SUSTAINABLE FOR WHOM?

EXECUTIVE SUMMARY

The Impact of SGMA's Groundwater Sustainability Plans

UCDAVIS
Center for Regional Change

EXECUTIVE SUMMARY

INTRODUCTION

Studies estimate that 1.5 – 2.5 million Californians rely on domestic wells to meet their household water needs (Johnson and Belitz 2015; Dieter et al. 2018; Pace et al. 2020). But because domestic wells are often shallow, they are also often sensitive to changes in groundwater levels. As such, sustainable groundwater management has an important role to play in safeguarding the health and safety of residents and the achievement of California’s recognized Human Right to Water.

The concept and meaning of 'sustainable groundwater management' is broadly contested. This is because the way sustainability is implemented deeply affects the health and productivity of the interconnected social, economic, and physical systems that rely on aquifers. Historically, ‘sustainable yield’ has been defined as the amount of water able to be extracted from a groundwater system without undesirable results (Todd 1961). The vagueness of ‘undesirable results’, however, led to a push to explicitly include harm to the interconnected socio-economic systems as a component of undesirable results (Freeze and Cherry 1979) . Theoretically, sustainable yield under this definition combines the needs of society and the physical constraints of aquifers, with the goal of maximizing long-term use and minimizing harm to the physical and social systems (Sophocleous 1997; 2000; Gleeson, Alley, et al. 2012). However, the task of minimizing social harm has been interpreted differently by various interest groups (Rudestam and Langridge 2014). A general definition of social harm and sustainability more broadly can also mask the vast disparities between social groups (based on race, ethnicity, class and other factors) as they experience the impacts of water distribution and management. Given the ambiguity of defining sustainability, it is important to understand how this concept is defined in local contexts and what impacts its definition has on different users when it is applied in policy.

Historical groundwater management in California over the twentieth century was not sustainable, but rather, extractive in nature (Gleeson, Wada, et al. 2012). Chronic aquifer depletion has lowered groundwater levels and made shallow domestic wells vulnerable to losing access to water. From 2012 to 2016, during the worst drought in California’s recorded history, rapid groundwater level decline caused domestic well failure (Jasechko et al. 2017; Feinstein et al. 2017; Gailey, Lund, and Medellín-Azuara 2019; Pauloo et al. 2020), loss of groundwater dependent ecosystems (The Nature Conservancy 2014), and subsidence (Liu et al. 2019). During this drought, the state received reports of more than 2,500 household well failures, primarily located in low-income communities and communities of color in the San Joaquin Valley. Although extreme, these impacts are not new, as disparities in access to drinking water in disadvantaged communities have persisted for decades (Pannu 2018; London 2018).

The loss of drinking water access challenges the feasibility of accomplishing the goals set forth in AB 685 (CA SWRCB 2012), or California's Human Right to Water. This bill outlines California's commitment to ensuring clean, affordable, and accessible drinking water for every Californian, and requires state agencies to consider the Human Right to water in policies that concern domestic well users. But as disproportionate impacts to disadvantaged communities during the recent drought have clearly shown, AB 685 remains aspirational; significant work is needed to realize this vision for all Californians.

One such area of significant work involves how California manages groundwater as a vital, shared, and scarce resource. During the 2012-2016 drought, the legislature passed the Sustainable Groundwater Management Act (SGMA) to establish a new framework for groundwater management in California. Under SGMA, Groundwater Sustainability Agencies (GSAs), created from existing public agencies, specify their definitions of sustainability. GSAs must also prevent six different 'undesirable results', including chronic groundwater overdraft[1]. These undesirable results are codified, and their prevention implemented, in Groundwater Sustainability Plans (GSPs). These documents establish a path to sustainability by setting Measurable Objectives (MO) and Minimum Thresholds (MT) for six indicators of sustainability related to undesirable results that are significant and unreasonable. A MO represents optimal conditions, and a MT is a threshold beyond which significant and unreasonable results will occur for environmental, social, or economic uses of groundwater. This analysis in this report is focused on the MTs set for lowering of groundwater levels.

Although SGMA intends to lead California towards a future of groundwater sustainability, the design of the law and the ambiguity of groundwater sustainability means that 'sustainability' will be determined locally by GSAs. Hence, it is critical to understand how local agencies assess sustainability via GSPs, based on their established MOs and MTs, as well as the spatial boundaries of their monitoring networks. The detrimental and inequitable impacts of the 2012 - 2016 drought, and the prospect of additional, longer, and more severe droughts forecasted under climate change (Rhoades, Jones, and Ullrich 2018; Swain et al. 2018), intensifies the importance of decisions made by GSAs, which will directly affect the state's ability to advance the Human Right to Water.

[1] Under SGMA, undesirable results specifically include reduction of groundwater storage, lowering of groundwater levels, seawater intrusion, degraded water quality, land subsidence and depletion of interconnected surface water.

To provide this information, this report analyzes 41 GSPs in 19 critical priority subbasins in California (in the San Joaquin Valley, Central California, and the Central Coast) to assess monitoring well coverage and the impact of MTs on domestic well failure. We find that GSPs range in lateral spatial coverage (33 - 100 %) and coverage of domestic wells (43 - 100%) within their boundaries. Overall, estimated domestic well failure rates are on par with a management regime of "business as usual" or status quo groundwater extraction (Pauloo et al. 2020). Results suggest that 1,000 - 6,000 wells are at risk of failure in critical priority basins under proposed MTs. In what follows we present the research methodology, key results, and a set of policy recommendations to assist the achievement of sustainable groundwater management in California that is compatible with the state's efforts to achieve the human right to water.

METHODOLOGY

This report examines the minimum thresholds (MTs) set for lowering of groundwater levels in 41 GSPs submitted to the Department of Water Resources for review in January 2020. These GSPs are located within 19 of 20 critically overdrafted basins in the state and, in this study, are separated into three 'regions' - San Joaquin Valley, Coastal, and Central (Figure 1). Because a domestic well requires a certain water level for operation and some require shallower water levels than others, MTs have important implications for well production and operation throughout the state. One lens to understand different definitions of groundwater sustainability (and undesirable results) is to translate GSA's local definitions into local impacts, as they are required to do as well[2]. This study defines the impacts as the extent of domestic well failure that separates undesirable results from the sustainable operating range as represented by MT groundwater levels.

Figure 1. Map of GSPs for critical priority basins analyzed in this study, categorized by region in California.

[2] 23 CCR **§354.26** (b) The description of undesirable results shall include the following: Potential effects on the beneficial uses and users of groundwater (CA DWR 2014).

