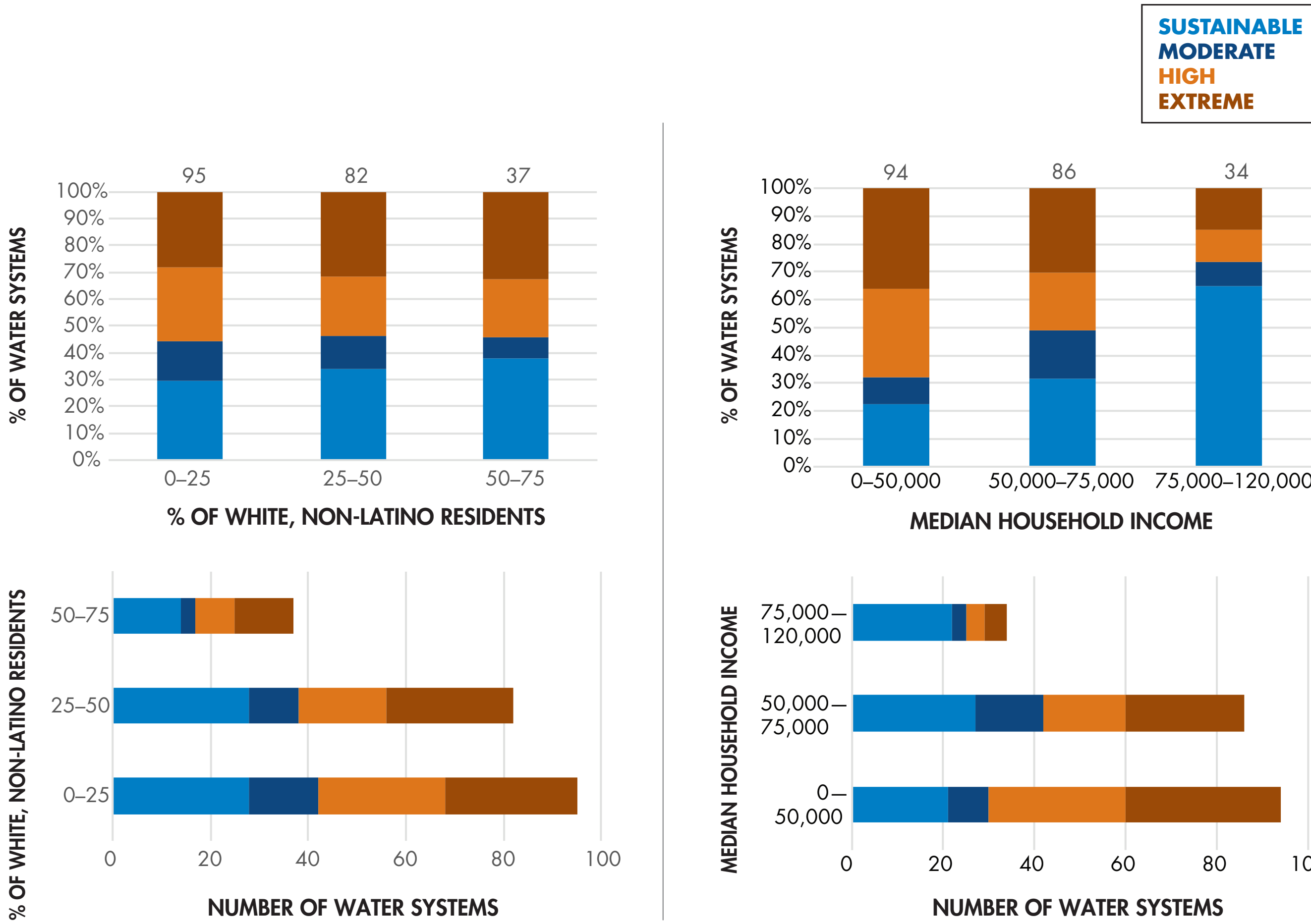
### Figure 8. Percent and Number of Water Systems Vulnerable to Minimum Thresholds by System Size




*Source: Author's calculations based on population served by water system from Pace et al (2019) and well depths and locations from California SWRCB (2021c).*

An estimated 1 million people are served by water systems that have at least 30% of their wells vulnerable to minimum thresholds (Table 3). Small water systems and water systems serving populations whose households make less than $75,000 per year are more likely to have partially or fully dry wells (Figure 9). There are about the same number of sustainable systems in all categories of income, however there are substantially more moderate, high, and extreme vulnerability systems with households making less than $75,000 per year. Furthermore, systems with households that make on average over $75,000 per year have four times as many active wells under minimum thresholds. There are similar percentages of water systems in each vulnerability category when broken up by the percentage of White, non-Latino population in each water system.

