SUSTAINABLE FOR WHOM?

The Impact of Groundwater Sustainability Plans on Domestic Wells

UCDAVIS
Center for Regional Change

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GLOSSARY

AB 685 - The Human Right to Water requires the state to recognize and consider in all policy that "every human being has the right to safe, clean, affordable, and accessible water adequate for human consumption, cooking, and sanitary purposes." The human right to water extends to all Californians, including disadvantaged individuals and groups and communities in rural and urban areas." (CA SWRCB 2012)

Critically Overdrafted Groundwater Basin - As defined by SGMA, "A basin is subject to critical overdraft when continuation of present water management practices would probably result in significant adverse overdraft-related environmental, social, or economic impacts." (DWR 2018a)

Domestic Well - A well used for household purposes and fewer than 5 connections.

Interpolation - A process of inferring, or creating, new data based on the shape or values of available data. (Bivand, Pebesma, and Gómez-Rubio 2008)

Minimum Threshold (MT) - A minimum threshold is the quantitative value that represents the groundwater conditions at a representative monitoring site that, when exceeded individually or in combination with minimum thresholds at other monitoring sites, may cause an undesirable result(s) in the basin. (Laird and Cowin 2016)

Measurable Objective (MO) - Measurable objectives are quantitative goals that reflect the basin's desired groundwater conditions and allow the GSA to achieve the sustainability goal within 20 years. (Laird and Cowin 2016)

SGMA - "A three-bill legislative package, composed of AB 1739, SB 1168, and SB 1319, collectively known as the Sustainable Groundwater Management Act (SGMA). It outlines the "management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results."" (DWR 2014)

Total Completed Depth (TCD) - The depth of the bottom of a well. Usually measured in feet below ground surface.

Well Failure, Well Vulnerability, Dry Well - These terms are used synonymously within this report. They all refer to a well that is unable to function due to groundwater levels being below the pump or total completed depth of the well.

INTRODUCTION

Groundwater is a hidden resource that creates interdependencies between users sharing a common basin. In other words, users can make decisions to extract groundwater independent from the decisions of their neighbors (Giordano and Villholth 2007), but when one user extracts water, less remains for others. Dramatic droughts and groundwater overdraft in aquifers around the world have highlighted the critical importance of this resource for social, economic, and environmental well-being. It is increasingly recognized that solutions to groundwater overdraft require the expertise of scientists and residents, that respond to community perceptions and values (Simpson and Loë 2014) and incorporate all users and uses of groundwater into planning (Hoogesteger and Wester 2017).

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 et al. 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 Central 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 et al. 2018).

Such 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 their policies that concern domestic well users. But as the recent drought and its disproportionate impacts have clearly shown, AB 685 remains aspirational; significant work is needed to realize this vision for all Californians.

One such area for improvement concerns how California manages groundwater as a vital, shared, and scarce resource. As wells failed due to increased groundwater usage during the 2012-2016 drought, the legislature passed the Sustainable Groundwater Management Act (SGMA) establishing a new framework for managing groundwater in California. SGMA, which went into effect in January 2015, establishes a framework within which local agencies specify their definitions of sustainability. Under the Act, Groundwater Sustainability Agencies (GSAs), created from existing public agencies, are tasked with preventing 'undesirable results', such as groundwater overdraft. These undesirable results are codified and implemented in Groundwater Sustainability Plans (GSPs), documents that establish a path to sustainability by setting Measurable Objectives (MO) and Minimum Thresholds (MT) for six indicators of sustainability, including groundwater levels. A MO represents optimal conditions, and a MT is a threshold beyond which significant and undesirable results will occur for environmental, social, or economic uses of groundwater.

Although SGMA intends to lead California towards a future of groundwater sustainability, the design of the law and the ambiguity of definitions of groundwater sustainability means that making 'sustainability' operational will be determined locally by GSAs. Hence, it is critical to understand how local agencies assess sustainability through 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 climate change which is forecasted to bring additional, longer, and more severe droughts (Rhoades, Jones, and Ullrich 2018; Swain et al. 2018), intensifies the importance of decisions made by GSAs, which will directly impact the state's ability to advance the Human Right to Water.

This report analyzes 41 GSPs in 19 critical priority subbasins in California 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 status quo management regime of "business as usual" groundwater extraction (R. A. Pauloo et al. 2020). Results suggest that 1,000 - 6,000 wells are at risk of failure in critical priority basins under proposed MTs.

UNDERSTANDING GROUNDWATER SUSTAINABILITY PLANS

SGMA defines sustainability as the management of groundwater in a manner that can be maintained without causing undesirable results. 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. While the goal of SGMA is to promote sustainable groundwater use, what is considered 'a significant and unreasonable undesirable result' is left for local agencies to define. With this essential concept open to interpretation, agencies mandated to prepare these plans have defined sustainability in different ways. Local flexibility is necessary when managing groundwater resources in a changing climate, but too much flexibility may further perpetuate socially and environmentally inequitable, unsustainable, and harmful outcomes.

Groundwater Sustainability Agencies (GSAs) are responsible for writing Groundwater Sustainability Plans (GSPs), or 20-year roadmaps for achieving sustainable groundwater use. Determining what the threshold of impact as a result of groundwater use counts as undesirable is left partly to local consensus, subject to approval by the Department of Water Resources (DWR). Every GSP establishes its own definitions of sustainability by setting two sustainable management criteria: Measurable Objectives (MOs) and Minimum Thresholds (MTs). MTs outline the minimum conditions required to avoid significant and unreasonable impacts that result from lowering of groundwater levels. MOs are sustainability goals where the balance between users of groundwater can be maintained over time. These thresholds are measured and set at specific monitoring wells within a subbasin. Some GSAs set MOs above current groundwater levels, in other words their plans aspire to improve upon recent conditions, while others are set well below any historically observed conditions, thus allowing for worsening conditions (Figure 1).

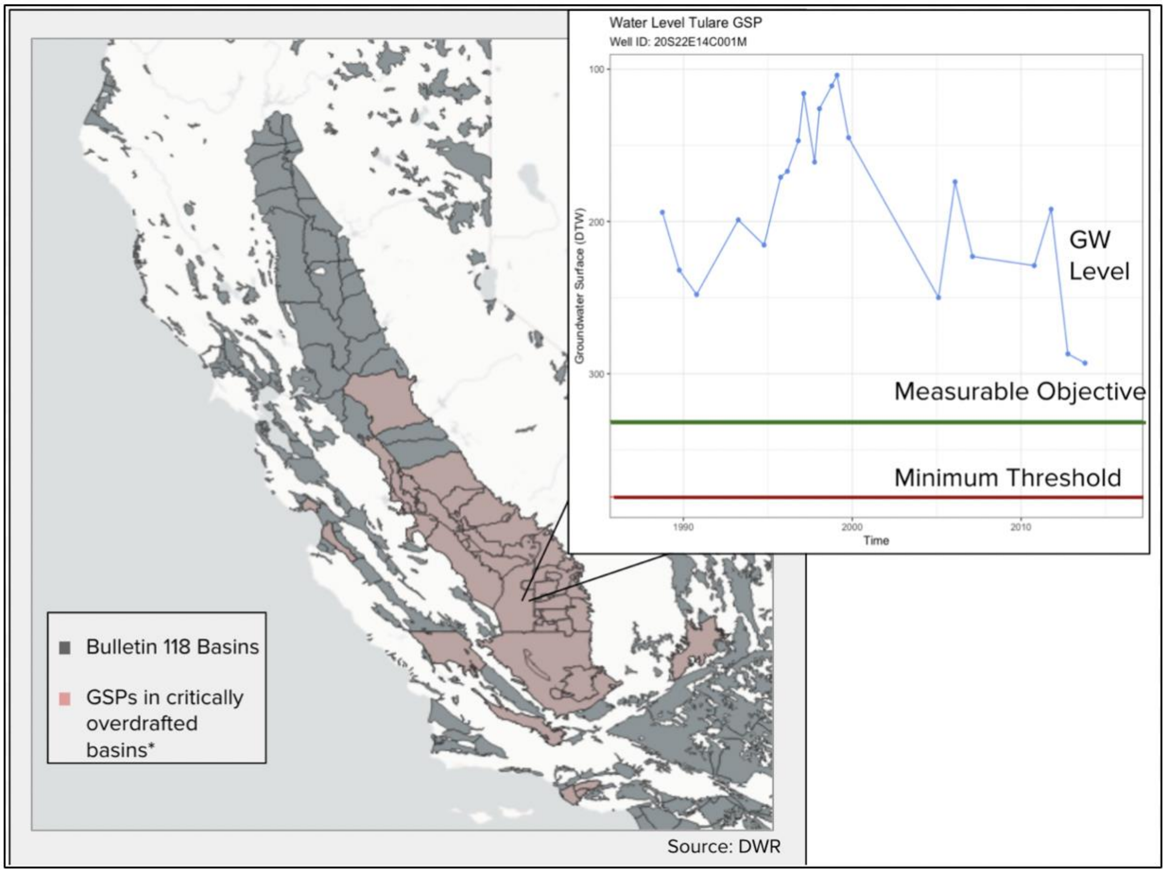

Figure 1. Map of study site and monitoring well hydrographs. Minimum thresholds are defined at monitoring wells and are set below observed groundwater levels. Hydrograph and sustainability criteria shown are from Tulare GSP.

MTs within GSPs define the lowest acceptable groundwater level before undesirable results, as defined locally, occur. Because a well requires a certain water level for operation and some wells require shallower water levels than others, these thresholds have important implications for well production and operation throughout the state. One lens to understand different definitions of groundwater sustainability is to project the impacts of these local definitions. In this case, the impacts are the extent of well failure that separates undesirable results from the sustainable operating range as represented by MT groundwater levels. It is unlikely that all basins will reach their minimum thresholds at the same time, and it is difficult to predict if they will ever reach these levels. They are, however, benchmarks of sustainability and they communicate when and where managers think undesirable results will occur.

Minimum thresholds 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 minimum threshold is exceeded. Each monitoring well most accurately represents groundwater conditions within a certain radius around that well. 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 instance, if production wells are too far from a monitoring well and/or left outside of a monitoring network, it will be difficult if not impossible to measure groundwater sustainability, and thus to implement management actions if and when minimum thresholds are exceeded.

METHODOLOGY

STUDY AREA

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 2). 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 impacts, as they are required to do as well (DWR 2014). 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.

