Improving Access of Climate Information for Communities Vulnerable to Drought in California

By

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Executive Summary

Improving Access of Climate Information for Communities Vulnerable to Drought in California is a project conducted with the Governor's Office of Planning and Research (OPR) based in Sacramento, California. The project evaluates drought vulnerability utilizing a case study approach, focusing on the San Joaquin Valley of California. The objective of the project is to provide OPR with the factors that contribute to drought vulnerability in local communities, and with recommendations for supporting local drought resilience work.

The State of California is committed to reducing the disproportionate impacts of climate change on vulnerable communities (PRC 71340) that experience "heightened risk and increased sensitivity to climate change and have less capacity and fewer resources to cope with, adapt to, or recover from climate impacts" (OPR, 2018). This project directly supports this new and crucial work by developing insights not only to where drought is likely to disproportionately affect communities ("vulnerable communities"), but also by aiding the State in curating and streamlining its support of local drought resilience work.

The State has a plethora of valuable resources that are intended to provide stakeholders with rich and accurate climate information. However, there is still question as to how local communities are accessing and using this climate information disseminated by the State, and how the State could better support evidence-based water management in drought-prone communities. This project interviewed key stakeholders in drought management in the San Joaquin Valley to gain insight as to how local managers are interacting with and using state information resources, and what new resources could be most helpful for their local work.

This project investigates the spatial location of communities vulnerable to drought in the San Joaquin Valley and the ability of the State to support local drought resilience work with climate information using a mixed-method approach. The following questions guided my research:

1. What are the characteristics of San Joaquin Valley communities most vulnerable to the impacts of drought and where are these communities spatially concentrated?
2. What barriers do these communities in the San Joaquin Valley face in accessing and implementing climate information related to drought?
3. What improvements to the State's existing tools or new services could best help translate and apply climate information for resilience-building efforts in communities in the San Joaquin Valley?

I used a literature review and subsequent geospatial analysis to identify factors that predispose communities to the impacts of drought. Using these factors, I developed two new indices, one focused on social vulnerability factors associated with disproportionate impacts of drought, and a second focused on water resources vulnerability factors. This allowed me to identify, spatially, communities that are likely to be disproportionately vulnerable to drought in the San Joaquin Valley. Then, I conducted qualitative interviews with water resources managers and other individuals intimately involved in drought resilience work in the San Joaquin Valley to learn about 1) the types of sources they use to obtain the information they need to plan for drought, and 2) the recommendations they have for the State to improve information-sharing.

The project identified significant vulnerability to drought in communities outside of the Fresno Metropolitan area (approximately 50-mile radius). This highlights Fresno County as an important geographic entity to focus drought resilience work in, and invites considerations around what vulnerability factors in rural areas, particularly related to water resources infrastructure, could be addressed through resilience efforts (e.g., expanding municipal water services to unincorporated communities). Other key insights from the geospatial analysis were the differences in vulnerability factors in the western and eastern regions of the San Joaquin Valley; the western region had much higher social vulnerability, while the eastern region had much higher water resources vulnerability.

The project also illuminated the ways in which the State is currently supporting drought planning in local organizations and municipalities in the San Joaquin Valley and how this support could be improved. Notably, key informant interviews highlighted that there was knowledge and use of state resources among interviewees, but that there was ample opportunity to improve the usability and applicability of these resources for local users. My key recommendations for OPR include developing a guide to help users distinguish between multiple state resources and understand their unique utilities for their work, and to increase communication about the ability of state grants to support technical assistance and data collection for local practitioners. I also recommend that the State improves its metadata policies to ensure that local organizations can access and assess characteristics of data available from the State, such as date of collection and methodology.

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Acronyms

Table 1: Acronyms

Acronym	Definition
CWS	Community Water System
DWR	Department of Water Resources
ICARP	Integrated Climate Adaptation and Resiliency Program
OPR	Governor’s Office of Planning and Research
SJV	San Joaquin Valley
SSWS	State Small Water System

Introduction

Project Background

Improving Access of Climate Information for Communities Vulnerable to Drought in California is a project that investigates vulnerability to drought in communities in the agricultural region of the San Joaquin Valley. Specifically, this project uses geospatial analysis to investigate the spatial location of communities at disproportionate risk to drought in the San Joaquin Valley. Additionally, interviews with key stakeholders provide recommendations to the State of California to support drought resilience efforts, particularly related to improving the dissemination of climate information.

Background on the San Joaquin Valley

The San Joaquin Valley of California (SJV) (Figure 1) is one of the most productive agricultural regions in the U.S. (CNRA, 2022a). Almonds, dairy, and grapes are the most lucrative crops in the region, which has 920,000 acres of agricultural land (San Joaquin Council of Governments, 2023). The SJV is also home to diverse and disadvantaged communities (Fresno State Central Valley Health Policy Institute, n.d.), many with connections to agriculture. Communities in the SJV such as those in San Joaquin County suffer from high poverty and mortality rates, and there are hundreds of disadvantaged unincorporated communities in the SJV (CBPR, 2020; San Joaquin Valley REAP, 2022).

Notably, current climate change predictions suggest that communities in the SJV will experience extreme heat, water system stress, drought, flooding, and fires (California Climate Adaptation Strategy, 2024). Local temperatures are expected to increase between 4-5 degrees Fahrenheit by 2050 and between 5-8 degrees Fahrenheit by 2100, exposing communities in the SJV to a variety of consequences (CNRA, 2022a).

While the SJV faces numerous impacts from climate change, drought will likely most severely impact the agricultural livelihoods of those living in the Valley. Drought cycles naturally occur in the SJV, but the length of dry seasons and severity of drought is expected to increase with climate change (CNRA, 2022a). Snowpack in the Sierra Nevada, which normally supplies water to the Valley, is expected to decline (CNRA, 2022a). Also contributing to drought is the Valley's loss of local wetlands; over 95% of the Valley's original wetlands have been lost as a result of diking and draining of the Sacramento-San Joaquin Delta in the 1850's for agriculture (CNRA, 2022a; Madani and Lund, 2012). This loss in wetlands has severe implications for water retention and storage in the Valley. Rising temperatures and changes in precipitation patterns will prolong dry seasons (CNRA, 2022a) impacting local crops such as almonds and grapes. Despite recent flooding events in the SJV from snow pack melt (CA DWR, 2023a), in the long-term, this region is expected to have severe drought seasons (CNRA, 2022a).