### Figure 9. Water System Vulnerability by System Demographics




*Source: Author's calculations using water system boundaries from Pace et al (2019), well depths from California SWRCB (2021c), and U.S. 2019 5-year American Community Survey Census Tables S1903 and B03002.*

NOTES: Water system vulnerability as characterized by the percentage of White, non-Latino residents and the median household income per water system. Charts A and B show the percent of water systems, while C and D show the number of water systems within each category.

However, there are twice as many extremely vulnerable water systems where the White population is less than 25% than where it is over 50%.

Although many low-income communities are served by small water systems, a small proportion of water systems serve relatively wealthier, suburban and exurban communities, as evidenced by the large number of small and higher income water systems with no impacted wells. These water systems typically have deep wells that are largely unaffected by minimum thresholds.

## WATER QUALITY AND WATER QUANTITY

Solutions for systems facing water quality challenges can also improve the security of their water supplies. Using partnership zones identified in Feinstein et al. (2020), we assessed large, high-performing water systems and small, underperforming water systems for their vulnerability to minimum thresholds. This analysis allowed us to understand whether minimum threshold groundwater levels (1) increase the vulnerability of large systems, or (2) allow for vulnerable small systems with poor water quality to also gain the benefit of a secure water supply through regionalization solutions, such as physical and managerial consolidation.

Large, high-performing water systems are more resilient to minimum thresholds while small, underperforming water systems are quite vulnerable (Table 5). An estimated 56% of high-performing system wells remain active, along with 47% of small water systems. Nearly 20% of small, underperforming system wells will be fully dewatered at minimum thresholds, while only 10% of large, high-performing water system wells are likely to experience full dewatering. Thus, small systems already struggling to provide clean water to customers are also more vulnerable to declining groundwater levels and could lose access to water entirely. Both high-performing and underperforming systems have about 35% of water system wells likely to be partially dewatered.

While large utilities often have larger ratepayer bases to fund well remediation or purchase additional water, small utilities may not. The confluence of water quality and quantity stressors further challenge small water systems. Consolidation between large, high-performing systems and small, underperforming systems may assuage water quality concerns today and vulnerabilities to declining groundwater levels in the future. However, challenges remain: funding mechanisms for consolidation are unclear, the actual economic feasibility of such projects remains unevaluated, and there may be local resistance to mergers.

**Table 5. Percent of Active and Dewatered Wells at Minimum Thresholds, by Performance Category**

| | Large, High-Performing System | Small, Underperforming System |
|---|---|---|
| % Active Wells | 56 | 47 |
| % Partially Dewatered Wells | 34 | 34 |
| % Fully Dewatered Wells | 10 | 19 |

*Source: Author's calculations based on system performance categories from Feinstein et al (2020), well status categories from Water Foundation (2020), and well depths and locations from California SWRCB (2021c).*

# SECTION 4. CONCLUSIONS AND RECOMMENDATIONS

PSWs are vulnerable if water levels reach minimum thresholds set forth in GSPs. If water levels decline to the minimum thresholds, 1.46 million people served by 117 water systems could be impacted in the SJV. Well impacts will be most significant for small systems with few wells. Small water systems also often have less financial capacity to quickly repair, remediate, or replace compromised wells. Hundreds of thousands of people reliant on small water systems and domestic wells are vulnerable if groundwater levels reach minimum thresholds. The finding that small water systems in the SJV which serve low-income customers, often of color, are most vulnerable is consistent with similar studies (Balazs et al. 2012; Bostic et al. 2020; Dobbin et al. 2020). In addition to future vulnerability to lowering groundwater levels, these water systems and the communities they serve face compounding challenges, from poor air quality (Ortiz-Partida 2020) to systemic exclusion from larger water systems (London et al. 2018). Groundwater sustainability agencies need to prepare to support small systems and domestic wells with additional data collection on who is vulnerable, robust mitigation frameworks, support in searching for alternative water supplies, and consolidation efforts.