MTs are set at monitoring wells located within a GSP area. The monitoring network is used to understand basin conditions and when to best implement mitigation measures when a MT is exceeded. Importantly, each monitoring well most accurately represents groundwater conditions in a specific radius around that well. Having sufficient monitoring wells in the appropriate locations is critical to accurately represent conditions across a basin; the capacity to measure groundwater sustainability defined by MOs and MTs is only as robust as the spatial density of the monitoring well network. It is paramount, therefore, to have enough monitoring wells in the appropriate locations to accurately represent conditions across a basin. For example, if production wells are too far from a monitoring well and left outside of a monitoring network, it will be challenging to measuring groundwater sustainability at these wells, which will in turn problematize implementation of management actions if and when minimum thresholds are exceeded.

DWR guidelines for a monitoring network suggests that optimal monitoring networks range from 2 to 10 monitoring wells per 100 mi2 depending on the amount of pumping and complexity of the geology (Heath 1976; DWR 2010; Hopkins 2016). In other words, a monitoring well can represent 10 - 50 mi2 of lateral extent. (In this study, we do not include vertical monitoring zones, which depend on local geologic properties including the porosity, hydraulic conductivity, and connectivity of sediments.) To approximate DWR's guidelines of lateral coverage, 36 mi2, or township-level, buffers are set around each monitoring well with the MT specified in a GSP, also consistent with basins pumping in excess of 5,000 acre-feet/year (Hopkins 2016). The total area of the buffer is compared to the area of the GSP in order to assess the percentage of monitoring network coverage. The buffer area is also compared to the location of domestic wells within a GSP, in order to understand the percentage of domestic wells that fall within the monitoring network. In this study, we focus on the unconfined and the semi-confined aquifer in which domestic wells tend to be screened, thus we only consider monitoring wells with MTs set above 400 ft in the coverage metric, as deeper water levels are likely below confining sediments.

To understand how MTs might affect domestic wells, we interpolate a theoretical groundwater surface that approximates how deep the groundwater level is likely to be across the study area using MTs specified in GSPs. The extent of the buffer is considered the maximum distance an interpolation can be performed without significant uncertainty. This surface represents a hypothetical estimation of what the groundwater level may look like if the water level reaches the level of the minimum thresholds.

Declining groundwater levels pose a threat to groundwater wells, particularly shallow ones. Moreover, pumps are susceptible to reduced water production and mechanical damage as the groundwater above the pump falls within the net positive suction head (Tullis 2007), but for the purposes of this modeling exercise, we assumed no reduction in efficiency as this level is approached. Rather, we consider the estimated pump location and total completed depth as ‘failure thresholds’. If levels fall below the pump, the well will not produce water unless the pump is lowered so it can be re-submerged. If water levels drop below the bottom of the well entirely, the well must be deepened or a new one constructed to reach groundwater.

This study calculates a range for the percent of potential domestic well failures using the MT surface described above and both the total completed depth of wells and their estimated pump locations (Pauloo et al. 2020). To calculate the lower bound on the number of wells vulnerable to failure under proposed MTs, we assume wells fail when the MT drops below the total completed depth of the well, in other words, when there is no water in the well at all (Figure 2). Although more localized studies done by GSAs can estimate the average retirement age in their region, this study assumes a 30-yr well retirement age and only includes domestic wells constructed on or after 1990. This is consistent with calibrated well retirement ages determined by Gailey, Lund, and Medellín-Azuara (2019) and Pauloo et al. (2020) in their respective regional analyses of domestic well vulnerability[3].

We estimate the upper bound by comparing which wells have pump depths that are equal to or higher than the interpolated MT water level (Figure 2). Because estimated pump locations for domestic wells are not available in the Central and Coastal regions, the upper bound of well failures is only calculated for San Joaquin Valley subbasin GSPs (35 of 41 GSPs). Although this estimate is not available for all GSPs, it is extremely important because water levels near or below pump depths render wells unable to produce water thus depriving the well-dependent residents of drinking water and water for other essential household uses. For this reason, this estimate of the upper bounds of well-failure is most reflective of immediate water access conditions in residences. By contrast, the lower bound estimate using the total completed depth represents longer-term impacts to water security that can only be remedied by increasing the depth of the well.

[3] One recent study of 26 GSPs in the San Joaquin Valley relied on an underlying domestic well dataset (Pace et al. 2020) that did not assume any retirement age; the study authors also had to exclude 25% of well completion reports (13,000/45,000) due to missing information. The authors estimated 4,000 – 12,000 partial or completely dewatered domestic well by 2040 (Water Foundation and EKI 2020).

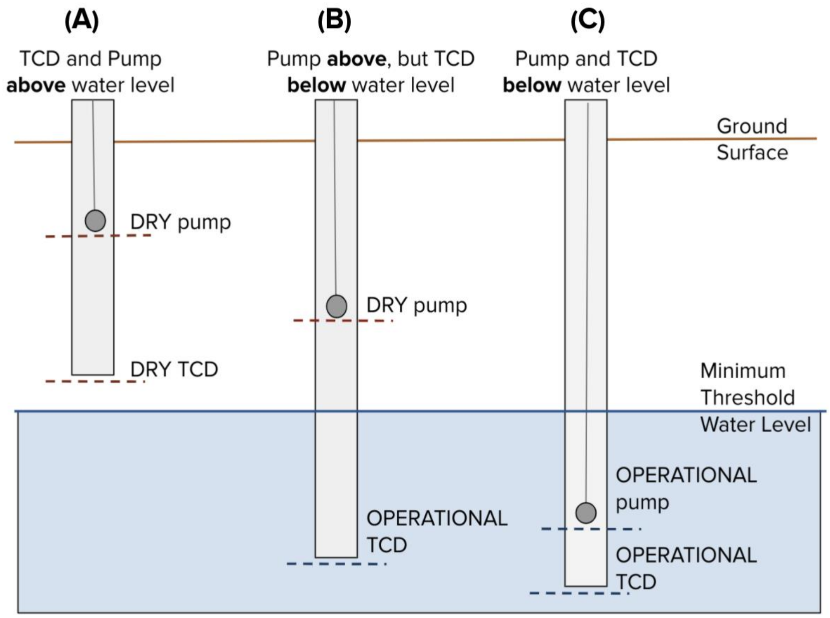

Figure 2. Conceptual model of well failure determination. Pump location used to determine well failure in SJV only.
(a) failing well according to both pump location and TCD.
(b) failing well according to pump location but active according to TCD.
(c) active well according to both pump location and TCD.

Finally, we estimate a range of the number of people reliant on domestic wells to estimate how many people rely on wells vulnerable to these MTs. The average household size is 3 people and domestic wells can support 1 – 4 households. Thus, we multiply the range of people reliant on one domestic well (3 – 12 people) by the number of wells vulnerable to MTs to obtain the range of people likely affected by MTs.