Figure 1: San Joaquin Valley, as defined by California's Fourth Climate Change Assessment.

Building Drought Resilience

The sectors expected to be most affected by climate change (e.g., agriculture) heavily employ low-income, communities of color (Shonkoff et al., 2011). In addition to facing job insecurity, low-income communities are also susceptible to financial insecurities brought about by climate change, as they spend more of their income on water, energy, and food, which are all likely to be affected given stresses on these necessities with climate change (Shonkoff et al., 2011). If ***vulnerability*** is defined as "a community's ability to anticipate, cope with, resist, and recover from the impact of major weather events" (Shonkoff et al., 2011), then there are certainly communities whose characteristics position them to be more vulnerable to climate change, and specifically drought.

The climate resilience and adaptation literature has identified ***resilience*** as "the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions" (Lavell et al., 2012). Therefore, one solution to climate change is to build resilience in local communities to extreme events, including drought. While the U.S., the State of California, and many counties and cities are currently working to build resilience to drought through a variety of programs and projects (see Literature Review, section on Resilience and Adaptation Strategies), there continues to be a great need to identify and fund a variety of evidence-based strategies to mitigate the impacts of drought, particularly for communities vulnerable to drought like those in the SJV.

The Governor's Office of Planning and Research (OPR) is currently conducting their Fifth Climate Assessment, which will generate updated technical climate data and projections for the SJV (ICARP, 2021). The fine-scale data generated from the Assessment, and prior Assessments, can be harnessed to design and implement drought resilience solutions and other climate resilience strategies to mitigate drought impacts in the SJV. However, given vulnerability to drought in communities in the SJV, more research is needed to 1) identify communities vulnerable to drought in the Valley and 2) understand how the State's climate information could be translated to be most useful for these communities in their resilience-building efforts.

Project Objectives

Through a rigorous geospatial analysis, this project seeks to answer:

1. What are the characteristics of San Joaquin Valley communities most vulnerable to the impacts of drought and where are these communities spatially concentrated?

Through a qualitative analysis of interviews with key stakeholders in drought resilience work in the SJV, this project seeks to answer:

1. What barriers do these communities in the San Joaquin Valley face in accessing and implementing climate information related to drought?

2. What improvements to the State's existing tools or new services could best help translate and apply climate information for resilience-building efforts in communities in the San Joaquin Valley?

Client

The Governor's Office of Planning and Research (OPR) of the State of California has been working to support communities vulnerable to natural hazards, such as those in the SJV, to build climate resilience through their Integrated Climate Adaptation and Resiliency Program (ICARP). OPR is currently conducting their Fifth Climate Assessment, which will generate technical climate data and projections for all regions of California (ICARP, 2021). ICARP is committed to supporting communities to build resilience by providing resources to translate and apply the technical climate science they generate (ICARP, 2021). ICARP defines "vulnerable communities" (PRC 71340) as communities that experience "heightened risk and increased sensitivity to climate change and have less capacity and fewer resources to cope with, adapt to, or recover from climate impacts" (OPR, 2018). ICARP is currently in the process of identifying how vulnerability factors translate to felt impacts of climate change, given local/social conditions. They are developing a Vulnerable Communities Platform, which serves as an online, public database where information on community vulnerability for climate impacts including drought would be accessible for policy and community use.

Literature Review

Current State Resilience and Adaptation Strategies

With the understanding that drought will impact local communities like those in the SJV, the State of California has implemented numerous programs and projects to support local communities. The State's Water Resilience Portfolio (2020) was developed as a blueprint for addressing drought and groundwater management. The portfolio supports local capacity by implementing projects to support four goals: 1) maintaining and diversifying water supplies, 2) protecting and enhancing natural ecosystems, 3) building connections, and 4) being prepared (CA DWR, 2020). Under the State's direction, the Countywide Drought and Water Shortage Contingency Plans developed by the Department of Water Resources (DWR) are specifically geared toward preparing vulnerable small water systems for drought. Projects and programs such as the Small Community Drought Relief Program focuses on providing immediate relief during drought periods to drinking water users through financial and technical projects (CA DWR, 2021a; CA DWR, n.d.).

DWR has also launched a task force known as the DRIP Collaborative to bring diverse water users (e.g., local governments, community-based organizations, non-profits, agricultural actors) together to implement solutions geared toward mitigating the impacts of drought on local communities (CA DWR, 2023b). In addition to bringing key collaborations to fruition, DWR, among other state agencies, is working to provide data and tools to local communities to enhance their planning for building drought resilience (CA DWR, 2023b).

Two key legislative and executive acts guide the State's adaptation and resilience work: Assembly Bill 1482 and Executive Order N323. Assembly Bill No. 1482 requires the State to update their climate adaptation strategy, which includes drought preparation, response, and resilience programs. Executive Order N323 was issued by Governor Newsom and extends the state of emergencies issued for drought in 2021; it also charges DWR, State Water Resources Control Board, and Fish and Wildlife Services to collaborate on drought mitigation through recharge projects and well permit restrictions. Counties are also working to build resilience and adapt to the impacts of drought through improved planning. For example, the SJV has developed the Water Blueprint to put forward proposed projects to the State for funding to mitigate drought and water scarcity through land use planning, groundwater recharge, and habitat restoration projects (Water Blueprint for the SJV, 2022).

Groundwater Management

Groundwater management in the SJV is a complex yet essential process. In the SJV, surface water and natural flows are often diverted to supply water for crop irrigation, and thus groundwater is a critical source of the area's water supply (CNRA and CA DWR, 2023). At the state level, groundwater is managed through the State's Sustainable Groundwater Management Act (SGMA), which was passed in 2014 as a response to the overextraction of groundwater (CA DWR, 2020). SGMA requires that each groundwater basin has a plan to have use sustainable by 2040 (CA DWR, 2020). As a result, groundwater usage will be substantially curbed through Groundwater Sustainability Plans (GSPs) in the Valley, which has 11 critically overdrafted basins (Hanak et al., 2023). Notably, there are concerns about how GSPs will impact water security for local communities in the SJV (Hanak et al., 2023).