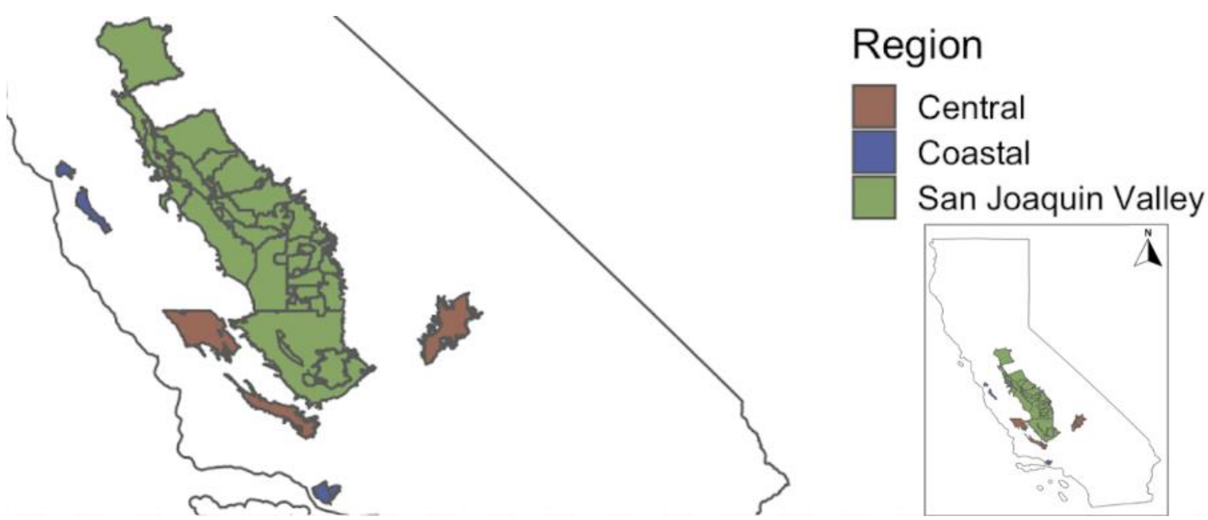

Figure 2. Map of the GSPs and their categorized regions

DATA

This analysis relies on three distinct data sources: monitoring wells with set MTs, public well completion reports, and seasonal groundwater measurements.

Current Groundwater Level Measurements

This study creates a current groundwater layer to understand the difference between current groundwater levels and the groundwater levels proposed by MTs.

For the San Joaquin Valley GSPs, seasonal (spring and fall) groundwater level data for 2018 and 2019 were used to determine the current groundwater level in the unconfined to semi-confined shallow aquifer, from which domestic wells draw. For each set of seasonal groundwater levels, we applied ordinary kriging to the log-transformed groundwater levels to map the data distribution and control for outliers. Ordinary kriging parameters were found by fitting a semivariogram with an exponential curve.

The geology in groundwater basins outside of the SJV is not as easily generalizable to a regional level, and thus current groundwater levels were not interpolated for basins external to the SJV.

Minimum Thresholds

We reviewed 41 GSPs, which include 973 unique monitoring wells with specified minimum thresholds.

All final GSPs were downloaded from the SGMA portal. From these plans, representative monitoring networks for the 'lowering of groundwater levels' sustainability indicator are extracted. To do this, well IDs are taken from tables in the GSPs and searched in the DWR Water Data Library (DWR 2012). This provides the coordinates (latitude, longitude) and reference elevation of the well. For each GSP, an Excel file of well names, coordinates, and specified MTs are recorded. If the name of the well is not found in the Water Data Library, then the map of the monitoring network was downloaded from the GSP and georeferenced in QGIS.

Reference elevations at the MT wells are estimated based on their elevation provided in the Water Data Library. If the specific MT well could not be found in the Water Data Library, then the well elevation is estimated from nearby wells with known elevations. Coordinates of MT wells are also gathered from the Water Data Library and are added to an Excel File for each GSP. If MTs were provided in units of feet above mean sea level, the reference elevation is used to convert the MT to depth to water, using the equation *Depth to Water = Reference Elevation - Feet above MSL (Mean Sea Level).* Depth to water is the necessary unit to compare the water table height to the depths of the pump intakes in the well completion reports. A shapefile containing the coordinates and MTs of wells is then created for every GSP.

Well Completion Reports

This study uses well completion reports from 943,469 wells from DWR (DWR 2018b). These wells are subset in a number of ways. First, only domestic wells are used. Second, in the SJV only, domestic wells are further subset by depth. If the bottom of the well is above the current groundwater level, it is removed. Current groundwater levels were used in basins outside of the SJV.

Finally, the well completion report database contains wells completed as far back as 1900. Since it is unlikely many wells from 1900 are still operational, only wells that are likely still in use need to be subset. The average retirement age of wells in the Central Valley is estimated to be 28 – 31 years (Gailey, Lund, and Medellín-Azuara 2019; R. A. Pauloo et al. 2020). However, anecdotal information from domestic well users and organizations working with domestic well users in the Central Valley suggests that this retirement age may be an underestimation of the average retirement age. To account for this uncertainty, different retirement ages were selected, and well counts were estimated for them (Table 1). This table clearly shows that depending on the retirement age selected, the number of wells and the average depth of the dataset changes significantly.

	Number of Wells	Average TCD
1960	87,330	205
1965	81,780	209
1970	77,006	213
1975	69,603	218
1980	54,570	228
1985	47,085	233
1990	36,142	242
1995	26,437	248
2000	19,980	254

Table 1. Table of retirement ages and number of wells within the dataset at each retirement age.

In the results that follow, the retirement age was conservatively assumed to be 29 years (wells completed in 1991 or later).

METHODS

In the following methods, we explain how we: define the lateral extent of monitoring networks, create a surface from the MT wells and use this surface to estimate the projected water level at domestic wells to find which wells are vulnerable to MT water levels.

Defining Coverage for Monitoring Networks

The unconfined to semi-confined potentiometric surface tends to approximately follow topography and is also influenced by nearby high capacity pumping wells. In California's SJV, most high capacity pumping occurs at depth beneath multiple confining layers, thus, water level variations due to that pumping are usually buffered from these effects.

The DWR guidelines for a monitoring network suggests that optimal monitoring networks range from 2 to 10 monitoring wells per 100 mi^2 depending on the amount of pumping and complexity of the geology (DWR 2010; Heath 1976; Hopkins 2016). In other words, a monitoring well can represent 10 - 50 mi^2 of lateral extent. In this study, we did not use vertical monitoring zones, which depend on local geologic properties including the porosity, hydraulic conductivity, and connectivity of sediments.

To approximate this recommended coverage level, 36 mi^2, or township-level, buffers are set around each monitoring well with the MT specified in the plan, 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.

To compute the "MT monitoring well coverage" we create and join 7mi (diameter) circular buffers around each MT well, and compare the area of these buffered regions to the GSP areas. In mountainous regions, like the coastal basins, topography was not taken into account when calculating this metric, resulting in a likely overestimation of the representation of groundwater conditions by monitoring wells.

Minimum Threshold Interpolation

We apply ordinary kriging to log-transformed minimum thresholds similar to methods used in Pauloo et al. (2020). An exponential model was fit to the semivariogram to obtain the kriging parameters. The values were back-transformed (bt) by taking the exponential of the prediction plus the variance divided by two. The means of the original MT values were compared to the mean bt values. The means differed by more than 5%. In order to correct for this, the bt values are scaled by the quotient: (mean of the original MT values over the mean of the bt values). Here we also calculate the 95% confidence interval of the kriging estimates to understand the uncertainty associated with this kriging estimate.

This methodology is performed for every subbasin in the SJV. For basins outside of the SJV, semivariograms could not be fit because the data was too sparse, so inverse distance weighting was used.

Checking for Confinement

Before assessing which wells will go dry, it is important to check that the domestic wells are in the same aquifer as the assessed minimum thresholds. If domestic wells are not in the same aquifer, then the change in groundwater level implied by the minimum thresholds will not necessarily change the groundwater level in the aquifer used by the domestic wells. In other words, distinctions between unconfined and confined aquifers are often not clear. Thus, in order to determine if MT monitoring wells occupy similar depth ranges as domestic wells, we analyze their relative depth distributions. In the SJV, we find good agreement. This suggests that water level changes in MT monitoring wells operate at similar levels of confinement for domestic wells, and hence the storage and head changes should also be similar (Figure 3).

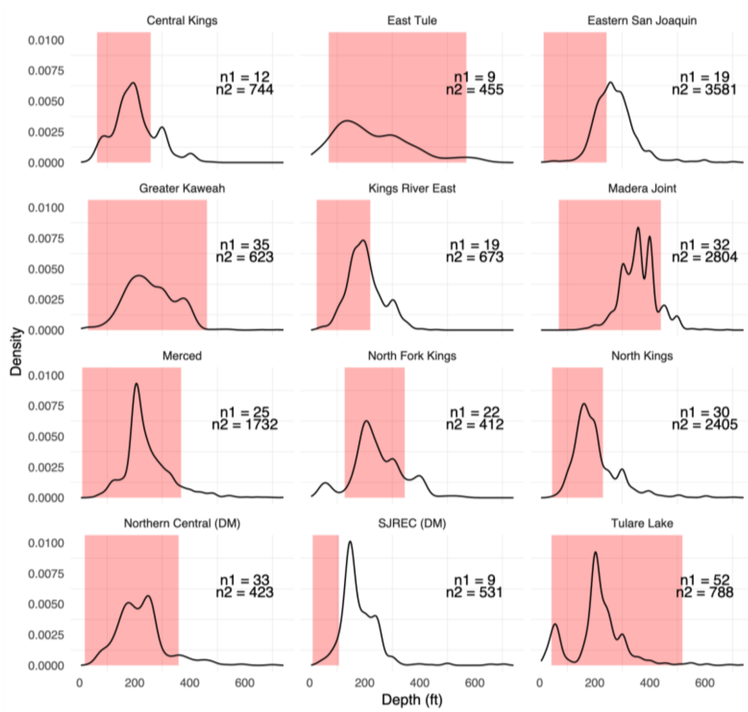

Figure 3. Plots of the distribution of monitoring well depths (n1: red) and range of domestic well depths (n2: black) in San Joaquin Valley GSPs

In the Coastal GSPs, most domestic wells have total completed depths much deeper than the minimum thresholds set in these plans (Figure 4). It is unlikely that domestic wells, especially in Salinas and Oxnard, are within the same confining layer as the minimum threshold wells. Although there is not good agreement between the minimum thresholds and the domestic well depths, an analysis was still performed to illustrate the general impacts to the few shallow domestic wells that do exist in the data.