RESULTS

1. Domestic wells will likely go dry if MT groundwater levels are exceeded

Across all 41 GSPs analyzed, 10% of domestic wells have total completed depths that are vulnerable to future dewatering if water levels reach MT levels (lower bound of dry well estimate). This statewide measurement, although useful in some respects, obscures important regional differences. Comparing critically overdrafted basins among the three study regions, the SJV stands out as having the most extreme potential impacts to water access in domestic wells (Figure 3).

Percentages alone can be misleading, as shown in Figure 3 and Table 1. Figure 4 conveys the same findings as a *quantity* of vulnerable domestic wells by GSP. In Coastal and Central Basins, less than 100 wells have total completed depths that are vulnerable to potential dewatering. In the San Joaquin Valley, in contrast, nearly 800 wells would need to be deepened (if possible) in order to access water because their total completed depths are above the MT water table (Figure 4).

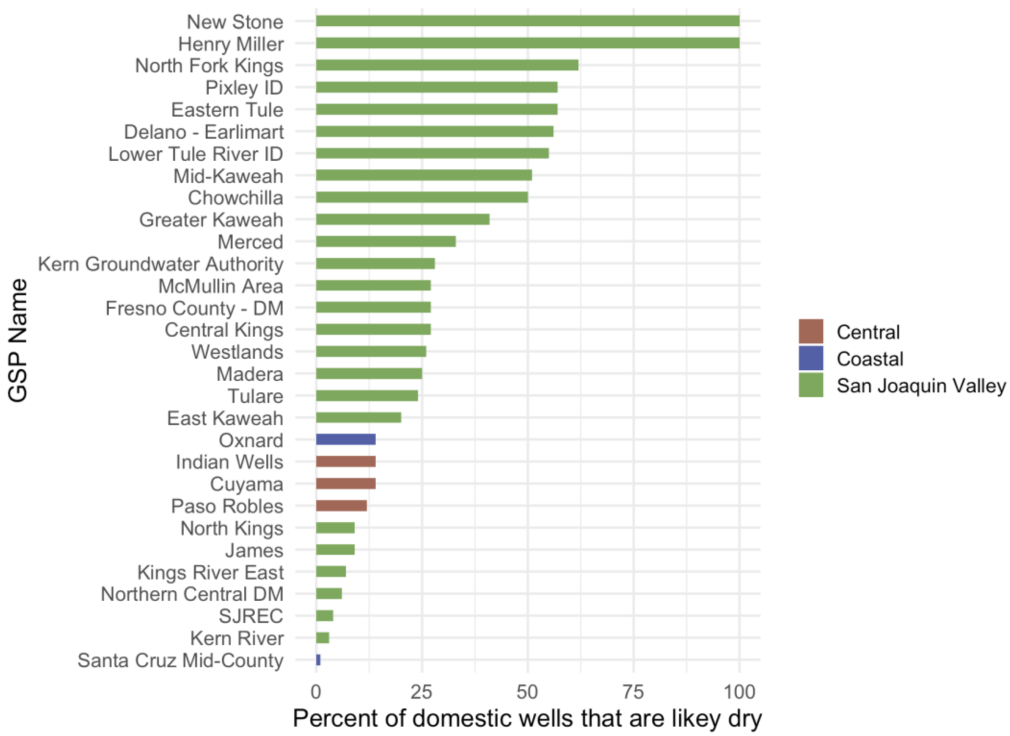

Figure 3. Percent of domestic wells vulnerable to MTs based on ***total completed depths*** *by GSP (y axis) and region (color).*

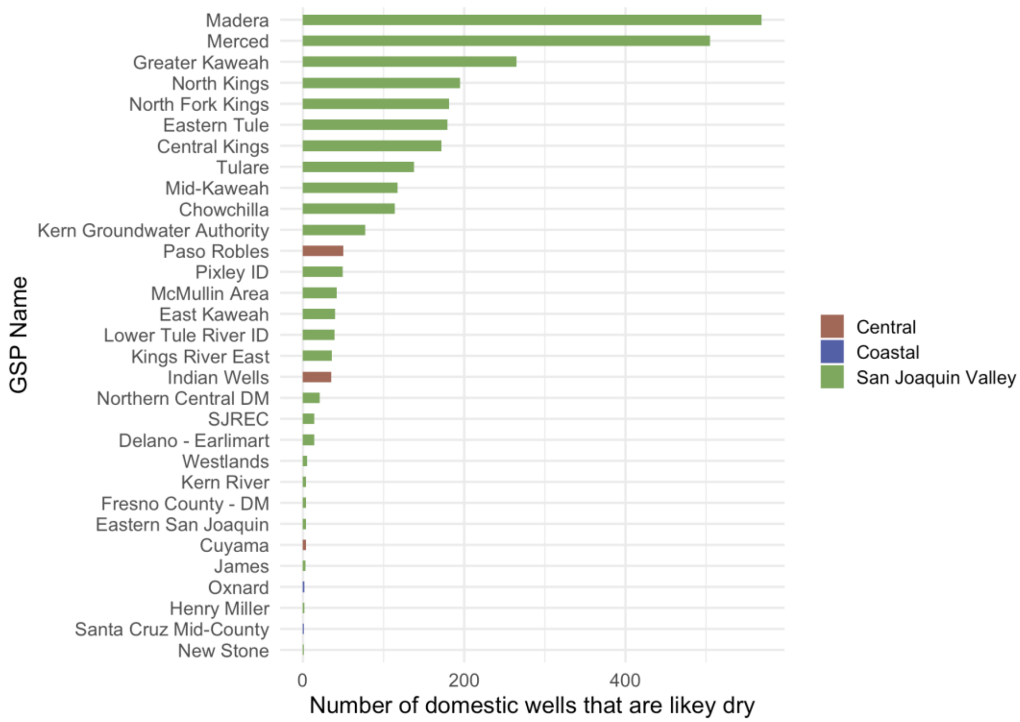

Figure 4. Count of domestic wells vulnerable to MTs based on ***total completed depths*** *by GSP (y axis) and region (color).*

	Total Completed Depth (TCD)			Pump Location		
	Average Well Failure (%)	Count of Well Failure (#)	Range of People Affected (#)	Average Well Failure (%)	Count Well Failure (#)	Range of People Affected (#)
San Joaquin	11%	765	2,295 - 9,180	61%	5,420	16,260 - 65,040
Coastal	4%	3	9 - 36	NA	NA	NA
Central	13%	89	267 - 1,068	NA	NA	NA

Table 1. Summary of the percent (rounded) and number of domestic wells and people vulnerable to MTs based on ***pump location and total completed depth (TCD).***

Table 1 also includes both the count and percentage, to better understand the quantity of vulnerable domestic wells in each GSP. In the San Joaquin Valley GSPs, 11% of, or 765 domestic wells have total completed depths above the minimum threshold surface. Using the upper estimate, however, 61% of domestic wells have estimated pump depths above the minimum threshold surface, indicating that about two thirds of wells are likely to fail at the MTs set by the GSAs, and assuming no mitigation measures are taken (e.g., pump lowering, well deepening). In other words, approximately 5,400 domestic wells in the San Joaquin Valley would at minimum need their pumps lowered in order to continue to function. The Merced GSP has the most wells with pump locations vulnerable to MTs (about 1,400 or 94%), potentially affecting a quarter of all domestic wells in the SJV.