In the SJV, the absence of sufficient water infrastructure in rural, unincorporated communities poses additional challenges for water management and security. In low density, rural areas in the Valley, many homes have domestic groundwater wells (London et al., 2018; Greene, 2021; Johnson and Belitz, 2015). Domestic wells are vulnerable to water quality issues (CNRA and CA DWR, 2023); notably, the State does not regulate domestic well water quality (California State Water Resources Control Board, 2011).

Some residents also have access to Community Water Systems (CWS) or State Small Water Systems (SSWS). However, both face challenges for management, particularly in terms of water quality. For example, CWS can be privately owned (e.g., by a mobile home park) and, while subject to state drinking water standards, many in the SJV are out of compliance (23%; London et al., 2018). Additionally, SSWS are not considered public water systems due to the small number of homes they serve and are not subject to water quality testing (London et al., 2018). Many SSWS also do not have sufficient technical support (CNRA and CA DWR, 2023). Given that 350,000 residents in the SJV live in unincorporated communities (London et al., 2018), the fragmented infrastructure impacts many residents' lived experiences with water quality and access. Additionally, 45% of individuals in Fresno County are renters, adding another layer of complexity to water management (Moser and Ekstrom, 2010).

Community Vulnerability and Groundwater Insecurity

The State of California considers Stockton, Merced, Lodi, and Madera (the four most populous cities in the SJV) to be frontline communities (CNRA and CA DWR, 2023), meaning communities that experience the first and worst of environmental consequences (CNRA and CA DWR, 2023). However, the State also recognizes that water security is threatened in urban and

rural communities in California (CNRA and CA DWR, 2023). After the 2012-2016 drought in California, much research was dedicated to understanding the impacts of drought on rural farmworkers and communities vulnerable to drought in California. Importantly, rural, economically disadvantaged communities in the SJV who live in geographic proximity to farms and other commercial water users experienced daunting consequences during droughts; rapid declines in the water table from the commercial overdrawing and water costs to individual consumers rising are just two of the impacts that particularly affected rural communities (CNRA and CA DWR, 2023).

Greene (2018) highlighted the absence of our understanding of *socioeconomic drought* in the SJV; essentially, how drought impacts the lived experiences of local communities' social and economic well-being. Greene 2018's research showed that drought impacted agricultural workers' employment, specifically those working in vegetable crops. Additionally, she found that many households in the SJV use domestic household wells, which were the first to dry during increased groundwater use during the drought. In fact, 230 wells were reported failed in Fresno and 2261 wells were reported failed in Tulare in the SJV (State of California, 2017). The combination of employment insecurity and water insecurity speaks to the importance of considering the social and economic experiences of local communities during periods of drought.

Qualitative research has emphasized the social and economic vulnerability of communities to drought (e.g., Greene, 2021), a departure from assessing climate vulnerability with solely biophysical variables. For example, factors including food insecurity, high poverty rates, low access to health care, and education pose communities in the SJV particularly vulnerable to socioeconomic drought (Greene, 2021). Additionally, many agricultural workers are undocumented, an identity that hinders individuals' ability to receive support through government or other social institutions, heightening drought vulnerability as well (Green, 2021). Notably, 47% of rural farmworkers in the Valley lack work authorization (Hernandez et al., 2016).

PART I: GEOSPATIAL ANALYSIS

Methods

Site selection, sometimes referred to as prioritization modeling or multi-criteria analysis, is a common method in geospatial analysis to identify locations based on their satisfaction of multiple criteria. This methodology has been used in a variety of applications in the literature. It has been used to select sites for industrial development based on spatial criteria such as proximity to roads and water sources (Rikalovic et al., 2014) as well as to select sites for wind farm development based on spatial criteria ranging from economic costs generated from land clearing to ecological impacts based on bird habitat (Van Haaren and Fthenakis, 2011).

More recently, this methodology has been used to understand areas most vulnerable to natural hazards. For example, Skilodimou et al. (2019) used multi-criteria analysis to identify areas in Greece hazardous to landslides, earthquakes, and floods based on spatial criteria associated with each hazard (e.g., slope of the landscape, precipitation). After identifying areas uniquely at risk for each hazard, the results of the hazard maps were overlaid and overall risk was classified to determine areas of very low, low, medium, high, and very high suitability for urban expansion (Skilodimou et al., 2019). In the context of drought, multi-criteria analysis has been used to identify drought-vulnerable areas based on climatic, biotic, and social factors (Chandrasekar, 2009). We chose to employ this methodology, but rather than identify areas where drought is expected to occur, we chose to select criteria that would identify communities likely to disproportionately experience the *effects* of drought, based on social, economic, and water infrastructure factors.

Model Development

The purpose of the multi-criteria prioritization model was to identify the communities in the SJV that would demonstrate the highest vulnerability to the impacts of drought. In ArcGIS Pro, I developed a "drought social vulnerability index," developed to reflect the social indicators identified by the literature that pose communities, particularly those agricultural, to lasting impacts from drought (Figure 2). This social vulnerability index was overlaid with a "frontline community water resources vulnerability index" that was developed from key water resources indicators that the literature reflected would pose vulnerable communities more vulnerable to drought, including domestic well density and water quality risks (Figure 3). The frontline community water resources index does not predict where drought will occur, rather, it highlights the hydrologic conditions that predispose frontline communities in the SJV to experience disproportionate impacts of drought. Combining these indices in a prioritization model allowed us to identify the communities most vulnerable to drought in the SJV.