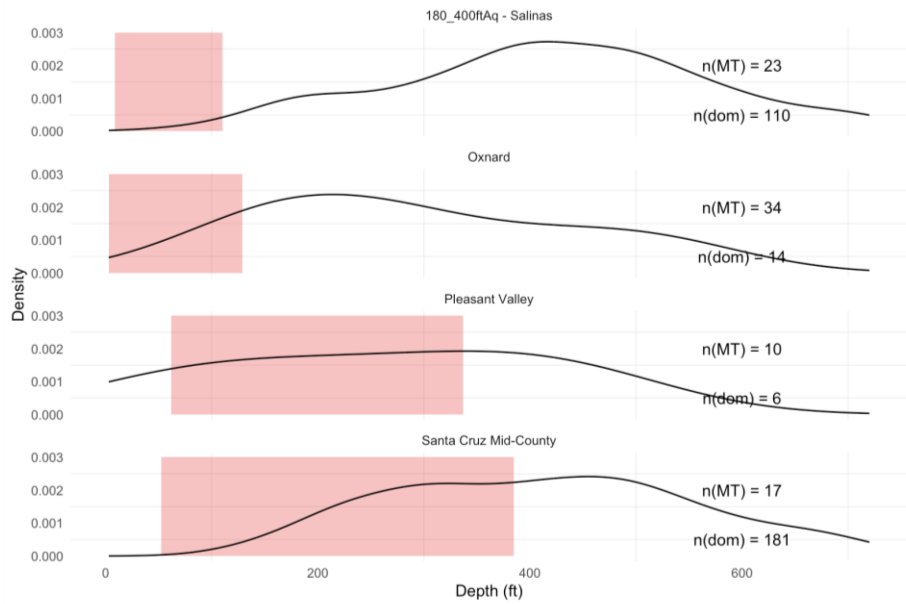

Figure 4. Plots of the range of monitoring well depths (n(MT): red) and distribution of domestic well depths (n(dom): black) in Coastal GSPs

Like Coastal GSPs, in Central GSPs most domestic wells have total completed depths that are deeper than the minimum thresholds set (Figure 5). In Cuyama, minimum thresholds are set at depths that generally align with the range of domestic well depths. Indian Wells and Paso Robles, however, do not have good agreement between the minimum threshold and domestic well depths, suggesting they are in different layers. Again, an analysis here was still performed to demonstrate general impacts to shallow domestic wells.

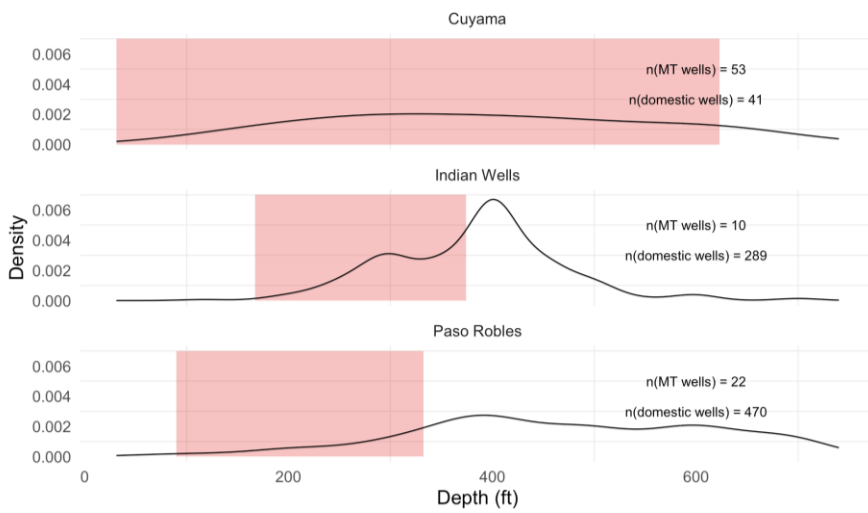

Figure 5. Density of domestic wells (black) and range of MT depths (red) in Central GSPs

Dry Well Analysis

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 (R. A. 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). As noted above, we only consider wells constructed on or after 1990, consistent with calibrated well retirement ages determined by Gailey et al. (2019) and Pauloo et al. (2020).

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 and thus the residents served by it without drinking water or water for other essential household uses. For this reason, this estimate 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.

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.

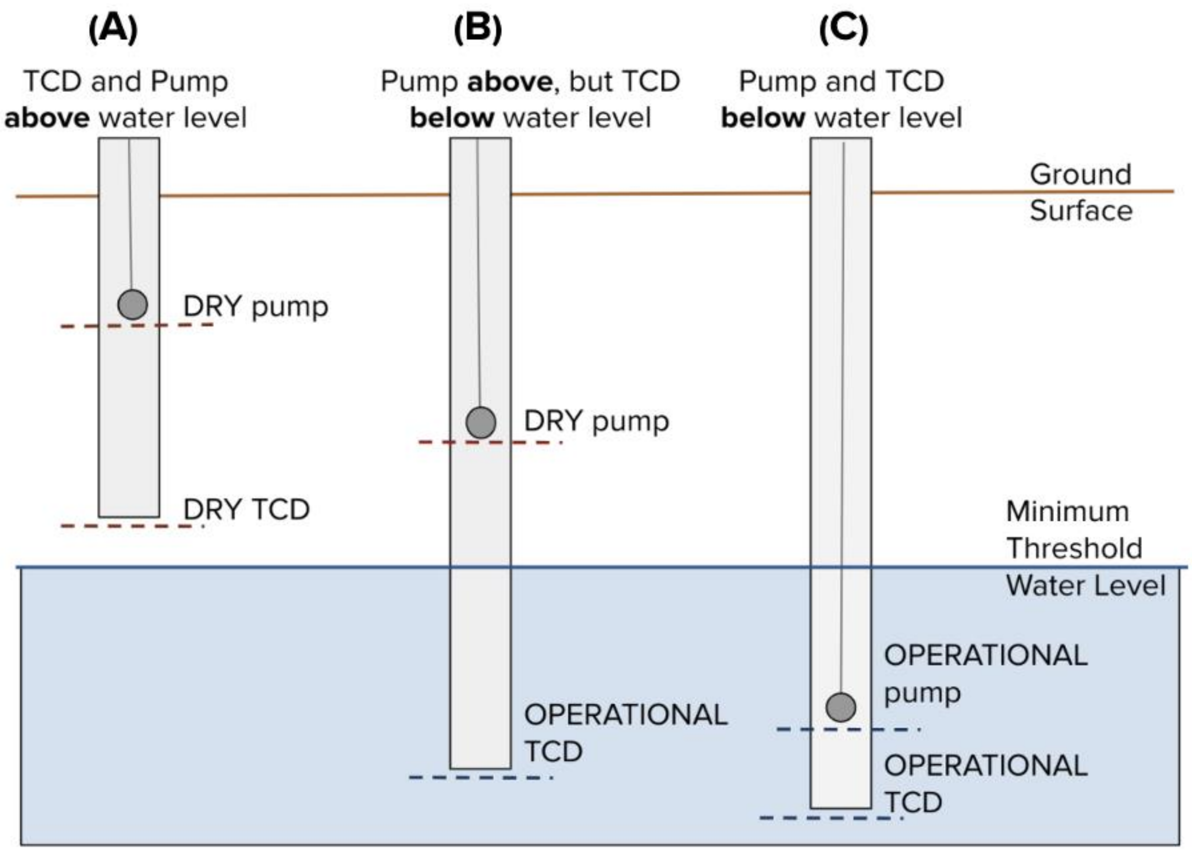

Figure 6. Conceptual model of well failure determination. Pump location used to determine well failure in SJV only.
(a) failing well according to both pump location and TCD.
(b) failing well according to pump location but active according to TCD.
(c) active well according to both pump location and TCD.

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

SAN JOAQUIN VALLEY

In the San Joaquin Valley (SJV) there are 11 critically overdrafted subbasins. Many people rely on groundwater as their exclusive source for drinking, agricultural, or industrial purposes. Especially as climate change likely lengthens droughts and surface water supplies become scarcer, groundwater in the SJV will increasingly be relied on. To compound this, these subbasins face already face dry domestic wells, degrading water quality, and subsidence (DWR 2016a; R. Pauloo, Fencl, and Escriva-Bou 2018; DWR 2018a).

Thirty four GSPs within the SJV are reviewed here. All plans are final except for those in the Madera subbasin. Plans in Madera are still considered drafts and are not yet approved by DWR. Although GSPs in Madera are not final, it is important to include them, as Madera contains 16% of domestic wells across all regions.

Of the three regions examined in this report, the SJV contains nearly all domestic wells (Table 2). Of domestic wells built after 1990 within the SJV plan areas, most are within only 4 GSPs - Eastern San Joaquin, Madera, North Kings, and Merced GSP management areas. Domestic wells in the SJV are shallower on average than wells in the Coastal or Central GSPs. The average pump depth is 55% shallower than the TCD (ranging from 44 - 74%). The implications of this are important - pumps will lose access to groundwater much earlier than the bottom of the well will.

GSP Name	Count of Domestic Wells (#)	Average TCD (DTW) (#)	Average Pump Depth (DTW) (#)	Fraction of All DWs (%)	Range of People Reliant on DWs (#)
Mid-Kaweah	251	302	148	1.3%	753 - 3,012
Chowchilla	259	368	195	1.3%	777 - 3,108
East Kaweah	266	253	117	1.4%	798 - 3,192
Kern Groundwater Authority	395	579	292	2.0%	1,185 - 4,740
North Fork Kings	439	246	145	2.2%	1,317 - 5,268
Northern Central DM	459	233	124	2.3%	1,377 - 5,508
Eastern Tule	491	225	104	2.5%	1,472 - 5,892
SJREC	570	180	89	2.9%	1,710 - 6,840
Greater Kaweah	751	256	113	3.8%	2,253 - 9,012
Kings River East	752	201	101	3.8%	2,256 - 9,024
Tulare	814	219	146	4.1%	2,442 - 9,768
Central Kings	819	201	114	4.2%	2,457 - 9,828
Merced	1,901	247	147	9.7%	5,703 - 22,812
North Kings	2,664	205	103	13.5%	7,992 - 31,968
Madera	3,070	357	258	15.6%	9,210 - 36,840
Eastern San Joaquin	3,901	279	168	19.8%	11,703 - 46,812
Total	18,566	327	179	94%	55,698 - 222,792

*Table 2. Number of wells per GSP and percent of total wells these wells comprise. DW = Domestic Well, DTW = Depth to Water *Only GSPs that have more than 1% of domestic wells in the whole dataset are shown. The totals at the bottom represent all GSPs, not just those shown. TCD and Pump Location are in units of Depth to Water.*

The SJV contains thousands of shallow domestic wells, making an analysis of this region paramount. With this information in mind, monitoring networks and the vulnerability of domestic wells are assessed below.

MTs are set at levels that allow for ‘business as usual’ pumping and are below current groundwater levels

Since it is likely the minimum thresholds and domestic wells are within the same aquifer, it is important to understand how much decline the MTs are suggesting can occur for policy assessment and projecting future groundwater conditions. All groundwater sustainability plans set sustainability thresholds below current water levels (Figure 7). Some plans are willing to manage groundwater levels that are over 200 feet below their current depth. The basins in the study are already considered critically overdrafted and substantial decline in critically overdrafted basins is likely not sustainable (DWR 2018a). In particular, within critically overdrafted basins undesirable results are likely to be seen, such as reduction in aquifer storage and land subsidence.