There is significant variability in domestic well failure across SJV GSPs. Some areas have no wells whose pump locations are vulnerable to MT water levels, while others have 80 – 100% of their wells vulnerable to the MT water level. Most notably, Merced, North Fork Kings, and Eastern Tule GSPs set MTs where greater than 90% of the domestic wells in their management areas pumps at risk of dewatering (Figure 5), totaling about 1,800 wells.

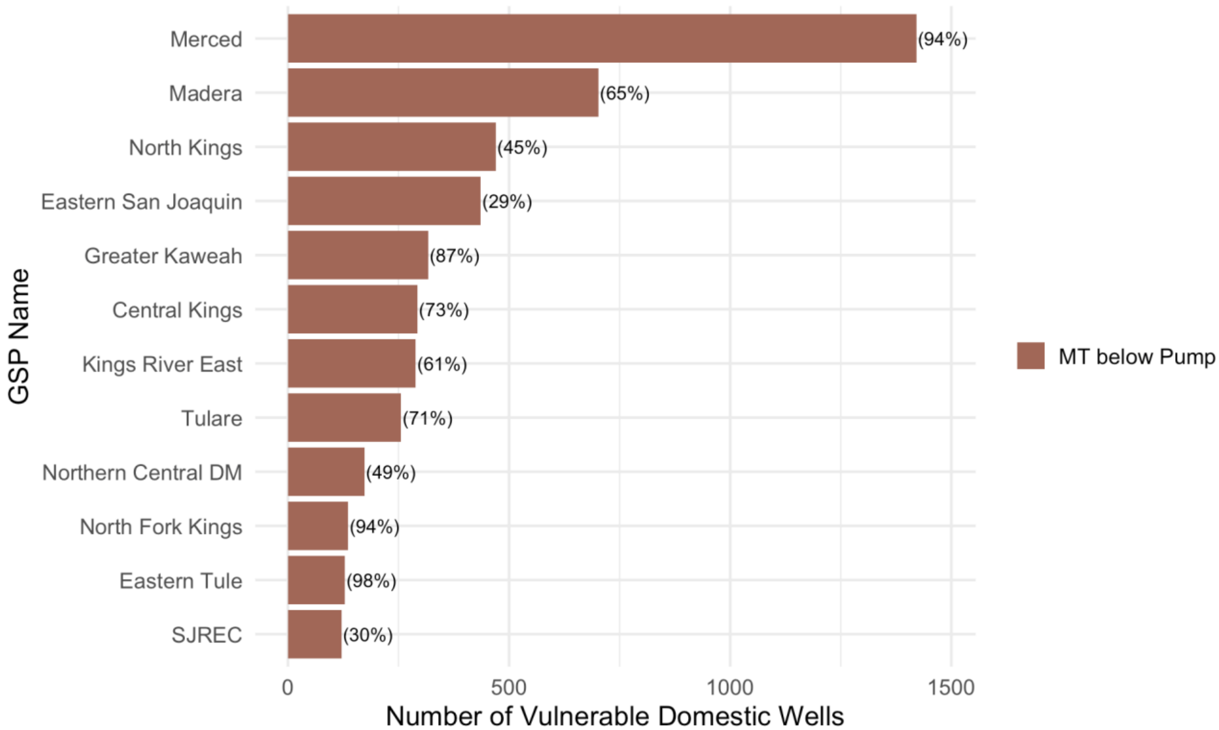

Figure 5. Number of domestic wells in the San Joaquin Valley vulnerable to MTs based on ***pump location****. Percents in parentheses represent the proportion of domestic wells vulnerable within each GSP. Shown are the 12 GSPs that cover 90% of domestic wells in the SJV.*

To understand how these results could affect disadvantaged communities (those with incomes less than 80% of the state median) specifically, we intersected domestic wells with vulnerable pumps with two different disadvantaged community (DAC) census geometries: 1) DWR's Disadvantaged Community Census Places (places) layer which uses 2016 ACS income data (DWR 2016a) and 2) DWR's Disadvantaged Census Block Groups (block groups), which also uses 2016 ACS income data (DWR 2016b)[4].

There are 203 CDPs within SJV GSPs, 132 of which are disadvantaged communities. 58 of these 132 disadvantaged community CDPs contain domestic wells completed after 1990 within their boundaries, totaling approximately 1,300 wells. Of those wells,

[4] In California, a disadvantaged community (DAC) is one with an average median household income (MHI) of less than 80% of California's overall MHI. DWR's 2016 DAC income threshold is $51,026 (80% of $63,783).

approximately 400 (30%) are vulnerable to dewatering at set minimum thresholds spread across 58 unique communities (Figure 6). These wells are located throughout many GSPs, but are concentrated in Merced, North Kings, Madera, and Eastern San Joaquin GSPs.