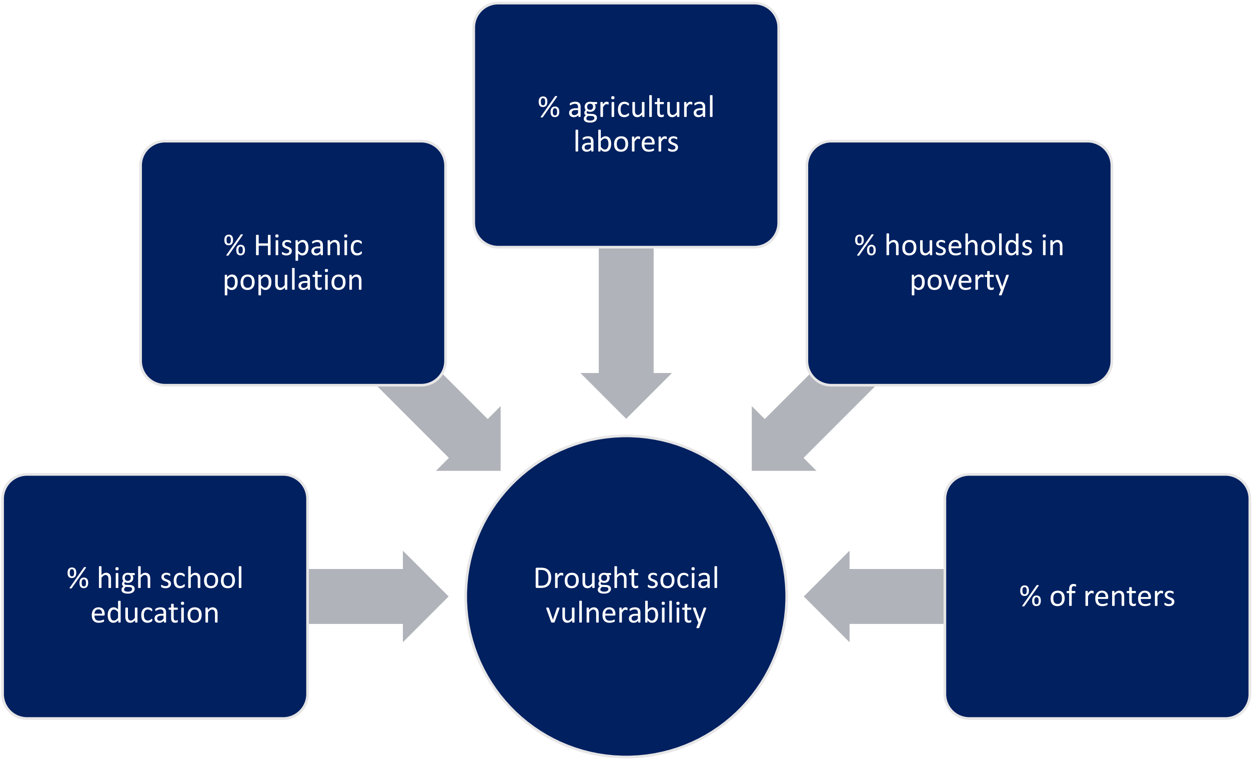

Figure 2: Conceptual framework for drought social vulnerability index.

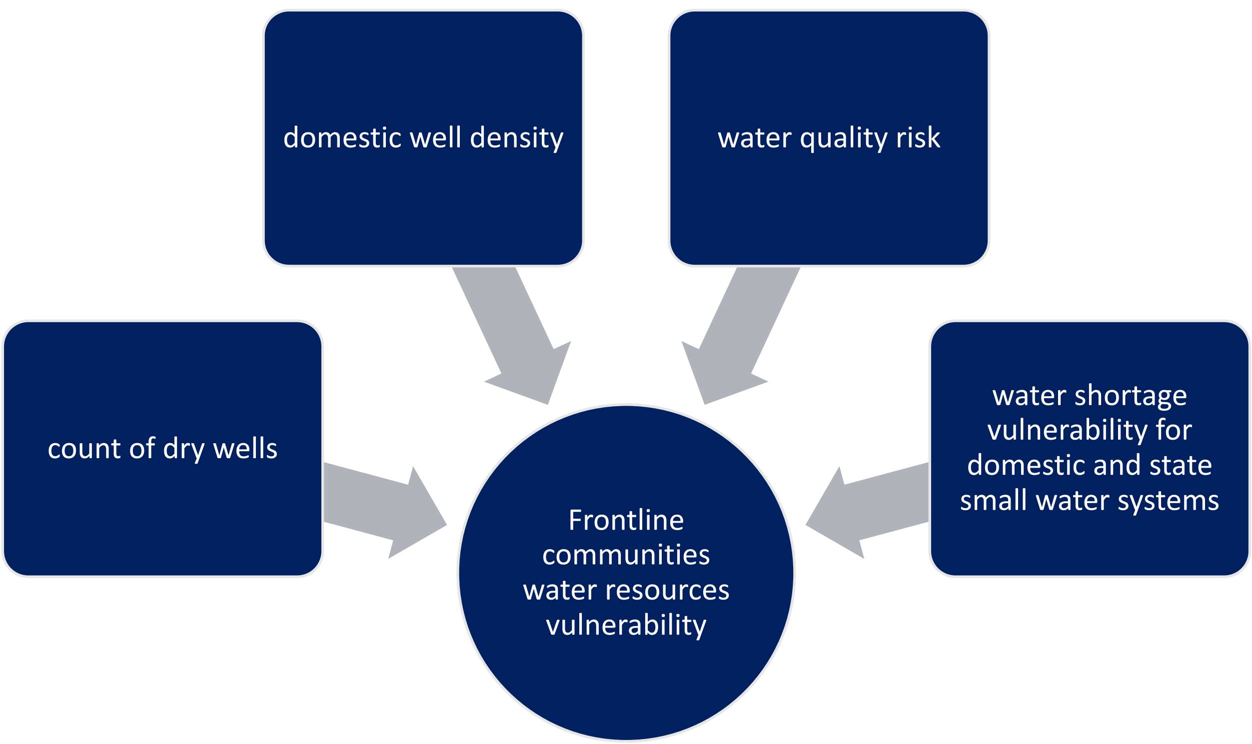

Figure 3: Conceptual framework for frontline communities water resources vulnerability index.

Data Sources

Table 2: Data sources for indicators included in indices.