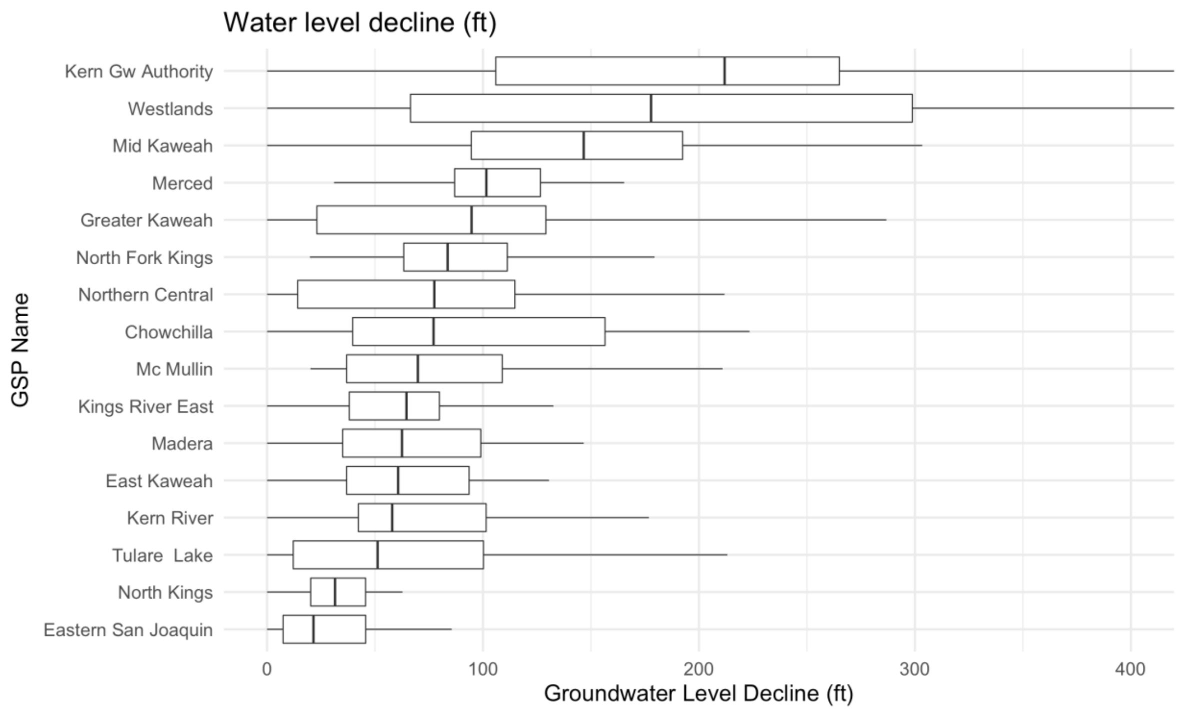

Figure 7. Boxplot of groundwater declines in GSPs with more than 15 wells with specified minimum thresholds

Domestic wells are vulnerable to MT water levels

Comparing critically overdrafted basins among the three regions, the SJV stands out as having the most extreme potential impacts to water access in domestic wells (Figure 8). In the San Joaquin Valley GSPs, 12% of domestic wells have total completed depths above the minimum threshold surface. Using the upper estimate, however, 67% 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, about 5,400 domestic wells in the San Joaquin Valley would at minimum need their pumps lowered in order to continue to function.

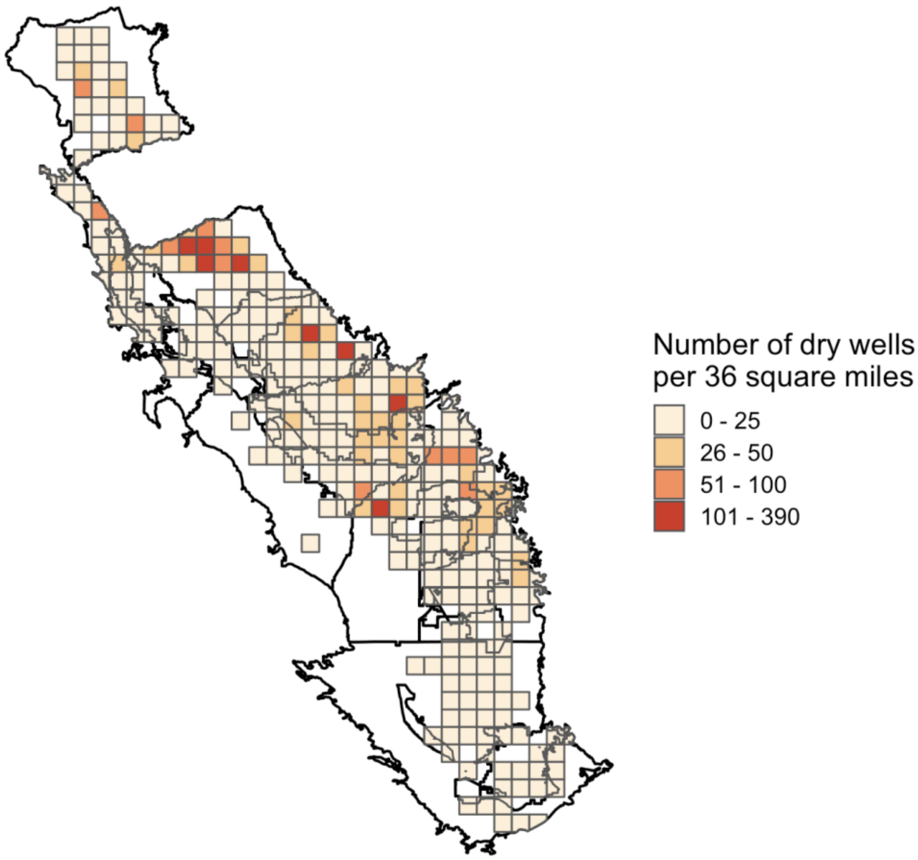

Figure 8. Map of the number of domestic wells with pump locations above the MT surface

There is significant variability in domestic well failure across GSPs. Some areas have few wells whose pump locations are vulnerable to MT water levels (as low as 20%) 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 9). Merced has the most wells with pump locations vulnerable to MTs (1,400), potentially affecting a quarter of all domestic wells in the area.

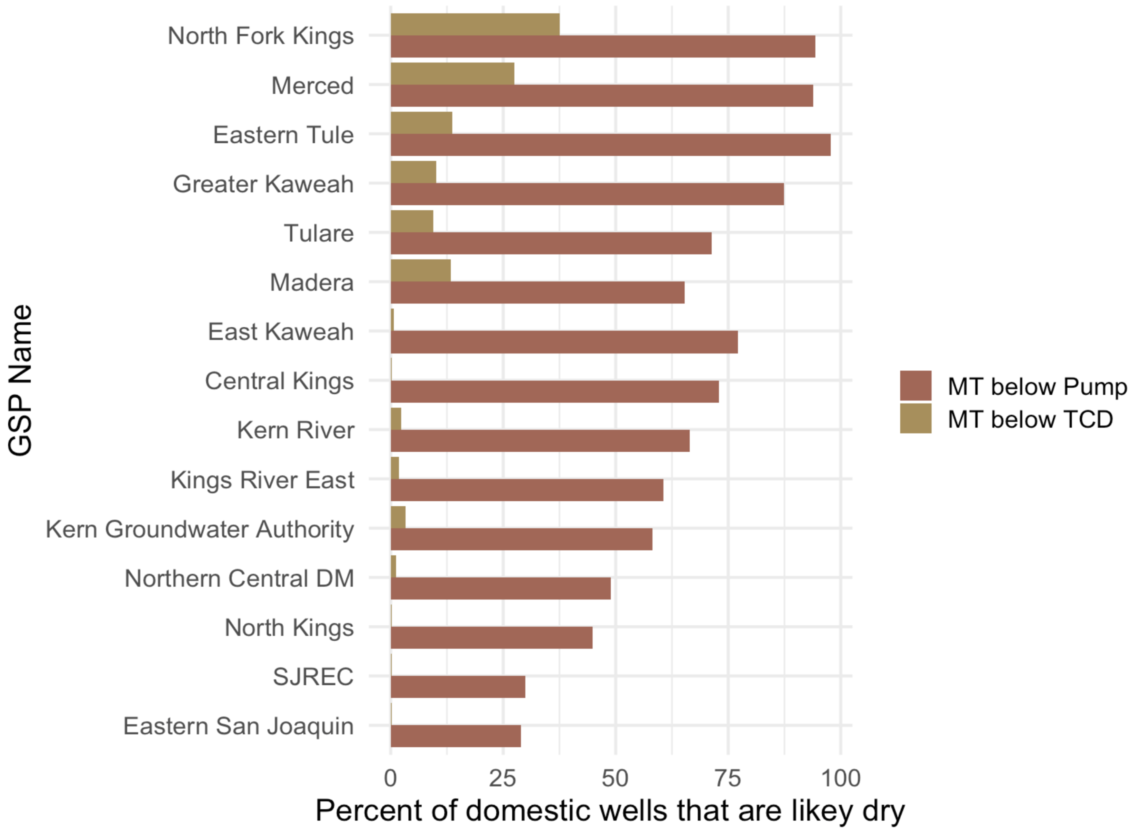

Figure 9. Percent of domestic wells with pump locations and total completed depths above the minimum threshold surface in GSPs with 95% of the domestic well population.

In addition, a wide range of people will be affected if wells go dry. In all SJV GSPs about 2,300 to 9,000 people may rely on wells with total completed depths above MTs. When the pump location is above MTs, 16,000 to 65,000 people may lose access to their water source (Table 3). Merced, Madera, North Kings, and Eastern San Joaquin GSPs together comprise over 50% of people likely to be affected by pumps losing access to water.

	Total Completed Depth			Pump Location		
GSP Name	Count of Well Failure (#)	Average Well Failure (%)	Range of People Affected (#)	Count of Well Failure (#)	Average Well Failure (%)	Range of People Affected (#)
Chowchilla	11	12%	22 - 132	75	81%	225 - 900
Mid-Kaweah	6	6%	18 - 72	95	98%	285 - 1,140
Kern Groundwater Authority	6	3%	18 - 72	104	58%	312 - 1,248
East Kaweah	1	1%	3 - 12	118	77%	354 - 1,416
SJREC	1	0%	3 - 12	121	30%	363 - 1,452
Eastern Tule	18	14%	54 - 216	129	98%	387 - 1,548
North Fork Kings	54	38%	162 - 648	136	94%	408 - 1,632
Northern Central DM	4	1%	12 - 48	173	49%	519 - 2,076
Tulare	34	9%	102 - 148	256	71%	768 - 3,072
Kings River East	9	2%	27 - 108	289	61%	867 - 3,468
Central Kings	1	0%	3 - 12	293	73%	879 - 3,516
Greater Kaweah	37	10%	111 - 444	317	87%	951 - 3,804
Eastern San Joaquin	2	0%	6 - 24	436	29%	1,308 - 5,232
North Kings	3	0%	9 - 36	470	45%	1,410 - 5,640
Madera	143	13%	429 - 1716	702	65%	2,106 - 8,424
Merced	415	27%	1,245 - 4,980	1421	94%	4,263 - 17,052
Total	765	12%	2,295 - 9,180	5,416	66%	16,248 - 64,992

Table 3. Number of wells and people vulnerable to MTs ***by total completed depth and pump location****. Average Well Failure Percent represents the percent of domestic wells within each GSP that are vulnerable. *Shown are GSPs with 95% of the domestic well population. Total includes all SJV GSPs.*

To understand how these results could affect disadvantaged communities (those with median 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 2016b) and 2) DWR's Disadvantaged Census Block Groups (block groups), which also uses 2016 ACS income data (DWR 2016c)[1].