We recommend the following actions in order to ensure the long-term sustainability of groundwater-dependent water systems and ensure the realization of the Human Right to Water.

### 1. Evaluate tradeoffs between lowering groundwater levels and well vulnerability and discuss findings in stakeholder meetings

Challenging decisions lie ahead, and the minimum threshold values outlined in submitted critical priority GSPs in the SJV do not protect drinking water access for a significant number of PSWs. Some PSWs will inevitably go dry before GSAs begin actively managing groundwater, especially if extended drought returns. To effectively support the Human Right to Water, well protection analyses should be included in future GSPs. GSAs can select different minimum thresholds and identify the scale of well rehabilitation and remediation required by each foot of vertical decline and the cost associated with providing alternative sources of water to inform planning and management. These decision support tools should also be paired with robust mitigation frameworks before wells begin to go dry. Stakeholders should be involved in the process of deciding which tradeoffs to make and the contents of the mitigation frameworks.

### 2. Establish regional partnerships between water systems to support water quality and quantity improvements

Water systems struggling to address contamination today may face the compounding challenge of inadequate water supplies in the future, challenging their ability to address both. Regional partnerships allow water systems to work together, from physically connecting systems to sharing administrative and technical resources (US Water Alliance 2018). These partnerships can help systems address challenges that result from smaller ratepayer bases and smaller economies of scale. The State Water Board Drinking Water Needs Assessment examines water systems that are currently struggling to meet water quality challenges, and regional partnerships used to address water quality could also potentially benefit water systems vulnerable to lowering groundwater levels.

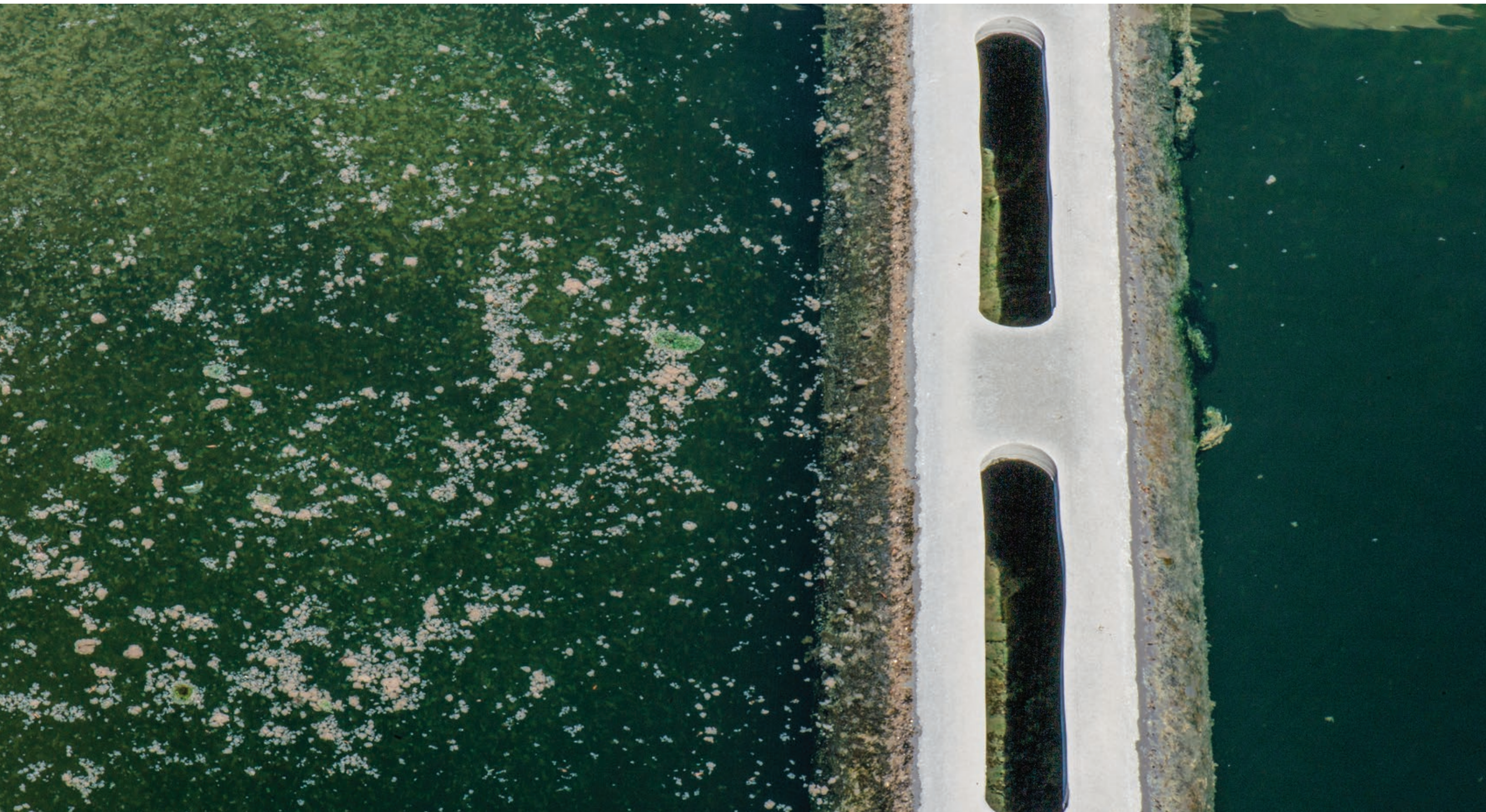
Physical consolidations can provide customers of struggling systems with access to larger water systems that have a sufficient ratepayer base to buffer groundwater level drops and changes in water quality. When supported by residents, physical consolidations allow water systems to grow and have sufficient income to adjust to shocks and stresses. This will be increasingly important as climate change alters weather patterns and if groundwater management does not sufficiently address drinking water access requirements.