Indicator	Data Source and Processing	Supporting Literature
Drought Social Vulnerability		
Percentage of renters per block group	American Community Survey 2021 (USCB, 2021). To determine percentage of renters, divided the total number of renter-occupied housing units by the total number of occupied housing units (columns B25003e3 and B25003e1, respectively).	Greene 2018; Moser and Ekstrom 2010; State of California Department of Water Resources 2021a (Small Water Systems and Rural Communities Drought and Water Storage Contingency Planning and Risk Assessment)
Percentage of the population in poverty per block group	American Community Survey 2021 (USCB, 2021). To determine percentage in poverty, divided the population for which ratio of income to poverty level is under .50 (income is 50% of the poverty level) by the total population for whom poverty status is determined (columns C17002e2 and C17002e1, respectively).	Greene 2021; California State Water Resources Control Board 2021b (Drinking Water Needs Assessment); Shonkoff et al. 2011; State of California Department of Water Resources 2021a (Small Water Systems and Rural Communities Drought and Water Storage Contingency Planning and Risk Assessment)
Percentage of the population that identifies as Hispanic per block group	American Community Survey Data 2021 (USCB, 2021). To determine the percentage of the population identifying as Hispanic, divided the total population identifying as Hispanic or Latino by the total population (columns B03002e12 and B03002e1, respectively).	Greene 2021; Shonkoff et al. 2011
Percentage of the population working in the agriculture industry per block group	American Community Survey Data 2021 (USCB, 2021). To determine the percentage of the population working in the agriculture industry, divided the total male civilian employed population working in the agriculture, forestry, fishing, and hunting industry summed with the total female civilian employed population working in the agriculture, forestry, fishing, and hunting industry by the total civilian employed population over 16 years of age (columns C24030e4, C24030e31, and C24030e1, respectively).	Greene 2018; Greene 2021; Shonkoff et al. 2011

Indicator	Data Source and Processing	Supporting Literature
Percentage of the population that completed a high school degree per block group	American Community Survey Data 2021 (USCB, 2021). To determine the percentage of the population with a high school diploma, divided the total population 25 years and older with a regular high school diploma by the total population 25 years and older (columns B15003e17 and B15002e1, respectively).	Greene 2021; Greene 2018; State of California Department of Water Resources 2021a (Small Water Systems and Rural Communities Drought and Water Storage Contingency Planning and Risk Assessment)
Frontline Communities Water Resources Vulnerability		
Count of dry wells	Dry Well Reporting System Data from California Natural Resources Agency, downloaded October 11, 2023 (CNRA, 2023). Data includes dry wells from 1999-2023. To determine the number of dry wells reported in each block group, I used the summarize within tool in ArcGIS Pro.	Greene 2018; State of California Natural Resources Agency and Department of Water Resources 2023 (California Water Plan)
Groundwater water quality risk	Domestic Depth Groundwater Quality (Water Quality Risk) by block group from California Water Boards (California State Water Resources Control Board, 2021a). Higher percentiles in this data set indicate higher water quality risk.	Greene 2018; State of California Natural Resources Agency and Department of Water Resources 2023 (California Water Plan); State of California Department of Water Resources 2021a (Small Water Systems and Rural Communities Drought and Water Storage Contingency Planning and Risk Assessment)
Water shortage vulnerability	Water Shortage Vulnerability Sections from California Natural Resources Agency (2022 analysis) (CNRA, 2022b). Total scores range from 0-100, with higher scores indicating higher vulnerability. Total scores are determined from alluvial basin and fractured rock area characteristics. Scores were recorded per MTRS. A zonal statistics approach was employed to determine the mean water shortage vulnerability score for each block group.	Greene 2021; Moser and Ekstrom 2010; State of California Department of Water Resources 2020 (Water Resilience Portfolio); State of California Department of Water Resources 2021a (Small Water Systems and Rural Communities Drought and Water Storage Contingency Planning and Risk Assessment)
Domestic well density	Domestic well density for 2022 from California Department of Water Resources Online System for Well Completion Records	Greene 2018; State of California Natural Resources Agency and

Indicator	Data Source and Processing	Supporting Literature
	(CA DWR, 2021b). Well density data were captured by MTRS without geographic coordinates; therefore, the data were joined to MTRS shapefile. A zonal statistics approach was employed to determine the mean number of domestic wells within each block group.	Department of Water Resources 2023 (California Water Plan)

Study Area

The study area was defined as the California Climate Change Assessment SJV Region. Using the Identity tool in ArcGIS Pro, block groups that fell within the SJV Region as defined by California's Fourth Climate Change Assessment (Figure 1) were selected for the model.

Drought Social Vulnerability

Data for the social vulnerability index were obtained from the American Community Survey (USCB, 2021). The five indicators of interest were: 1) percentage of renters, 2) percentage of households in poverty, 3) percentage of agricultural laborers, 4) percentage of Hispanic residents, and 5) percentage with high school education.

Shapefiles of block groups with American Community Survey data indicators were projected into NAD 1983 (2011) California (Teale) Albers (Meters). The polygons were rasterized (100x100 cell size) and then reclassified into quantiles with vulnerability scores 1-10. For four criteria – percentage of renters, percentage of households in poverty, percentage of agricultural laborers, and percentage of Hispanic residents – percentages in the highest quantiles assigned the highest scores (e.g., percentages in the 10^{th} quantile received a 10). Since we are interested in looking at the absence of high school education, high percentages of high school education were assigned low vulnerability scores (e.g., percentages in the 10^{th} quantile received a 1).

The weighted overlay tool in ArcGIS Pro was used to combine all five criteria into one raster. Each criterion was assigned equal weight in the model. The final result was a social vulnerability raster with scores 1-9 (no pixels received a weighted score of 10).

Frontline Community Water Resources Vulnerability

Data were obtained from the California Natural Resources Agency (CNRA, 2023; CNRA, 2022b), California State Water Resources Control Board (2021a), and California DWR (CA DWR, 2021b) for the water resources vulnerability index. All data were projected to NAD 1983 (2011) California (Teale) Albers (Meters).

For **count of dry wells**, the *Summarize Within* tool was used to determine the number of dry wells reported within each block group. I then rasterized the polygons using count of dry wells as cell value. For **groundwater quality risk**, percentiles of risk were provided by block group. I rasterized the polygons using the percentile of risk as the cell value. For **water shortage vulnerability**, I used a zonal statistics analysis to determine the average water shortage vulnerability score (reported per MTRS) for each block group and then rasterized the polygons using the average score as the cell value. For **domestic well density**, I used a zonal statistics analysis to determine the mean number of domestic wells in each block group and then rasterized the polygons using the average number as the cell value.

All four rasters were combined using the weighted overlay tool in ArcGIS Pro. Each criterion was assigned equal value. The final result was a frontline community water resources vulnerability raster with scores 1-10.

Synthesis

The final social vulnerability (scores 1-9) and frontline community water resources vulnerability (scores 1-10) rasters were combined using the weighted overlay tool in ArcGIS Pro. Each criterion was assigned equal weight, with classes 1-9. Zonal statistics was used to extract the synthesis score for each block group. Block groups received a vulnerability score 2-9 (no block group received a score of 1).