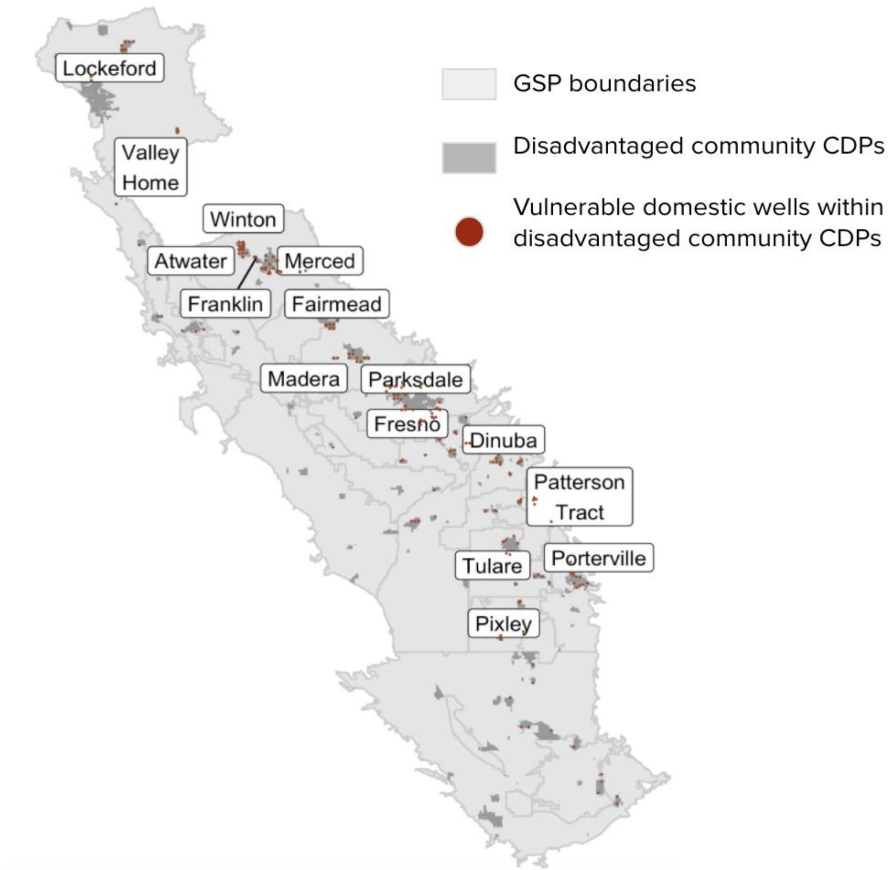

Figure 6. Disadvantaged community CDPs with domestic wells whose pumps are vulnerable to MTs. Labeled are disadvantaged communities with more than 5 vulnerable domestic wells within their boundaries.

There are 1,885 block groups within the SJV GSPs and 1,118 are classified as disadvantaged. Disadvantaged block groups make up 60% of the area within SJV GSPs. Within disadvantaged block groups, there are approximately 6,300 domestic wells completed after 1990; about 2,100 (30%) of which have pumps vulnerable to MTs (Figure 7). These 2,100 domestic wells comprise nearly 40% of all vulnerable wells within the SJV, indicating that if water levels decline, GSAs need to be prepared to support and fund enhanced mitigation efforts for vulnerable domestic wells that supply households in low-income communities, in particular.

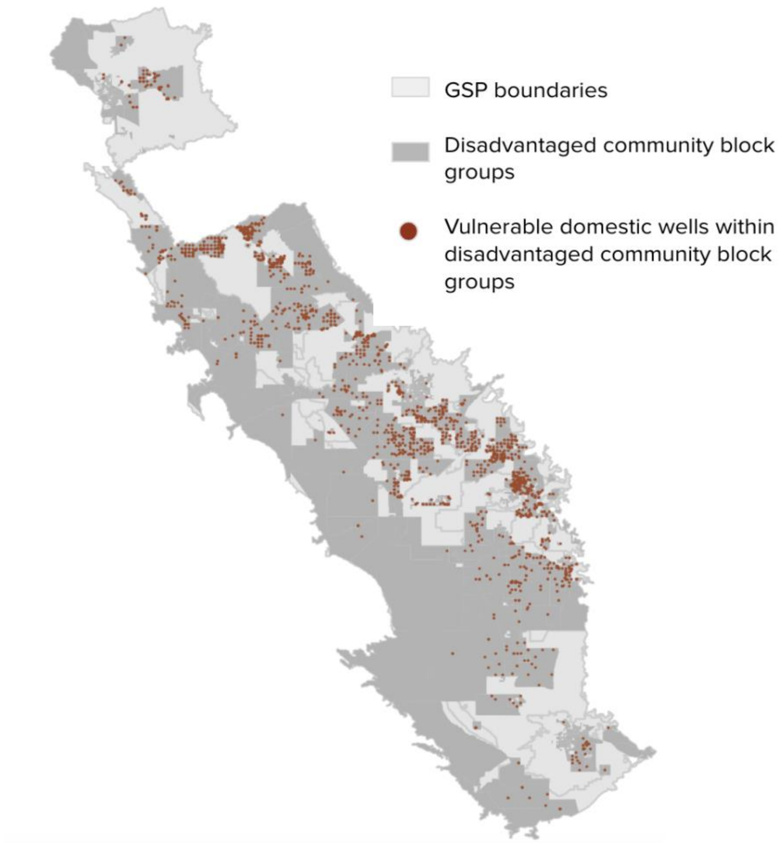

Figure 7. Disadvantaged community block groups with domestic wells whose pumps are vulnerable to MTs.

2. Monitoring networks cover most – but not all – domestic wells

Monitoring networks are essential to understanding and ensuring the longevity of sustainable water levels in a basin. They provide an understanding of groundwater levels at specific locations and, if water levels are recorded over time, can demonstrate long term trends at that location. In this report, proposed GSP networks are used as a proxy for the extent of the GSPs' ability to define sustainability and monitor progress towards that goal.

What percent of GSP management areas are included in current GSP monitoring networks?

Across all three regions and in most GSPs the established monitoring networks do not completely cover management areas (Figure 8). In other words, the networks do not have enough monitoring wells spread across their land area to represent groundwater conditions for all parts of the basin they manage. Coverage percentages, however, vary between plans and between regions. In the San Joaquin Valley, monitoring networks cover an average of 86% of the total management area but range from 33% to 100% coverage of individual GSPs (Table 2). Monitoring networks in coastal basins cover an average of 95%, ranging from 86% to 99% of their management areas. The excluded areas are found mostly along the edges of the basins, as well as in the central section of

Salinas Valley. Finally, the monitoring networks in the Central basins cover an average of only 41% of the total area in the region. Indian Wells' monitoring network extends over 24% of its basin area, with Paso Robles covering 33%, and Cuyama covering 67%.