### 3. Standardize data and methodologies

The findings in this report underscore the importance of centralized, standardized, and publicly available data and methods for assessing impact. First, water system demographics are not readily available, increasing the work required to do such assessments. The state should supply such a dataset to be incorporated into all GSPs. Second, public water supply well data is not easily accessible. GSAs should begin collecting and publishing PSW data that has primarily been collected by the counties. Finally, GSAs must collect and submit data on groundwater levels over time. Data from these monitoring networks can indicate the vulnerability of nearby domestic wells. Because all GSAs will provide data to the state, proactive, regional assessments of risk can be undertaken before people lose access to water during a drought or period of low groundwater levels. In other words, representative monitoring networks should be near vulnerable domestic and PSWs so that rapid solutions can be implemented if groundwater levels begin to decline. Finally, GSAs can improving coverage of well construction data via field investigations and engagement with potentially impacted well owners and systems.

### 4. Increase agency collaboration and communication

As the Department of Water Resources (DWR) reviews GSPs, they should work with the State Water Resources Control Board (SWRCB) to develop criteria that assess GSPs for their consideration of the Human Right to Water in the plans. Furthermore, the current versions of GSPs should be critically reviewed by DWR and SWRCB to ensure sufficient mitigation plans are in place. Finally, DWR and the SWRCB both have ongoing initiatives to improve data availability and provide additional analyses, such as the SWRCB's Aquifer Risk Map and Drinking Water Needs Analysis, and DWR's updated SGMA Data Viewer and Water Shortage Risk Tool. Discussions of how knowledge generated from all these efforts can assist GSAs in managing groundwater and preventing interruptions in drinking water service should be held between DWR, SWRCB, GSAs, and stakeholders.



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# APPENDIX A: DATASETS USED

**Data Source: California Safe Drinking Water Information System Detail**
Author: California State Water Resources Control Board
Web address: https://sdwis.waterboards.ca.gov/PDWW/
Accessed: 01/12/2021
Contents: PWSs in California (contains basic descriptive characteristics such as location, type of system, geography, and number of active/inactive wells)
Download Sample Size: NA – data was created by hand (entering the number of active wells by water system into a spreadsheet)

**Data Source: California Water System Boundaries**
Author: UC Berkeley Water Equity Science Shop
Web address: https://drinkingwatertool.communitywatercenter.org/data/#cws-interactive
Accessed: 01/12/2021
Contents: Shapefile with PWS boundaries in California
Download Sample Size: 2,851 active community water system boundaries

**Data Source: GAMA Public Supply Well Construction and GIS Information**
Author: California State Water Resources Control Board
Web address: https://gamagroundwater.waterboards.ca.gov/gama/datadownload
Accessed: 12/20/2020
Contents: Well location/construction data with GIS fields for PSWs across California
Download Sample Size: 31,261 wells (rows) with 20 attributes (columns)