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, 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.

[1] 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).

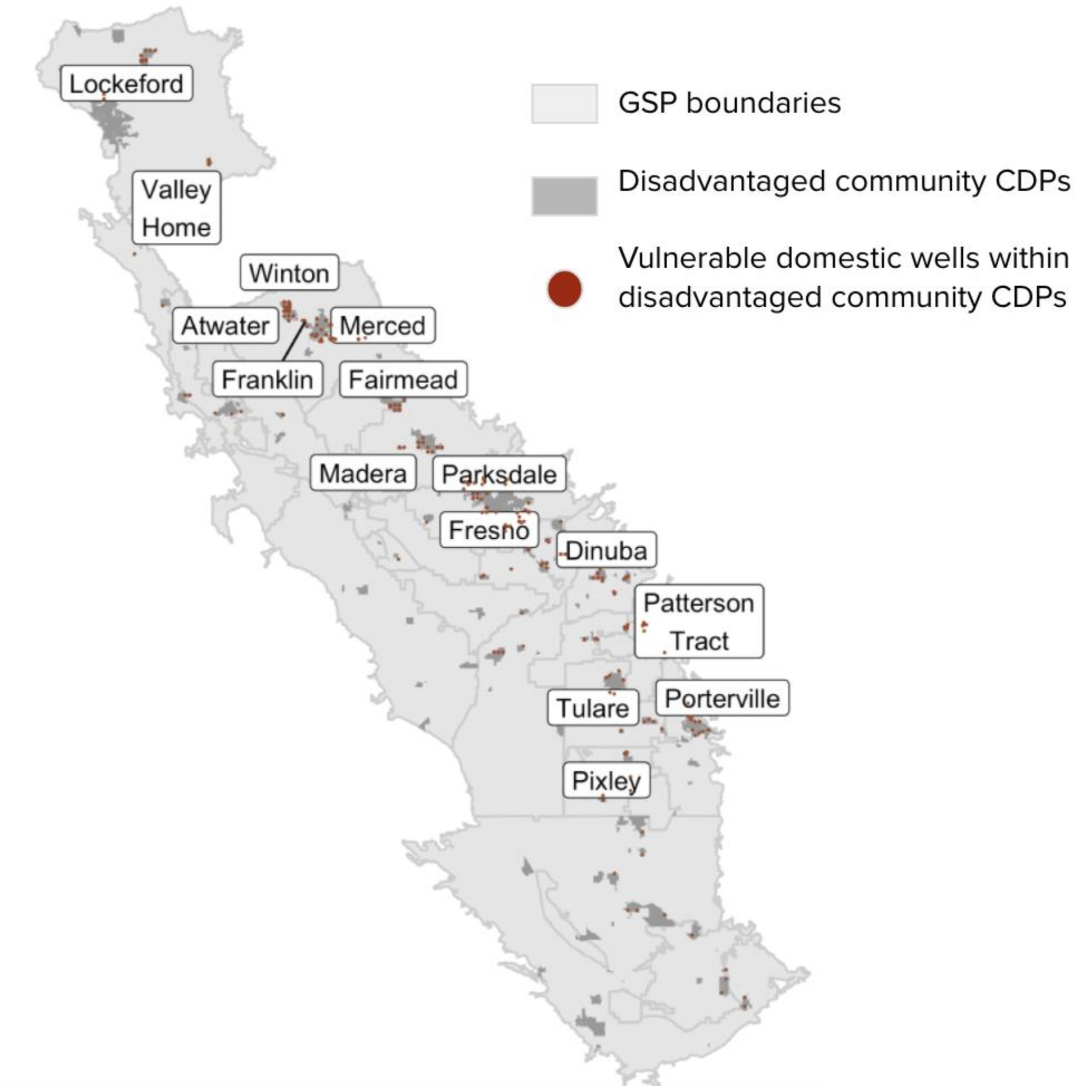

Figure 10. Disadvantaged community CDPs with domestic wells whose pumps are vulnerable to MTs. Labeled are disadvantaged communities with more than 5 vulnerable domestic wells within their boundaries.

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 11). 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 mitigation efforts for vulnerable domestic wells that supply households in disadvantaged areas, in particular.

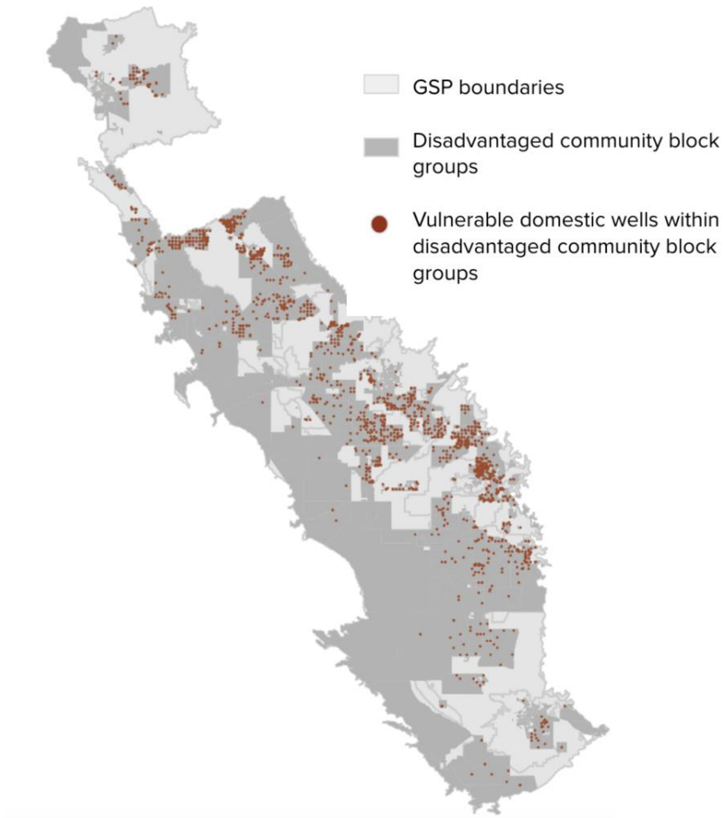

Figure 11. Disadvantaged community block groups with domestic wells whose pumps are vulnerable to MTs.

Another way to contextualize this level of groundwater decline is to compare it to modeled management scenarios. By comparing MTs to modeled groundwater scenarios we can approximate the average management goal of these GSPs. We compare well failures estimates assuming the MT is reached to well failure estimates under 3 different groundwater management scenarios by Pauloo et al. (2020):

- Strict sustainability: groundwater levels decline until 2020, and then are not allowed to decline afterward
- Business as usual: groundwater level decline proceeds at historical rates until 2040
- Glide path: groundwater levels gradually decline to a midpoint between the former two scenarios

We estimate that up to 6,000 domestic wells would fail if proposed MTs are reached, based on estimated pump location. This is consistent with domestic well failures seen in a business as usual groundwater level decline scenario. Importantly, this metric is an average across all critical priority basins, and we expect higher rates of well failure in basins with deeper MTs. These results are supported by visual comparison of the MT groundwater level and the business as usual groundwater level (Figure 12), which are well-aligned. This means that many GSP management plans do not improve groundwater conditions.

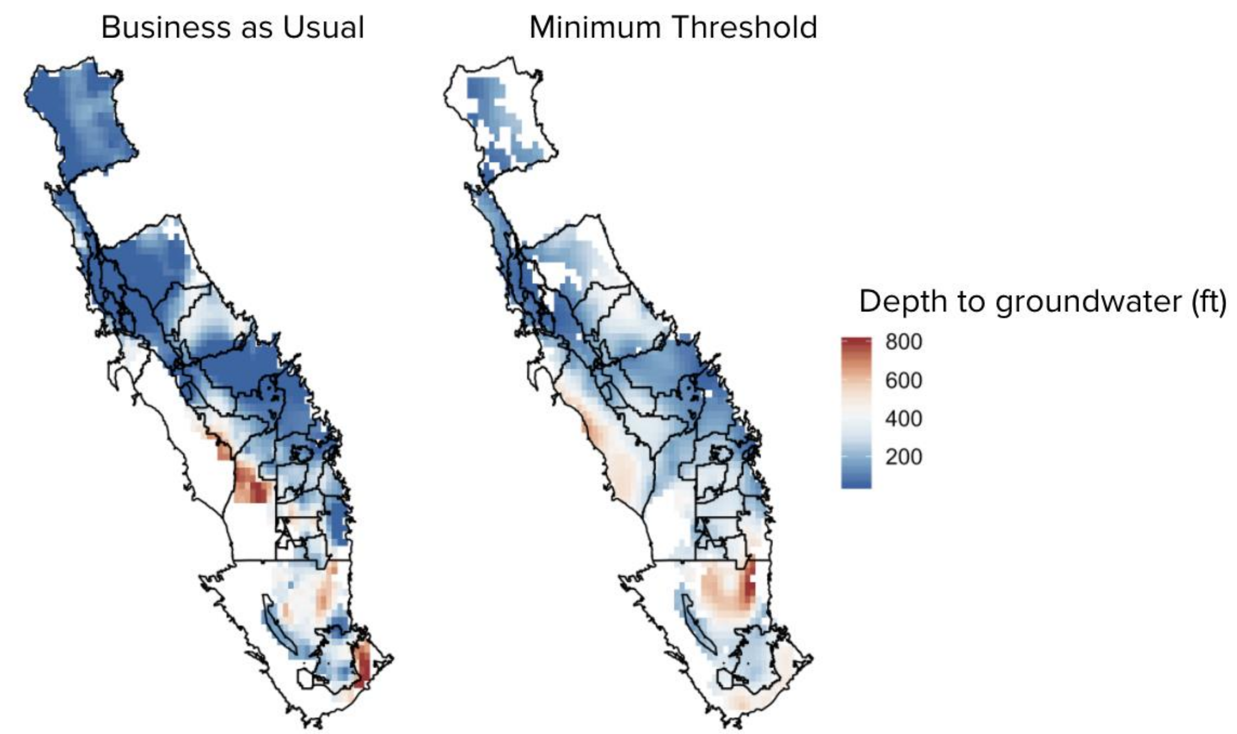

Figure 12. Comparison of groundwater levels modeled. Business as usual implies a consistent groundwater level decline until 2040. Minimum threshold represents the surface created by GSP MTs.