Results

300 of 2,638 block groups received a high vulnerability score (7-9) (Figure 4). Only one block group scored a 9, located in northeast Plano. Many high-scoring block groups were located within 50 miles of Fresno, outside of densely populated urban areas (Figure 5). 17 block groups received no score due to resolution limitations of the data; however, this represents less than one percent of all block groups in the study area.

Key takeaways from Figures 4-5 include the presence of block groups with high vulnerability scores within 50 miles of Fresno, but not in the city center. This highlights differences in vulnerability between urban and rural areas. Figure 5 demonstrates this difference quite clearly, where **communities in the downtown Fresno area have very low vulnerability scores while communities outside of Fresno in Caruthers and Riverdale have very high vulnerability scores**. These results invite us to consider how factors including proximity to agricultural work, distance from municipal water services, and others may contribute to relatively higher vulnerability in rural areas compared to urban areas in the SJV.

Another key takeaway from Figure 4 is the relative vulnerability across the entire SJV region, which is quite expansive. The results indicate that while vulnerability is heterogeneous throughout the SJV, that **there are concentrations of communities with higher vulnerability near Fresno and Visalia, compared to other cities in the SJV** such as Stockton, Modesto, and Bakersfield. Given this information, we can infer that Fresno County (includes Fresno) and Tulare County (includes Tulare) have higher concentrations of communities particularly vulnerable to the impacts of drought and are subsequently important candidates for drought resilience work.

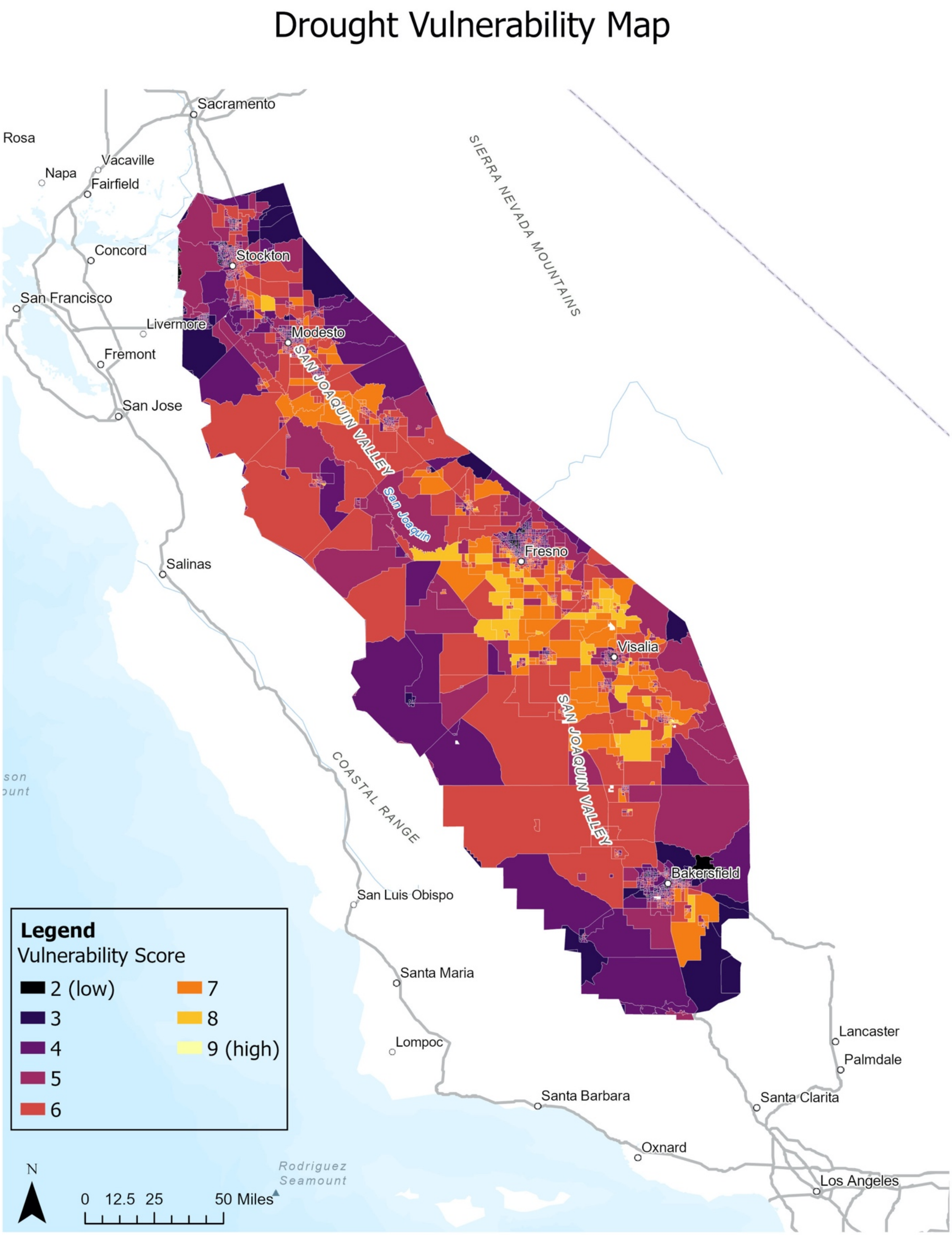

Figure 4: Frontline Community Drought Vulnerability Index.