**Data Source: Online State Well Completion Reports (OSWCR)**
Author: California Department of Water Resources
Web address: https://dwr.maps.arcgis.com/apps/webappviewer/index.html?id=181078580a214c0986e2da28f8623b37
Accessed: 12/20/2020
Contents: Shapefile of wells and associated construction information
Download Sample Size: 1,023,647 wells (rows) with 45 attributes (columns)

**Data Source: 2019 American Community Survey 5-Year Estimates, Table S1903—Median Income in the Past 12 Months**
Author: United States Census Bureau
Web address: https://data.census.gov/cedsci/table?t=Income%20and%20Poverty&g=0400000US06.860000&tid=ACSST5Y2019.S1903
Accessed: 03/01/2021
Contents: Population by income per ZCTA5 area
Download Sample Size: 1,764 ZCTA5 areas (rows) and 242 attributes (columns)

**Data Source: 2019 American Community Survey 5-Year Estimates, Table B03002—Hispanic or Latino Origin by Race**
Author: United States Census Bureau
Web address: https://data.census.gov/cedsci/table?q=B03002&tid=ACSDT1Y2019.B03002
Accessed: 05/01/2021
Contents: Population by race per ZCTA5 area and margins of error
Download Sample Size: 1,764 ZCTA5 areas (rows) and 22 attributes (columns)

## CHOOSING A PUBLIC SUPPLY WELL DATASET

Understanding how many groundwater-dependent wells are vulnerable to minimum thresholds requires information about the depth, location, age, and water system associated with each well. The State of California provides three data sources for municipal wells: the Safe Drinking Water Information System (SDWIS), Online State Well Completion Report (OSWCR) dataset, and SWRCB GAMA Public Wells. SDWIS provides the number of active and inactive wells in each water system, but no location or depth data. This is likely the most up-to-date information on how many wells are in use, but cannot be used for estimating which wells are vulnerable to declining groundwater levels. The number of active wells in SDWIS is used in this report as the "true" number of active PSWs in the SJV, and is the basis of comparison for deciding the accuracy of the two datasets that can be used for this analysis.

OSWCR and SWRCB GAMA, the two datasets with depth and location data, provide varying degrees of information. Table 1A outlines the differences between these three datasets.

**Table 1A. Comparison of Public Supply Well Data Sources**

| Data Needed | OSWCR | SWRCB GAMA | SDWIS |
|---|---|---|---|
| Age | Y | N | N |
| Public Water System ID | N | Y | Y |
| Location (Coordinates) | Y | Y | N |
| Underlying Data Source | Well Completion Reports | USGS/DHS Studies | SDWIS |
| Number of PSWs in CA | 12,294 | 23,085 | NA |
| Number of PSWs in SJV | 2,008 (avg year = 1998) | 4,595 | NA |
| Number of PSWs in SJV with Total Completed Depth Data | 1,872 | 530 | NA |
| Number of PSWs in SJV with Screen Data | 1,893 | 1,737 | NA |

*Source: California Department of Water Resources OSWCR dataset, GAMA Groundwater Information System (California SWRCB 2021c), Safe Drinking Water Information System (California SWRCB 2021b).*