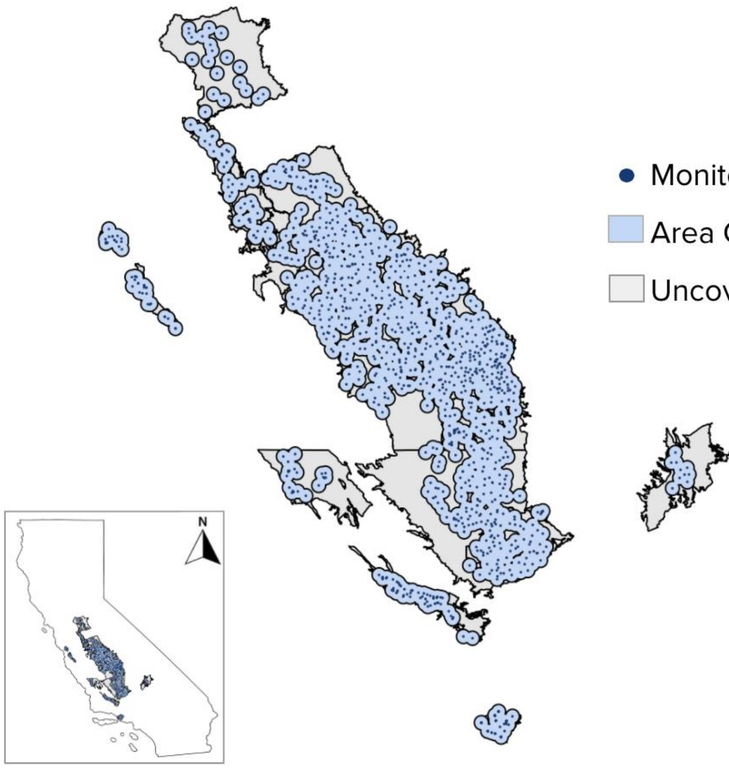

Figure 8. GSP monitoring networks wells with 36 mi² circular buffers consistent with (Heath 1976), indicating the areas covered and uncovered by monitoring wells.

What percent of domestic wells are included in current GSP monitoring networks?

Changes in groundwater levels are often driven by groundwater pumping, and thus such areas require close monitoring. Among the different types of wells, domestic wells are relatively shallow in depth, and thus the most vulnerable to the placement of MTs. Because they are the most vulnerable, a monitoring network is needed to cover areas with domestic wells. Overall, most domestic wells are included within the coverage areas of GSP monitoring networks, but for those that are left out, inadequate monitoring network coverage challenges basin-wide sustainability planning and a meaningful well failure assessment.

Monitoring network coverage of domestic wells varies by region and plan. Across all SJV GSPs, 92% of domestic wells fall within a monitoring network (Table 2). Four GSPs have monitoring networks that cover less than 80% of their domestic wells, with Eastern San Joaquin covering the fewest domestic wells, 43% of domestic wells in their subbasin. In coastal basins, domestic wells are also partially covered. In Salinas and Pleasant Valley, 65% and 83% of domestic wells are covered. All domestic wells are covered in Santa Cruz and Oxnard GSPs. Central basins don't cover most of their area, but they do cover on average 80% of domestic wells, with Paso Robles covering 75%, Indian Wells covering 78%, and Cuyama covering 88%.

	Average Area Covered (%)	Range Area Covered (%)	Average Domestic Wells Covered (%)	Range Domestic Wells Covered (%)	Number Domestic Wells Covered (#)
San Joaquin	86	33 - 100	92	43 - 100	15,000
Coastal	95	86 - 99	86	65 - 100	300
Central	41	24 - 67	80	75 - 88	700

Table 2. Summary of the percent and number domestic wells covered by GSP MTs by region.

It is important to note, however, that because GSPs have markedly different numbers of domestic wells in their management areas, similar percentages of domestic well coverage can mean very different things depending on the number of wells in different GSPs. For example, in Salinas where 68% of domestic wells are covered, about 40 domestic wells fall outside of the monitoring network and in Pleasant Valley, with 66% coverage, only 2 domestic wells are excluded and the San Joaquin River Exchange Contractors cover 78% of their basin, or about 500 domestic wells.

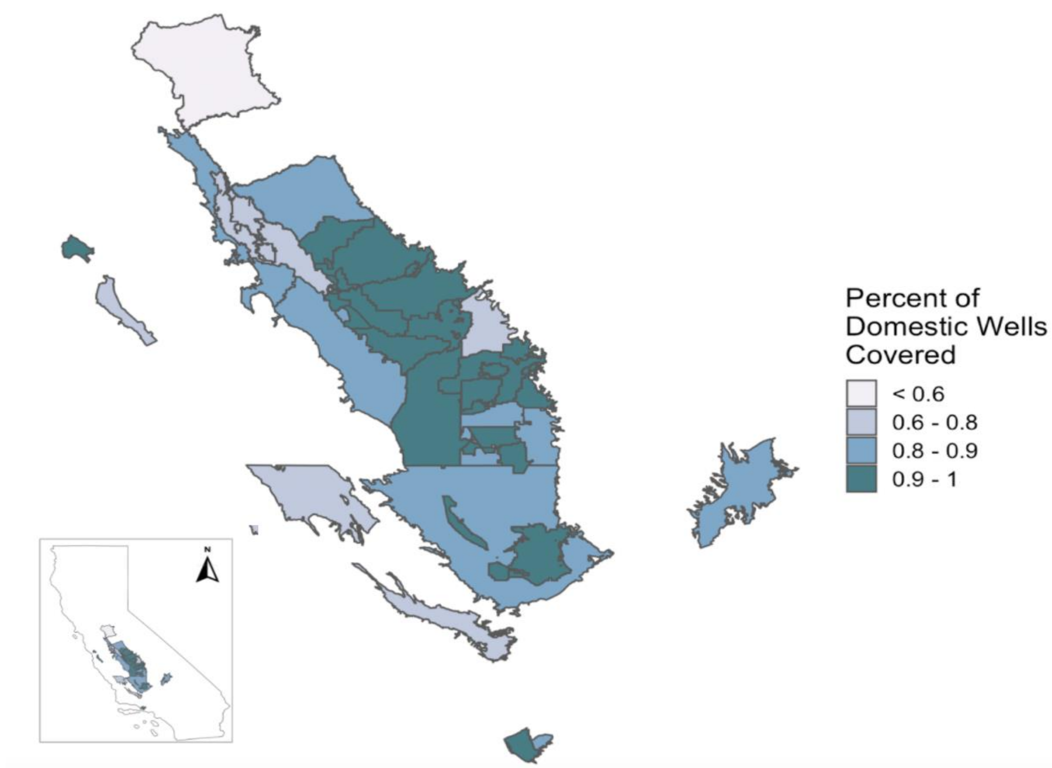

Figure 9. Map of the percent of domestic wells that fall within the GSP monitoring networks.

3. Policy Recommendations

Local definitions of sustainability defined by MTs differ by GSP and therefore, the potential implications for domestic well failure also differ among GSPs. Although GSPs set different MTs, what they all have in common is setting these MTs below current groundwater levels and even recent drought lows. This means that groundwater levels will decline in most subbasins, and that thousands of domestic wells are vulnerable. We now propose and discuss several recommended actions to address these risks.

A. *DWR can and should reject plans that are forecasted to cause significant well failure, and that lack sufficient mitigation plans*.

California state water agencies such as DWR have the regulatory power to reject groundwater plans. The Department of Water Resources can decide that minimum thresholds (MTs) set in GSPs may cause significant and unreasonable impacts to domestic wells and ask GSAs for revisions. If local GSPs are persistently insufficient, DWR has the power to intervene and manage groundwater basins in place of GSAs. State agencies should use the results presented in this report and similar studies to inform that intervention and management. Ultimately, if the state and GSAs cannot agree on what constitutes a significant and unreasonable impact, the state may overrule the GSAs on grounds of upholding the Human Right to Water.