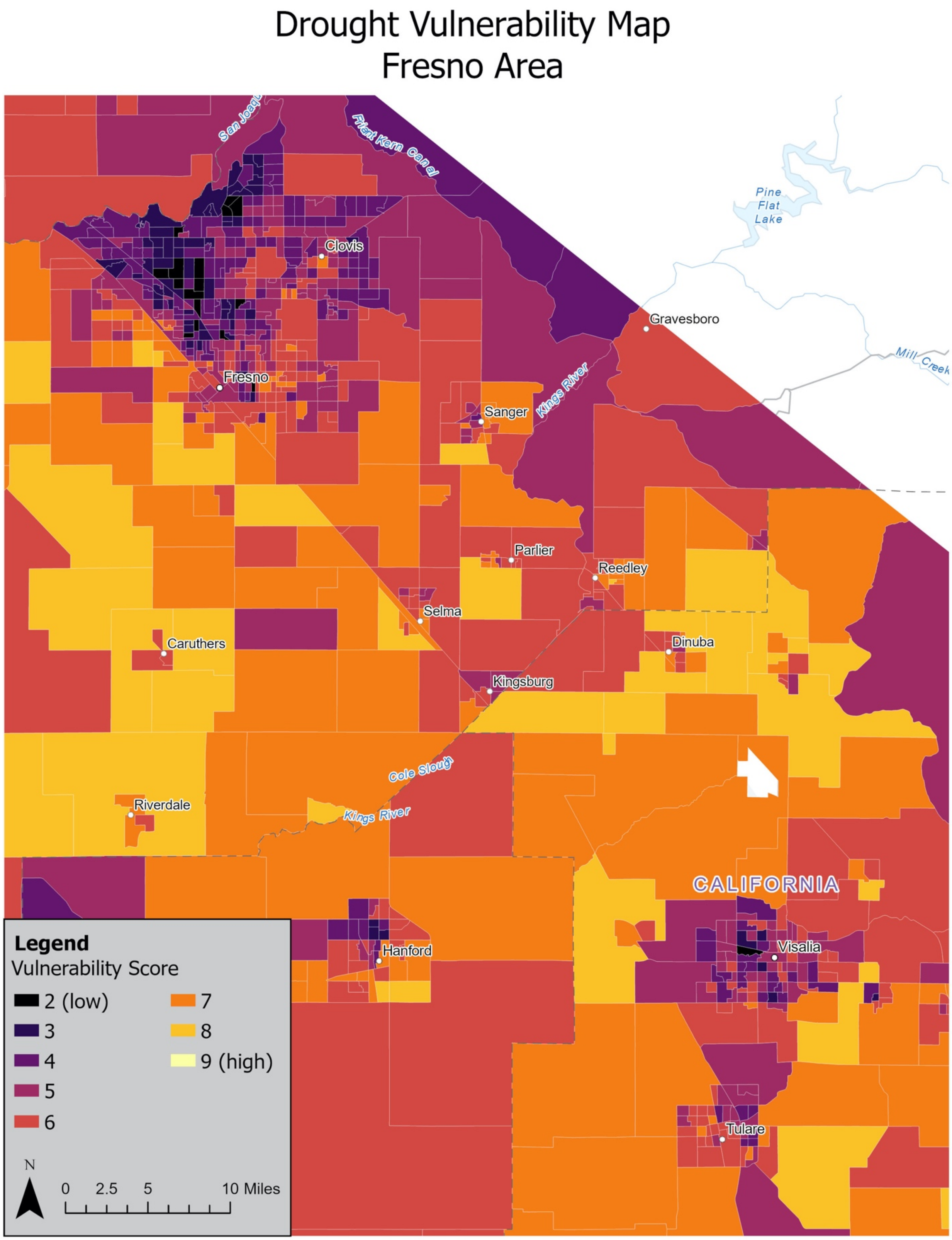

Figure 5: Frontline Community Drought Vulnerability Index in Greater Fresno Area.

Bivariate Visualization

The bivariate visualization (Figure 6) of our indices allows for the identification of areas with high water resources vulnerability (Figure 7) compared to those with high social vulnerability (Figure 8). This provides a finer resolution look at vulnerability, as the synthesis vulnerability index (Figures 4-5) masks areas that may have high vulnerability in just one of the categories. Areas in dark brown indicate combined heightened vulnerability, and these areas were largely concentrated around Fresno and Visalia (as demonstrated by Figure 4).

A key takeaway of Figure 6 is the **differences in water resources vs. social vulnerability in the western and eastern regions of the SJV.** Notably, the western region of the SJV scored very high for social vulnerability, while the eastern region of the valley scored higher for water resources vulnerability. There are multiple explanations for these differences (see discussion), one being that there are more permanent crops in the eastern region of the SJV, which have a higher water demand and could be impacting water vulnerability in that area.

Water Resources Vulnerability

One key takeaway of Figure 7 is **the differences in water resources vulnerability in urban and rural areas**. For example, when examining the City of Fresno, we can see that there is very low water resources vulnerability in the city center (scores 1-3), and vulnerability steadily increases as our radius of consideration expands and census block groups become more rural, until very rural areas of the western valley are reached (at which scale we see lower vulnerability again). This general pattern is evident in Visalia and Bakersfield.

Social Vulnerability

One key takeaway of Figure 8 is the **high presence of social vulnerability in the western region of the SJV.** Importantly, while Figure 3 suggests that these communities overall do not have the highest vulnerability to drought, the considerably high social vulnerability in these areas (e.g., communities west of Stockton, southwest of Visalia) is an important finding. These communities may be particularly important to focus other resilience-building efforts in, as there is considerable evidence that socially vulnerable communities often endure disproportionate impacts to natural hazards.