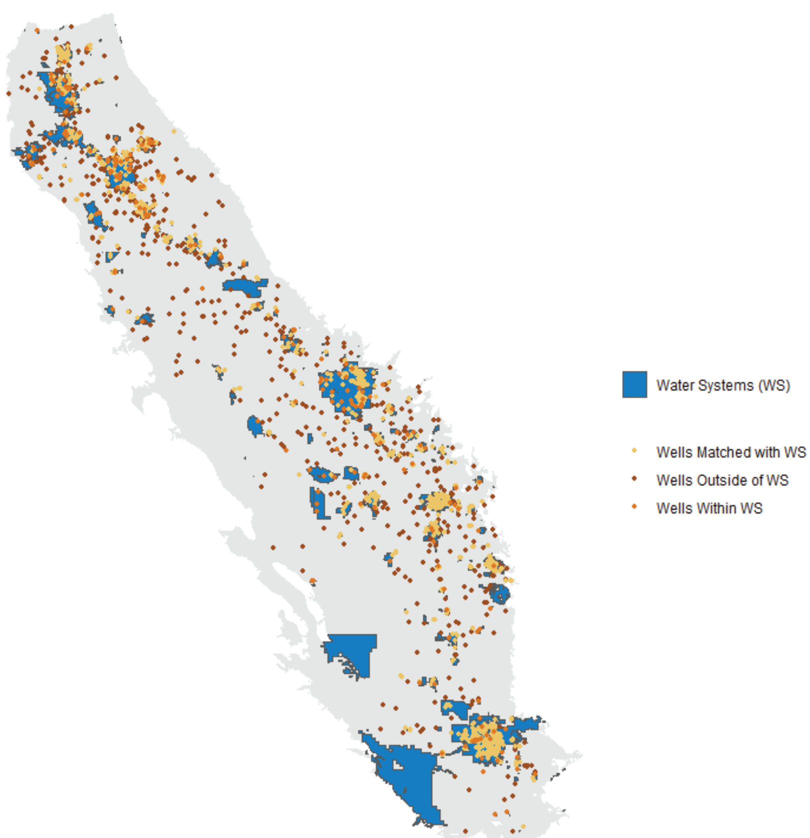
The OSWCR and SWRCB GAMA data have tradeoffs in use and do not report similar numbers of PSWs, with SWRCB estimating twice as many wells in the SJV. Both, however, overestimate the number of wells in use relative to SDWIS. SDWIS identifies 3,116 wells used for municipal supply, with 1,700 estimated to be active. OSWCR estimates over 2,000 active wells, while SWRCB estimates about 4,600.

There are some additional challenges associated with each dataset. It is unclear what the SWRCB data is used for, how many of the wells within the dataset are currently active, or how old the wells are. Conversely, the OSWCR dataset underestimates the number of PSWs by about 40%, but it is likely that many of the wells in the dataset are currently active. In addition, OSWCR data has precedent for use in well failure analyses (Water Foundation 2020). Neither dataset provides information on the water systems supplied, so a spatial analysis must be performed to understand which water systems are most vulnerable.

## CONNECTING WATER SYSTEMS TO WELLS IN THE SAN JOAQUIN VALLEY

Groundwater is a scarce resource. As water levels decline and groundwater wells dry up, water providers are required to go outside of their boundaries for access to water. Sometimes, wells will become contaminated, also forcing systems to search around their perimeters for cleaner water. Because wells do not always fall within water system boundaries, a simple spatial intersect is not sufficient to connect water systems to their wells. A spatial intersect using SWRCB data results in 1,482 wells tied to 281 water systems, underestimating the number of water systems with wells by 30%. SDWIS identifies 402 water systems with active wells. OSWCR identifies 243 systems and SWB GAMA identifies 281 water systems with at least one well.

**Figure 1A. Public Supply Wells Inside and Outside Water System Boundaries, as appears in SWRCB GAMA dataset.**




*Source: GAMA Groundwater Information System (California SWRCB 2021c)*

The spatial intersect does not perfectly match wells to water systems (Figure 1A). As a result, further work estimating wells' distance to the boundary of the water system is needed. We completed a distance matrix from each well that falls outside of a water system to the nearest boundary of a water system, and assigned wells to their closest water system. This didn't improve the accuracy of the estimate, but allowed wells outside of water systems to be associated with a system.

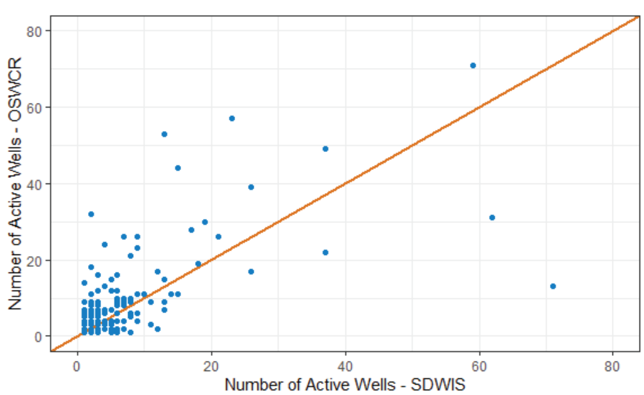
### Table 2A. Comparison Between SDWIS Attribution of Wells and OSWCR and GAMA intersections