B. *Robust and well-funded mitigation programs are needed to address inevitable domestic wells failure*.

Mitigation programs that do not monitor for or protect domestic wells with water supply contingency plans are in violation of the Human Right to Water. The responsibility of funding and providing clean water to residents who lose access to their domestic wells should not fall to other government programs, like the State Water Board's SAFER program. Instead, these costs should be paid locally, as they are a direct result of local decisions in defining groundwater sustainability. See Self Help Enterprises, Leadership Counsel for Justice and Accountability, and Community Water Center (2020).

C. *Additional studies on the socio-economic profile of populations dependent on domestic wells should be conducted to ensure that California meets its commitment to the Human Right to Water.*

Many low-income people and people of color live in disadvantaged communities and rely on vulnerable domestic wells. These same households and communities often lack the financial and political capital to influence groundwater planning and definitions of sustainability. Analyses of these disparities are important to develop effective and equitable policy solutions. In addition, it is impossible to understand these disparities without knowing how many people are reliant on domestic wells. Furthering studies done by Johnson and Belitz (2015) and Pace et al. (2020) can shape decision making and mitigation actions in a robust way.

D. *Use more than one metric for assessing impact to domestic wells.*

Understanding the total completed depth of a well gives the lowest, most conservative, estimate of well failure under MTs. Performing an analysis of this kind with full understanding of the pump locations of domestic wells provides a more realistic, usually higher, well failure estimate. However this parameter is difficult to ascertain, and well owner participation in a future study would help reduce the uncertainty inherent in this approach.

E. *Improve the extent and density of monitoring networks.*

Sustainability can only be managed where there are sufficient monitoring networks. GSAs can improve their understanding of domestic well vulnerability and ability to respond to undesirable results by adding more monitoring wells across their area, especially in areas where domestic wells are present. Nonprofit advocacy groups provide a framework for establishing monitoring networks and management actions that protect domestic wells and mitigate well failure. See Self Help Enterprises, Leadership Counsel for Justice and Accountability, and Community Water Center (2020)

F. *Understand the distribution of domestic well ages, depths, and pumping capacities.*

The analyses in this report are limited by a lack of information about exact pump locations in all basins and an inadequate understanding of domestic well retirement ages. 1990 is likely an underestimation of the average retirement age of domestic wells. When assessing impacts to domestic wells, GSAs should make a concerted effort to gather data on the wells, including the age, pump location, and total completed depth of all domestic wells. More complete domestic well data will inform assessments of the impacts of MTs, which can then be used to define more reasonable MTs that protect domestic wells. Furthermore, this data may be used to inform other critical management questions. For instance, can strategic siting of managed aquifer recharge reduce the vulnerability of domestic wells to failure (Maples, Fogg, and Maxwell 2019).

G. *Require monitoring well construction details, groundwater contours, and SMCs to be included in the public data portals.*

It is incredibly challenging to understand the impacts of MOs and MTs when the data is provided exclusively in pdf form as is the case in current GSPs. For greater transparency, all data that is able to be made public should be available in formats that are easily accessible to the public.

In conclusion, GSAs can improve GSPs to better protect vulnerable domestic wells and their users by ensuring monitoring networks offer adequate coverage in areas where domestic wells are present, understanding attributes of domestic wells in their area (i.e., location, age, depth, pump location), and redefining sustainability through resetting their MOs and MTs. In this way California can make bold strides towards meeting its visionary policy on the Human Right to Water.

AUTHORS

Darcy Bostic recently received her Master's in Hydrologic Sciences from the University of California Davis and is now a Research Associate at the Pacific Institute. She is the lead researcher and writer of the report.

Kristin Dobbin is a PhD candidate in the Graduate Group in Ecology at the University of California Davis. She provided valuable advice for the study and editing of the report.

Rich Pauloo recently received his PhD in Hydrologic Sciences from the University of California, Davis and now works as a Project Scientist with Larry Walker and Associates. He provided valuable data, data analysis, and methodology for the study.

Jessica Mendoza and Michael Kuo are undergraduate research assistants in the Center for Environmental Policy and Behavior. They provided data analysis assistance on the project.

Jonathan London is Associate Professor in the Department of Human Ecology and Faculty Director of the Center for Regional Change. He was the primary investigator (PI) for this project and editor of the report.

PREFERRED CITATION

Bostic, Darcy; Kristin Dobbin; Rich Pauloo; Jessica Mendoza; Michael Kuo; Jonathan London. 2020. *Sustainable for Whom? The Impact of Groundwater Sustainability Plans on Domestic Wells.* UC Davis Center for Regional Change.

ACKNOWLEDGEMENTS

We would like to thank Water Foundation and Microsoft AI for Earth for their funding of this project. Thank you to Leadership Counsel for Justice and Accountability, Self Help Enterprises, Community Water Center, Amanda Fencl, Mark Lubell, Graham Fogg, Alvar Escriva-Bou, and Helen Dahlke for their input and advice. Thank you to Chelsea Jimenez for designing this report.

REFERENCES

CA DWR. 2014. “SGMA.” 2014. http://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management.

CA SWRCB. 2012. “Human Right to Water.” Human Right to Water. 2012. https://www.waterboards.ca.gov/water_issues/programs/hr2w/.

Dieter, Cheryl A., Molly A. Maupin, Rodney R. Caldwell, Melissa A. Harris, Tamara I. Ivahnenko, John K. Lovelace, Nancy L. Barber, and Kristin S. Linsey. 2018. “Estimated Use of Water in the United States in 2015.” USGS Numbered Series 1441. *Estimated Use of Water in the United States in 2015*. Vol. 1441. Circular. Reston, VA: U.S. Geological Survey. https://doi.org/10.3133/cir1441.

DWR. 2016a. “Census Place Disadvantaged Communities.” https://gis.water.ca.gov/arcgis/rest/services/Boundaries/i03_Census_Place_DisadvantagedCommunities_2016/MapServer.

———. 2016b. “DWR DAC Block Group Layer.” https://gis.water.ca.gov/arcgis/rest/services/Boundaries/i03_Census_BlockGroup_DisadvantagedCommunities_2016/MapServer.

DWR, CA. 2010. “Groundwater Elevation Monitoring Guidelines.” https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/CASGEM/Files/CASGEM-DWR-GW-Guidelines-Final-121510.pdf.

Feinstein, Laura, Rapichan Phurisamban, Amanda Ford, Christine Tyler, and Ayana Crawford. 2017. “Drought and Equity in California.” Pacific Institute.