Monitoring networks cover most – but not all – domestic wells

Changes in groundwater levels are driven by groundwater pumping, and thus such areas should be closely monitored. 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 needs to cover areas with domestic wells. Overall, most domestic wells are included within the coverage areas of GSP monitoring networks. For those that are left out, inadequate monitoring network coverage prevents basin-wide sustainability planning and a meaningful well failure assessment. This means that the implementation of mitigation actions may not apply to these wells or could impact them in unknown ways.

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

In the SJV, there is great variation in the number of MT wells per GSP, the MT levels set at each well, and the proportion of GSP area covered by the monitoring wells. In the SJV the percent of area covered by the monitoring networks is on average 86%, but ranges from 33 to 100% (Figure 13).

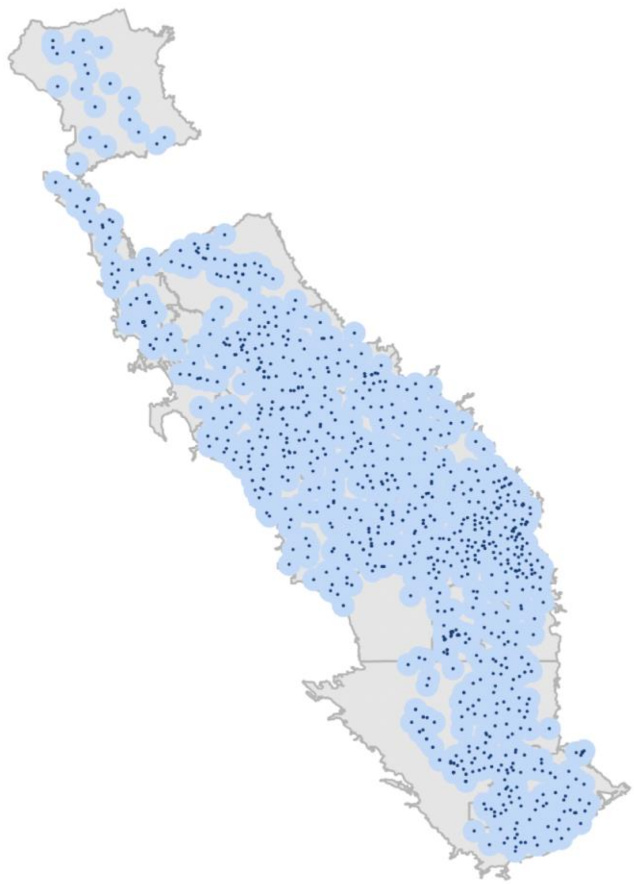

*Figure 13. **Map of area covered by minimum threshold networks**. The blue dots represent monitoring wells with specified minimum thresholds, the grey represents the buffers around each monitoring well, and the white is all areas that are not covered by the buffers.*

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

Across all SJV GSPs, 92% of domestic wells are covered (Figure 14). 4 GSPs cover less than 80% of their domestic wells, with Eastern San Joaquin covering the fewest domestic wells, only 43% of the entire domestic well population in their subbasin.

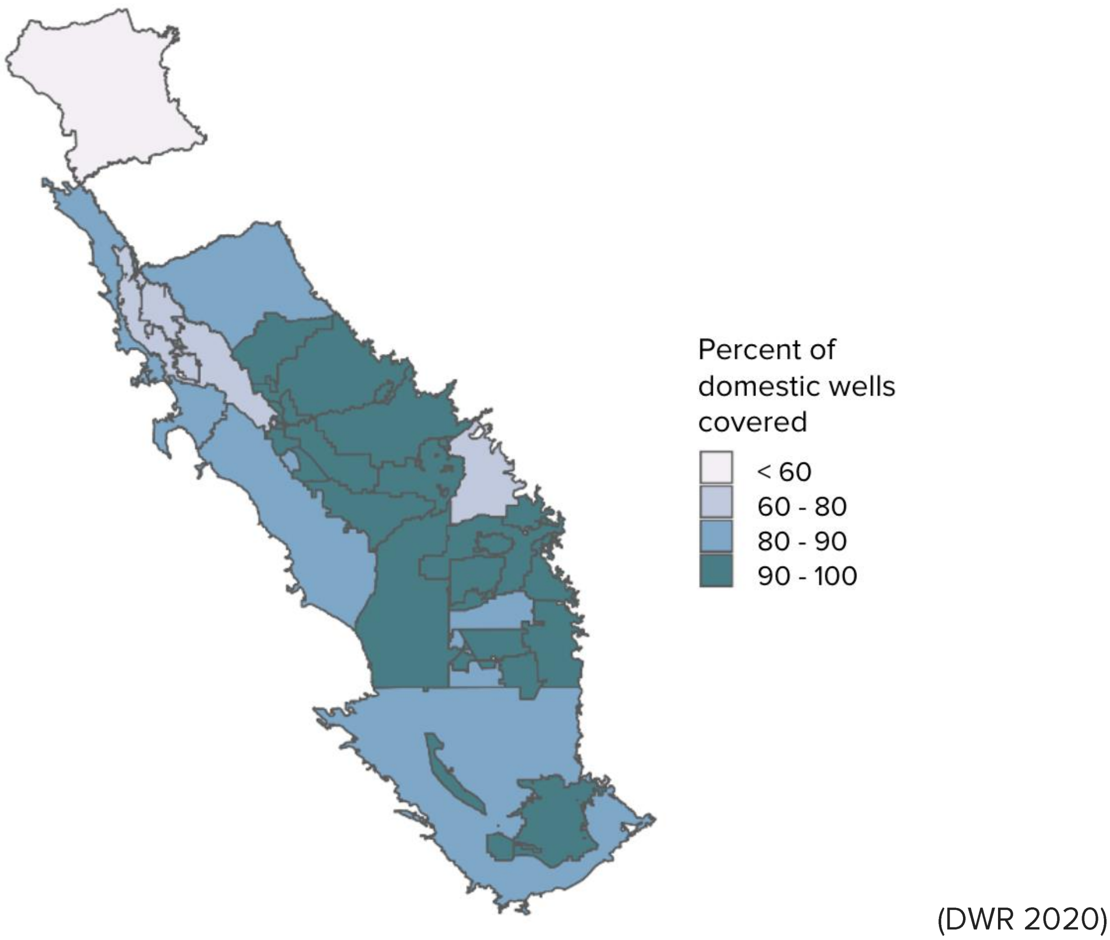

Figure 14. Map of the percent of domestic wells that fall within the monitoring network. On average, 92% of domestic wells within the SJV are within a GSP monitoring network.

COASTAL BASINS

There are 4 coastal basins - Santa Cruz, Pleasant Valley, Oxnard, and 180/400ft Aquifer - Salinas Valley. These coastal basins are also categorized as critically overdrafted. In particular, seawater intrusion is causing the salinization of the groundwater, reducing the amount available for use (DWR 2020). Coastal basins have, for decades, been managing groundwater levels to prevent seawater intrusion. Preventing decline in groundwater levels, for them, has been a necessary policy decision and that others can make as well. Although these basins have been managing water levels since the early 1900s, they are still using more groundwater than can be replenished in order to maintain a balance at the saltwater-freshwater interface. Thus, while lowering groundwater levels is a concern, changes in salinity present a more immediate threat to domestic wells close to the coast.

Domestic wells in this region are sparse, comprising only 1% of all wells examined in this report (Table 4). They are also the deepest of all domestic wells analyzed and during the 2012 - 2016 drought, no domestic wells were reported as going dry in these areas (DWR 2016a). Groundwater is still relied on by many water agencies, however. For example, Soquel Water District in Santa Cruz relies entirely on the underlying groundwater basin for potable water distribution.

GSP Name	Count of Domestic Wells (#)	Average TCD (DTW)	Percent of All Domestic Wells (%)	Range of People Reliant on DWs (#)
180/400ft Salinas	110	459	0.6%	330 - 1,320
Oxnard	14	348	0.1%	42 - 168
Pleasant Valley	6	370	0.0%	18 - 72
Santa Cruz Mid-County	181	435	0.9%	543 - 2,172
Total	311	403	2%	933 - 3,732

Table 4. Domestic wells and people reliant on them in each GSP as a count and the percent of the entire well dataset

Furthermore, these GSPs recognize the geologic complexity within their management areas. This acknowledgement of complexity combined with unavailability of dense monitoring networks screened within each of the complex parts of the aquifers makes an assessment of how minimum thresholds change groundwater levels challenging. The analysis that follows is an abstraction of the current geologic complexity in order to set a general, baseline understanding of the consequences of reaching minimum threshold water levels in these areas.

Few wells go dry in Coastal GSPs

If MTs are reached, water levels still remain above most domestic wells in coastal GSP areas. In all basins, 1% of domestic wells go dry under MT projections. No wells are vulnerable in Salinas or Pleasant GSPs, and few are vulnerable in Oxnard. Santa Cruz has the highest density of domestic wells, with 181 within their boundaries. These coastal basins' relationships with sea water intrusion require water levels to remain high, thus reducing the risk of water tables dropping below well depths.

Figure 15. Map of the number of domestic wells with total completed depths above the MT surface

As further shown in Figure 15, Santa Cruz has the highest percentage of domestic wells vulnerable to lowering water levels, with Pleasant Valley and Oxnard having no wells with total completed depths above the MT water level. Fourteen percent (2 out of 14) wells in Oxnard are vulnerable, while 1 well in Santa Cruz may be shallower than the MT water level.

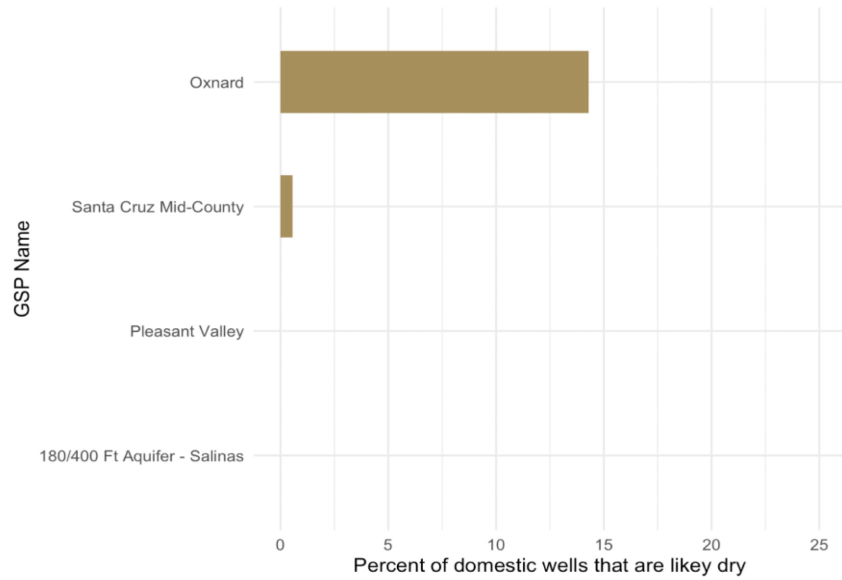

Figure 16. Chart of the percent of domestic wells with total completed depths above the minimum threshold surface

In Santa Cruz and Oxnard GSPs, about 10 – 40 people could be impacted by vulnerable wells. This number is perhaps low enough to warrant the GSP to contact these households and discuss their vulnerability with them.