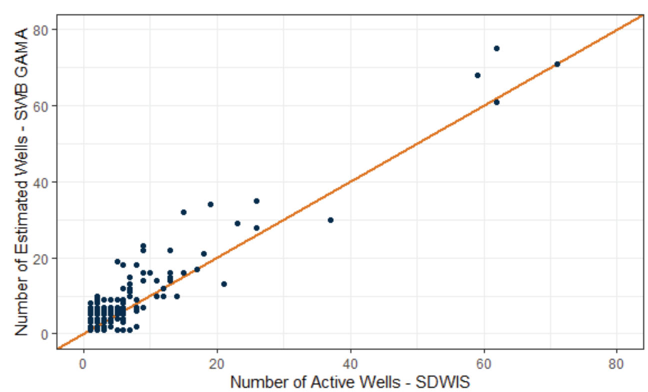
| | SDWIS | OSWCR | SWRCB GAMA |
|---|---|---|---|
| Number of Systems with at Least One Well | 402 | 243 | 281 |
| Average Number of Wells per System | 4.2 | 7.8 | 6.2 |
| Median Top of Screen Inside/ Outside Water Systems | NA | 225/260 | 219/200 |
| Number of Wells Outside Water Systems | NA | 1162 | 643 |
| Number of PSWs that Intersect with CWS Boundaries | 3,116 | 731 (40% of PSWs with Top of Screen data) | 1,094 (63% of PSWs with Top of Screen data) |

*Source: California Department of Water Resources OSWCR dataset, GAMA Groundwater Information System (California SWRCB 2021c), Safe Drinking Water Information System (California SWRCB 2021b).*

Finally, the number of wells per water system is overestimated in both datasets. The SDWS data, however, provides a relatively closer approximation (Figure 2A).

### Figure 2A. Actual Number of Wells per Water System Versus Estimated Number Based on Available Data




*Source: California Department of Water Resources OSWCR dataset, GAMA Groundwater Information System (California SWRCB 2021c), Safe Drinking Water Information System (California SWRCB 2021b).*

# APPENDIX B: IMPACTED WELLS BY GROUNDWATER SUSTAINABILITY PLAN

| GSP_Name | Public Supply Wells in GSP | Active PSWs | Partially Dry PSWs | Fully Dry PSWs | Impacted PSWs (Partially+Fully Dry) |
|---|---|---|---|---|---|
| Alpaugh | 5 | 5 | 0 | 0 | 0 |
| Buena Vista | 5 | 4 | 1 | 0 | 1 |
| Central Kings | 50 | 40 | 3 | 7 | 10 |
| Chowchilla | 17 | 7 | 3 | 7 | 10 |
| Delano-Earlimart | 16 | 6 | 7 | 3 | 10 |
| East Kaweah | 14 | 5 | 3 | 6 | 9 |
| Eastern San Joaquin | 117 | 106 | 7 | 4 | 11 |
| Eastern Tule | 51 | 10 | 26 | 15 | 41 |
| Fresno County - Delta Mendota | 1 | 0 | 0 | 1 | 1 |
| Grasslands | 2 | 2 | 0 | 0 | 0 |
| Greater Kaweah | 58 | 17 | 25 | 16 | 41 |
| Henry Miller | 1 | 0 | 1 | 0 | 1 |
| James | 8 | 3 | 3 | 2 | 5 |
| Kern Groundwater Authority | 99 | 47 | 45 | 7 | 52 |
| Kern River | 171 | 109 | 62 | 0 | 62 |
| Kings River East | 54 | 37 | 9 | 8 | 17 |
| Lower Tule River ID | 17 | 4 | 9 | 4 | 13 |
| Madera | 52 | 20 | 21 | 11 | 32 |
| McMullin Area | 8 | 4 | 1 | 3 | 4 |
| Merced | 71 | 34 | 13 | 24 | 37 |
| Mid-Kaweah | 85 | 19 | 42 | 24 | 66 |
| North Fork Kings | 19 | 7 | 8 | 4 | 12 |
| North Kings | 125 | 95 | 17 | 13 | 30 |
| Northern Central DM | 42 | 34 | 1 | 7 | 8 |
| Pixley ID | 7 | 0 | 5 | 2 | 7 |
| Root Creek | 1 | 1 | 0 | 0 | 0 |
| SJREC | 36 | 34 | 2 | 0 | 2 |
| South Kings | 19 | 18 | 1 | 0 | 1 |
| TriCounty WA - Tule | 5 | 2 | 1 | 2 | 3 |
| Tulare | 45 | 35 | 5 | 5 | 10 |
| Westlands | 6 | 2 | 4 | 0 | 4 |

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