Freeze, R. Allen, and John A. Cherry. 1979. *Groundwater*. http://hydrogeologistswithoutborders.org/wordpress/1979-english/.

Gailey, Robert M., Jay R. Lund, and Josué Medellín-Azuara. 2019. “Domestic Well Reliability: Evaluating Supply Interruptions from Groundwater Overdraft, Estimating Costs and Managing Economic Externalities.” *Hydrogeology Journal* 27 (4): 1159–82. https://doi.org/10.1007/s10040-019-01929-w.

Gleeson, Tom, William M. Alley, Diana M. Allen, Marios A. Sophocleous, Yangxiao Zhou, Makoto Taniguchi, and Jonathan VanderSteen. 2012. “Towards Sustainable Groundwater Use: Setting Long-Term Goals, Backcasting, and Managing Adaptively.” *Groundwater* 50 (1): 19–26. https://doi.org/10.1111/j.1745-6584.2011.00825.x.

Gleeson, Tom, Yoshihide Wada, Marc F. P. Bierkens, and Ludovicus P. H. van Beek. 2012. “Water Balance of Global Aquifers Revealed by Groundwater Footprint.” *Nature* 488 (7410): 197–200. https://doi.org/10.1038/nature11295.

Heath, Ralph C. 1976. “Design of Ground–Water Level Observation–Well Programs.” *Groundwater* 14 (2): 71–77. https://doi.org/10.1111/j.1745-6584.1976.tb03635.x.

Hopkins, Janie. 2016. “A Field Manual for Groundwater-Level Monitoring at the Texas Water Development Board,” 26.

Jasechko, Scott, Debra Perrone, Kevin M. Befus, M. Bayani Cardenas, Grant Ferguson, Tom Gleeson, Elco Luijendijk, et al. 2017. “Global Aquifers Dominated by Fossil Groundwaters but Wells Vulnerable to Modern Contamination.” *Nature Geoscience* 10 (6): 425–29. https://doi.org/10.1038/ngeo2943.

Johnson, Tyler D., and Kenneth Belitz. 2015. “Identifying the Location and Population Served by Domestic Wells in California.” *Journal of Hydrology: Regional Studies* 3 (March): 31–86. https://doi.org/10.1016/j.ejrh.2014.09.002.

Liu, Zhen, Pang-Wei Liu, Elias Massoud, Tom G. Farr, Paul Lundgren, and James S. Famiglietti. 2019. “Monitoring Groundwater Change in California’s Central Valley Using Sentinel-1 and GRACE Observations.” *Geosciences* 9 (10): 436. https://doi.org/10.3390/geosciences9100436.

London, Jonathan. 2018. “The Struggle for Water Justice in California’s San Joaquin Valley: A Focus on Disadvantaged Unincorporated Communities.” 2018. https://regionalchange.ucdavis.edu/sites/g/files/dgvnsk986/files/inline-files/The%20Struggle%20for%20Water%20Justice%20FULL%20REPORT_0.pdf.

Maples, Stephen R., Graham E. Fogg, and Reed M. Maxwell. 2019. “Modeling Managed Aquifer Recharge Processes in a Highly Heterogeneous, Semi-Confined Aquifer System.” *Hydrogeology Journal* 27 (8): 2869–88. https://doi.org/10.1007/s10040-019-02033-9.

Pace, Clare, Carolina Balazs, Lara Cushing, and Rachel Morello-Frosch. 2020. “Locating Domestic Well Communities in California: A Methodological Overview.” UC Berkeley.

Pannu, Camille. 2018. “Bridging the Safe Drinking Water Gap for California’s Rural Poor.” *Hastings Environmental Law Journal* 24 (2): 19.

Pauloo, R A, A Escriva-Bou, H Dahlke, A Fencl, H Guillon, and G E Fogg. 2020. “Domestic Well Vulnerability to Drought Duration and Unsustainable Groundwater Management in California’s Central Valley.” *Environmental Research Letters* 15 (4): 044010. https://doi.org/10.1088/1748-9326/ab6f10.

Rhoades, Alan M., Andrew D. Jones, and Paul A. Ullrich. 2018. “The Changing Character of the California Sierra Nevada as a Natural Reservoir.” *Geophysical Research Letters* 45 (23): 13,008-13,019. https://doi.org/10.1029/2018GL080308.

Rudestam, Kirsten, and Ruth Langridge. 2014. “Sustainable Yield in Theory and Practice: Bridging Scientific and Mainstream Vernacular.” *Groundwater* 52 (S1): 90–99. https://doi.org/10.1111/gwat.12160.

Self Help Enterprises, Leadership Counsel for Justice and Accountability, and Community Water Center. 2020. “Framework for a Drinking Water Well Impact Mitigation Program.” https://d3n8a8pro7vhmx.cloudfront.net/communitywatercenter/pages/3928/attachments/original/1590776730/Well_Mitigation_Print.pdf?1590776730.

Sophocleous, Marios. 1997. “Managing Water Resources Systems: Why ‘Safe Yield’ Is Not Sustainable.” *Groundwater* 35 (4): 561–561. https://doi.org/10.1111/j.1745-6584.1997.tb00116.x.

———. 2000. “The Origin and Evolution of Safe-Yield Policies in the Kansas Groundwater Management Districts.” *Natural Resources Research* 9 (2): 99–110. https://doi.org/10.1023/A:1010139325667.

Swain, Daniel L., Baird Langenbrunner, J. David Neelin, and Alex Hall. 2018. “Increasing Precipitation Volatility in Twenty-First-Century California.” *Nature Climate Change* 8 (5): 427–33. https://doi.org/10.1038/s41558-018-0140-y.

The Nature Conservancy. 2014. “Groundwater and Stream Interaction in California’s Central Valley: Insights for Sustainable Groundwater Management.” 2014. https://www.scienceforconservation.org/assets/downloads/GroundwaterStreamInteraction_2016.pdf.

Todd, D.K. 1961. “Ground Water Hydrology.” *Quarterly Journal of the Royal Meteorological Society* 87 (371): 122–122. https://doi.org/10.1002/qj.49708737126.

Tullis. 2007. “Fundamentals of Cavitation.” In *Hydraulics of Pipelines*, 119–32. John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470172803.ch5.

Water Foundation, and EKI. 2020. “Estimated Numbers of Californians Reliant on Domestic Wells Impacted as a Result of the Sustainability Criteria Defined in Selected San Joaquin Valley Groundwater Sustainability Plans and Associated Costs to Mitigate Those Impacts.” https://waterfdn.org/wp-content/uploads/2020/05/Domestic-Well-Impacts_White-Paper_2020-04-09.pdf.