GSP Name	Count of Well Failure (#)	Average Well Failure (%)	Range of People Affected (#)
180/400ft Salinas	0	0%	0
Pleasant Valley	0	0%	0
Santa Cruz Mid-County	1	1%	3 - 12
Oxnard	2	14%	6 - 24
Total	3	4%	9 -36

*Table 5. Number of wells and people vulnerable to MTs **by total completed depth**. Average Well Failure Percent represents the percent of domestic wells within each GSP that are vulnerable.*

Monitoring networks in Coastal GSPs cover majority of area and domestic wells

Monitoring networks in coastal basins cover 92% of the total area (Figure 17). Areas along the edges of the basins are left out, as well as a central section in the Salinas Valley GSP. Only monitoring wells screened within the shallowest sections of the aquifers are included in this calculation.

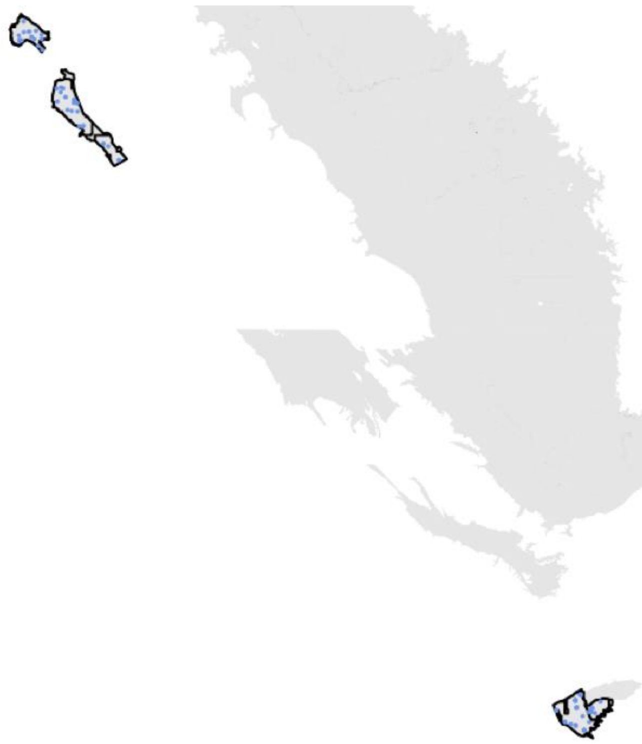

Figure 17. Map of area covered by minimum threshold networks

Domestic wells are also covered nearly completely in all basins. In Salinas and Pleasant Valley GSPs, 68% and 66% of domestic wells are covered, leaving 37 and 2 domestic wells outside of the monitoring network, respectively.

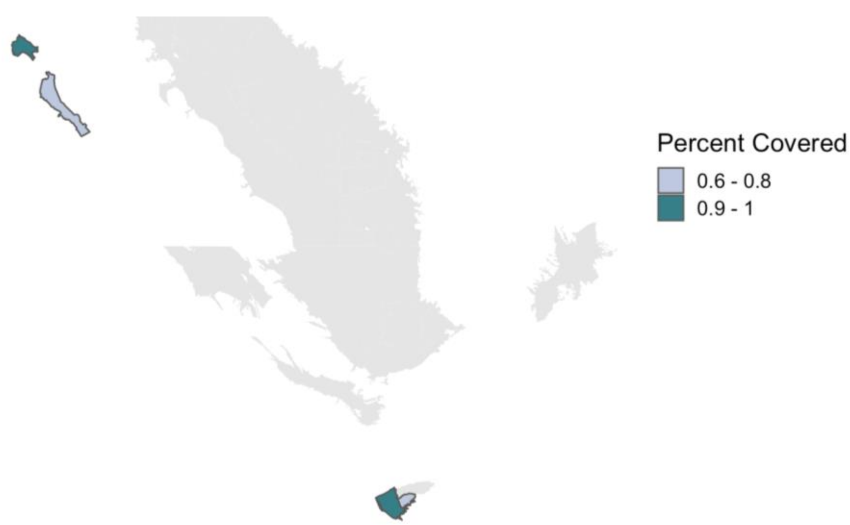

Figure 18. Map of the percent of domestic wells covered by the MT buffers by GSP

CENTRAL BASINS

The Central basins are composed of the Indian Wells, Paso Robles, and Cuyama GSPs. These basins suffer from declining water levels and subsidence resulting in loss of storage. For example, in Paso Robles "water levels have been dropping rapidly in recent years, with many areas experiencing groundwater level declines of more than 70 feet" (DWR 2020). Additionally, these GSPs have failed to analyze the impact of their minimum thresholds on vulnerable groundwater users within their basins (Dobbin et al. 2020).

Together, their boundaries encompass 800 domestic wells, primarily located in Paso Robles, with few in Cuyama. Like the coastal basins, many domestic wells are deep, and likely pull water from a confined aquifer system.

GSP Name	Count of Domestic Wells (#)	Average TCD (DTW)	Percent of All Domestic Wells (%)	Range of People Reliant on DWs (#)
Cuyama	41	458	0.2%	123 - 492
Indian Wells	289	389	1.5%	867 - 3,468
Paso Robles	470	479	2.4%	1,410 - 5, 640
Total	800	442	4%	2,400 - 9,600

Table 6. Wells in each GSP as a count and the percent of the entire well dataset

15% of domestic wells are vulnerable to MT water levels

The analysis of which wells are vulnerable to MTs that follows is a generalization of the aquifer systems present in these GSPs and are used to broadly understand impacts to domestic wells. Although some domestic wells are deeper than the MTs, some domestic wells are still vulnerable and impacts to those wells should be assessed. Overall, 13% of domestic wells have total completed depths above the minimum threshold surface set in these three GSPs and could fail (Figure 19). Most acutely, domestic wells are affected on the western side of Paso Robles and in central Indian Wells. 49 domestic wells in Paso Robles and 35 in Indian Wells are vulnerable.

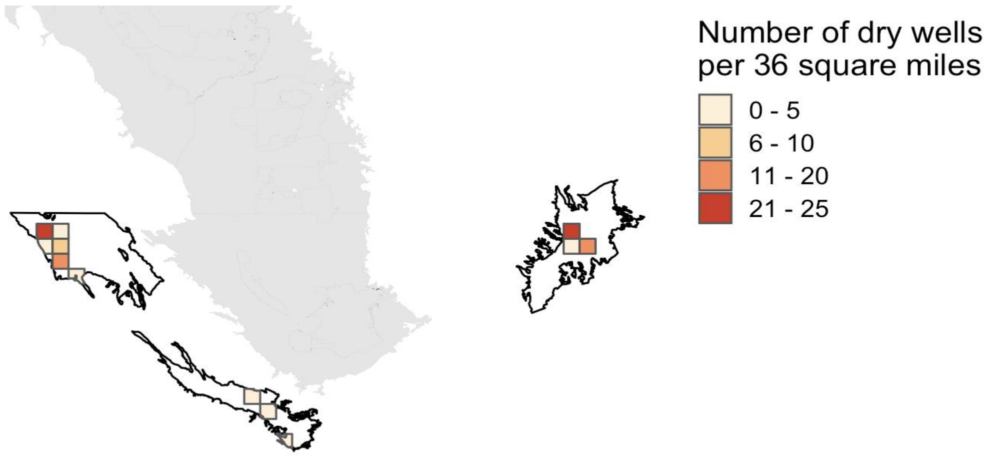

Figure 19. Map of the number of domestic wells with total completed depths above the MT surface

These three GSPs have similar percentages of domestic wells vulnerable to lowering water levels.

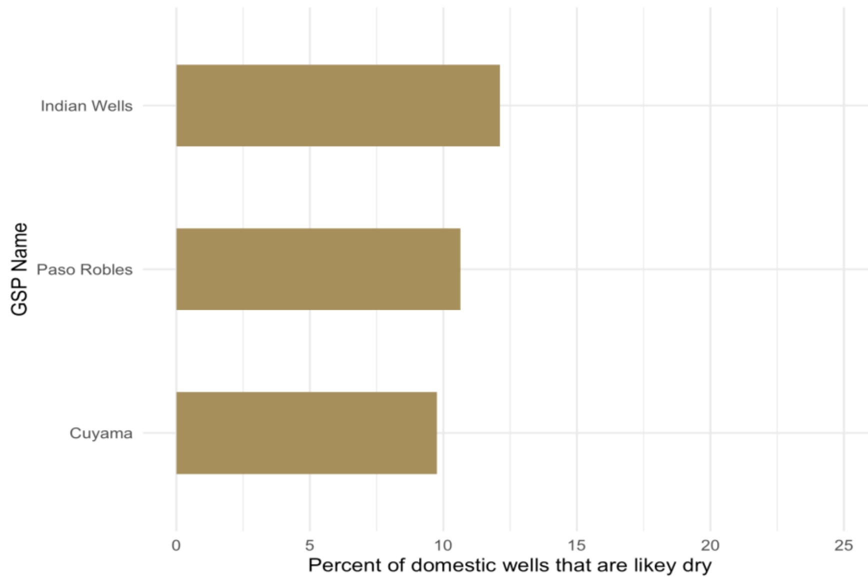

Figure 20. Chart of the percent of domestic wells with total completed depths above the minimum threshold surface

Although the percentage seems low, the 89 wells with total completed depths above the MT surface could be relied on by 300 – 1,000 people, primarily located in Paso Robles and Indian Wells.

GSP Name	Count of Well Failure (#)	Average Well Failure (%)	Range of People Affected (#)
Cuyama	4	14%	12 - 48
Indian Wells	35	14%	105 - 420
Paso Robles	50	12%	150 - 600
Total	89	13%	267 - 1,068

Table 7. Number of wells and people vulnerable to MTs ***by total completed depth****. Average Well Failure Percent represents the percent of domestic wells within each GSP that are vulnerable.*

Monitoring network coverage is sparse

The monitoring networks in these basins do not cover much lateral area. Overall 33% of the basin areas are covered. Indian Wells covers 20% of its basin area, with Paso Robles following with 27% coverage, and Cuyama with 63%.

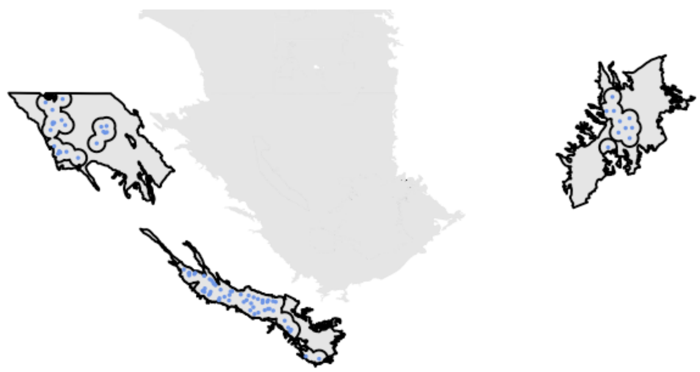

Figure 21. Map of area covered by minimum threshold networks

Although these basins don't cover most of their lateral area, they do cover most domestic wells within their boundaries. In other words, minimum thresholds are defined for 70 - 90% of domestic wells within these boundaries.

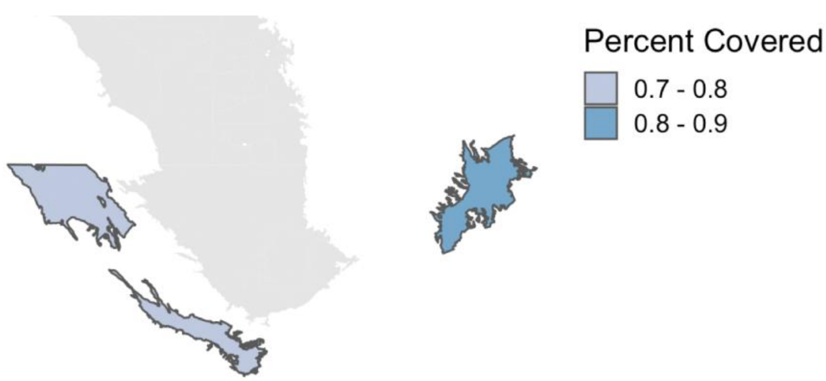

Figure 22. Map of the percent of domestic wells covered by the MT buffers by GSP

DISCUSSION

California residents losing access to their source of water clearly represents "significant and unreasonable impacts" for beneficial users. Local definitions of sustainability, therefore, should seek to preserve drinking water access whenever possible, where wells do go dry GSAs need to have proactive mitigation measures (i.e., drilling new, deeper domestic wells or providing alternative water sources with established funding sources) in place to avoid household water shortages.

In order to understand how water management goals could alter groundwater elevation and impact domestic wells, we collected sustainability criteria from 43 groundwater sustainability plans. We show how locally developed sustainability goals do in terms of coverage of basin area, exacerbate domestic well failure and further decrease water tables.

Furthermore, monitoring networks provide a real-time understanding of groundwater conditions. Monitoring networks examined here also are the loci for defining sustainability, or the minimum threshold below which undesirable results occur. In this study, there are insufficient monitoring wells to completely cover the case study basins. Although the subbasin areas are not sufficiently covered, most basins do provide coverage for at least 80% of the domestic wells within their boundaries. When an area is left out of a monitoring network, an understanding of groundwater levels in those areas is also lacking. When domestic wells fall outside of monitoring networks, sustainability is cannot be measured or defined and therefore if mitigation actions occur in these areas, their impact is likely to be unknown.

IMPACT OF MINIMUM THRESHOLDS ON WELL FAILURE AND VULNERABILITY

Sustainability thresholds are well below current groundwater levels in basins already determined to be critically overdrafted. Specifically, groundwater levels could decrease 100 feet before mitigation actions are required.

In the latest drought, more than 2,000 wells went dry in the SJV study area (R. Pauloo, Fencl, and Escriva-Bou 2018). California has also recognized the human right to water. When domestic well users lose access to their source of drinking water, California moves farther from the goal of ensuring that residents have safe, clean, affordable drinking water. The average well drilling costs over $20,000 (Jezdimirovic 2020). Many of those using domestic wells cannot afford to cover this cost. Furthermore, they are not the ones pumping high volumes of water that cause groundwater levels to decline so requiring them to shoulder this cost is both unfair and infeasible. Environmental justice advocates have long highlighted the disproportionate burden placed on lower-income communities to deal with environmental issues. The failure of sustainability plans to account for domestic well users is a clear example of this[2].

IMPLICATIONS FOR GROUNDWATER MANAGEMENT AND POLICY

Sustainability is an achievable goal only if clearly defined. Some GSPs define sustainability in a way that favors priorities of the dominant economic actors over vulnerable groundwater users (Jezdimirovic 2020) by setting sustainability measures that do not change historical trends of groundwater level decline. This allows the biggest users of groundwater to continue pumping at the expense of many whose wells have and will go dry. Domestic wells are shallower than wells used for large agriculture operations and thus, those who rely on domestic wells are disproportionately burdened by groundwater overdraft-related impacts.

When crafting SGMA, the CA legislature could have mandated the inclusion of domestic well users in all GSA boards and emphasized that the right for well owners to use groundwater for domestic purposes, regardless of hydrological conditions. This is the "local control" mandate that was intended to empower communities to address locally specific conditions and problems. It is known that actors sometimes collaborate only as a means of advocating their own interests, while largely lacking a willingness to contribute towards jointly negotiated solutions to common problems (Bodin 2017). In the case of GSPs, sustainability is defined in ways that reduce access to groundwater for shallow wells, often without the GSP recognizing how their thresholds impact domestic wells and providing sufficient mitigation plans (Dobbin et al. 2020).

California state water agencies have the regulatory power to reject groundwater plans. The Department of Water Resources can decide that minimum thresholds set in these plans are too low and ask GSAs for revisions. Alternatively, if local plans are insufficient, the State has the power to step in and manage groundwater basins for the local jurisdictions.

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[2] Domestic wells, small farmers with shallow wells, and groundwater dependent ecosystems that depend using the same aquifer as larger agricultural pumpers are left out of the decision making process that defines sustainability (Dobbin, Mendoza, and Kuo 2018).

LIMITATIONS OF THE STUDY

The data and analysis presented here are constrained by a few key limitations. First, the population of active domestic wells on which the analysis hinges is uncertain and incomplete. Not only does the state have no systematic state data to identify retired domestic wells but the average and distribution of well retirement ages in the state is also unknown. Here the currently active domestic well subset was based on a calibrated (theoretically determined), but not ground-truthed, retirement age of 29 years.

Although 1990 is used as the average retirement age for domestic wells, it is an estimate. It is known that there are many wells older than this (often serving disadvantaged communities) that are still in operation. It is also unlikely that many wells built after 1990 are out of operation. As such this is likely an underestimation of the average retirement age. By cutting off consideration of wells older than 29 years, the number of wells assumed to be currently in operation is underestimated and the average total completed depth is inflated. It is important to note that GSAs are responsible for *all* beneficial uses and users in their management area, not just ones built after an average retirement age.

Additionally, the well dataset used only represents wells with associated paperwork, or well completion reports. This is likely an underestimation of wells still in operation today. For example, the Santa Cruz GSP notes, “the County estimates that 20 - 40% of water supply wells in use are unpermitted non-municipal wells drilled prior to 1971.” This dataset also does not indicate the number of people or households reliant on each domestic well, which is known to vary across space (Johnson and Belitz 2015; Pace et al. 2020).

Finally, the current and MT water levels used in the analysis are interpolations from discrete well points. Heterogeneity resulting from complicated subsurface structure was not factored into the interpolation. The contours created from this interpolation are regional trends that cannot predict the groundwater level at a fine scale. They do not account for changes in topography or high volume pumping. The implication of this limitation is that current groundwater levels may be inaccurate at high resolutions.

POLICY RECOMMENDATIONS

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

1. ***DWR can and should reject plans that are forecasted to cause significant well failure, and that lack sufficient mitigation plans***. California state water agencies 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, the State has the power to intervene and manage groundwater basins in place of GSAs. It 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 should overrule the GSAs on grounds of upholding the Human Right to Water.

2. ***Robust and well-funded mitigation programs are needed to address 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 by those who use the most groundwater, 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).

3. ***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.

4. ***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. Using both TCD and pump location provides an idea of which mitigation solutions may be most useful. For example, pumps that are vulnerable may be able to be lowered instead of replacing a well entirely. If TCD is above the MT water level, then the MT may have to be raised, new wells drilled, or water provided from a different source.

5. ***Improve the extent and density of monitoring networks.*** Sustainability can only be defined and monitored where there are sufficient monitoring networks. GSAs can improve their understanding of domestic well vulnerability and ability to respond to undesirable results by adding and extending monitoring wells across their area, especially in areas where domestic wells are present. Nonprofit advocacy groups have provided 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).

6. ***Understand the distribution of domestic well ages, depths, and pumping capacities.*** Our analyses in this report are limited by a lack of information about exact pump locations in all basins and an inadequate basis for assessing 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. Well owner participation in a future study would help reduce the uncertainty inherent in this approach. 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, strategic siting of managed aquifer recharge may be able to reduce the vulnerability of domestic wells to failure (Maples, Fogg, and Maxwell 2019).

7. ***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 searchable and able to be compiled easily for analysis.

CONCLUSIONS

When domestic well users lose access to their source of drinking water, California fails to meet its commitment to ensure residents have safe, clean, affordable drinking water. In the latest drought, more than 2,000 wells went dry in California's Central Valley (Pauloo et al. 2020). California recognized the human right to water prior to this drought and scrambled to provide drinking water to those who lost access. However, thousands of California residents remain vulnerable to well failure and are insufficiently protected by GSPs prepared by GSAs. The Groundwater Sustainability Plans (GSPs) assessed in this document threaten the viability of shallow domestic wells. Thousands of domestic wells across the state could go dry if water levels reach the minimum threshold levels set by these GSPs.

GSAs can improve their plans by adding more monitoring wells across their area, especially in areas where domestic wells are present, understanding the distribution of domestic well ages and depths, and defining sustainability in a way that includes and protects the most vulnerable domestic wells and their users. 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. This way, minimum thresholds can be set, or mitigation actions can be prepared for the entire population of domestic wells in the basin. At minimum, with full information of domestic wells within the basin, the impacts of minimum thresholds can be assessed and outcomes can be calculated for a variety of average well retirement ages.

Sustainable groundwater management must be pursued through strategies to achieve equitable groundwater management. Future plans should be assessed for their inclusion of and impact on groups who have historically been excluded from management of this vital resource. It is crucial to consider not just groundwater quantity, but also quality, accessibility, and affordability when constructing groundwater management plans.

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