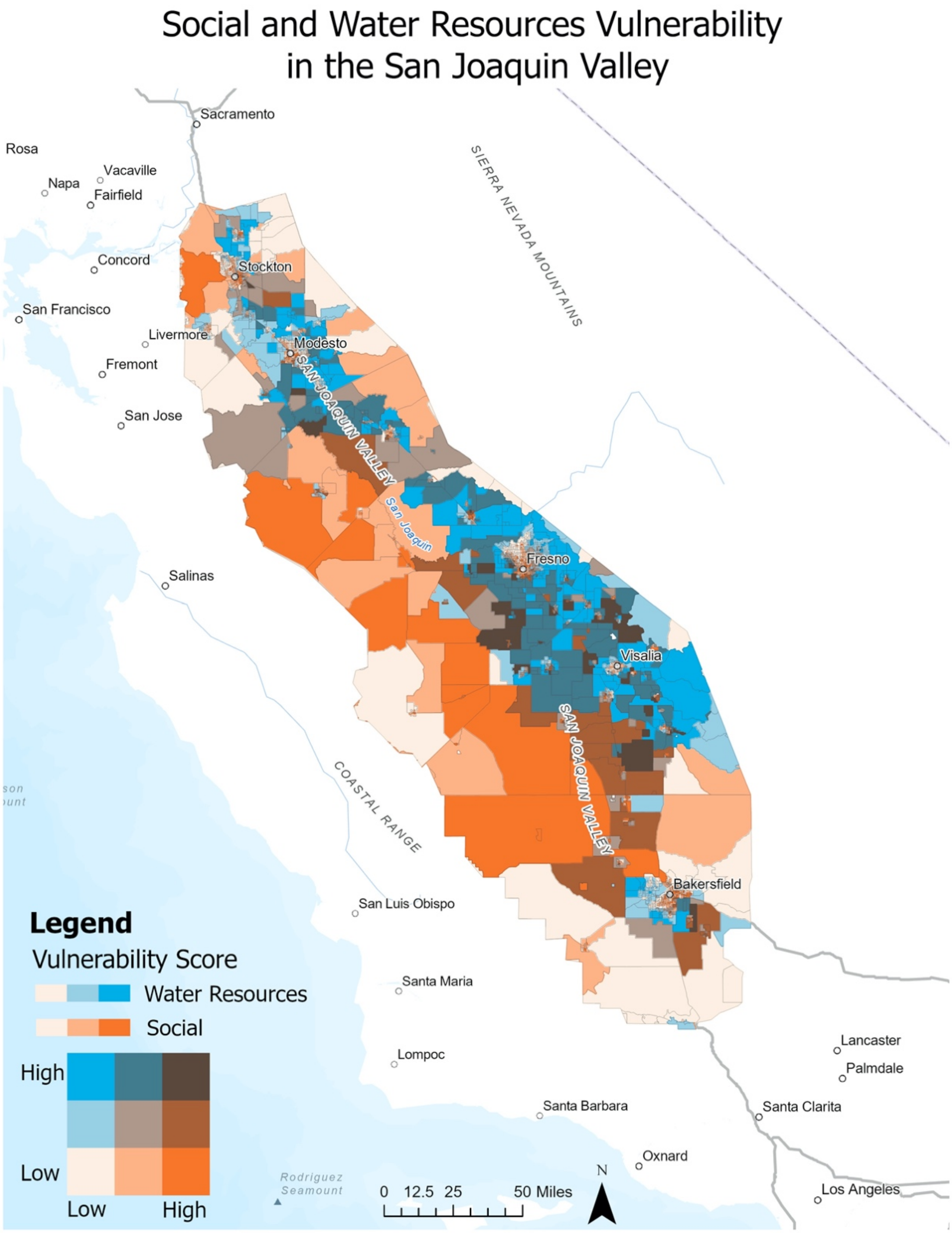

Figure 6: Bivariate Visualization of Frontline Communities Water Resources Vulnerability and Drought Social Vulnerability.

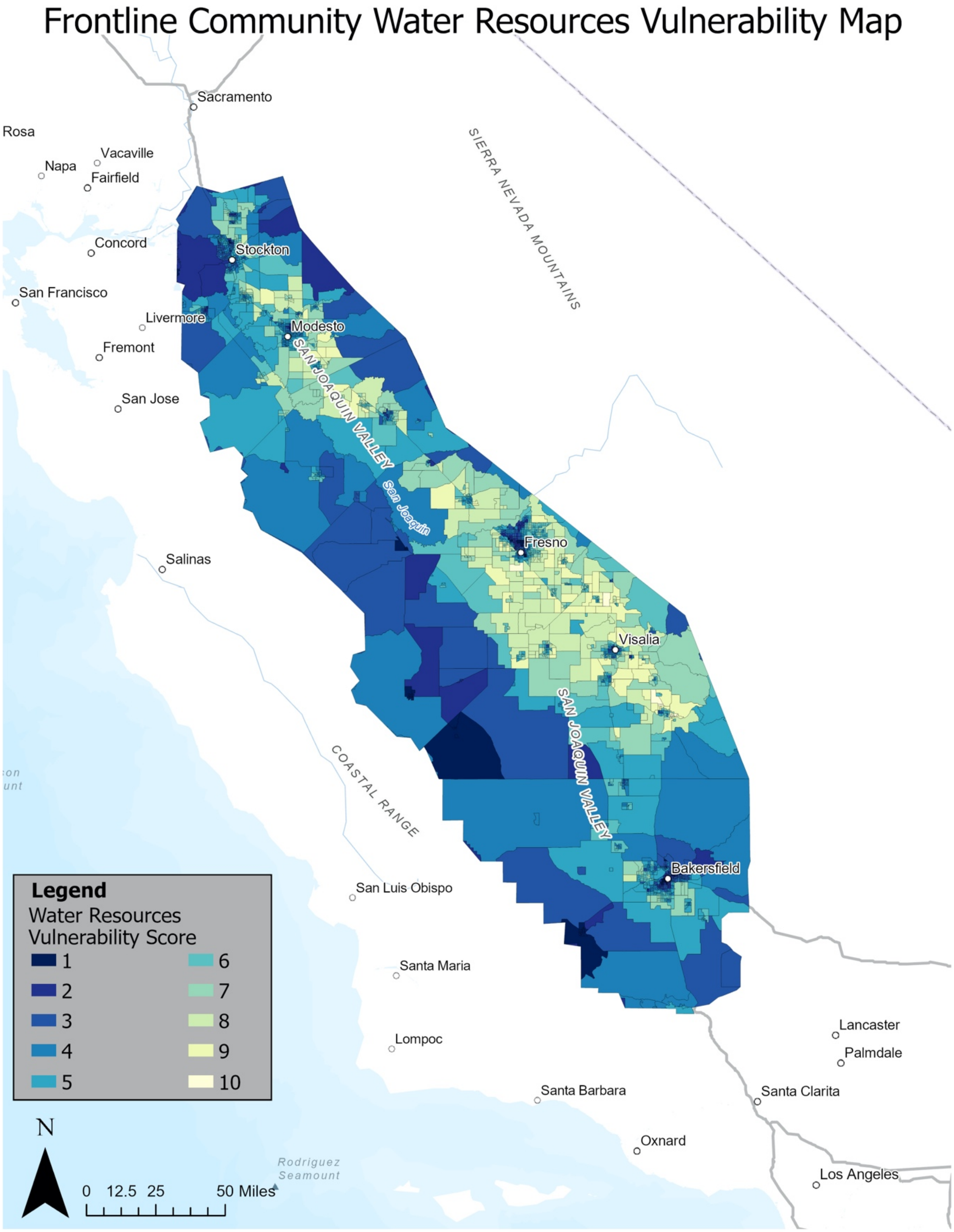

Figure 7: Frontline Community Water Resources Vulnerability Index.

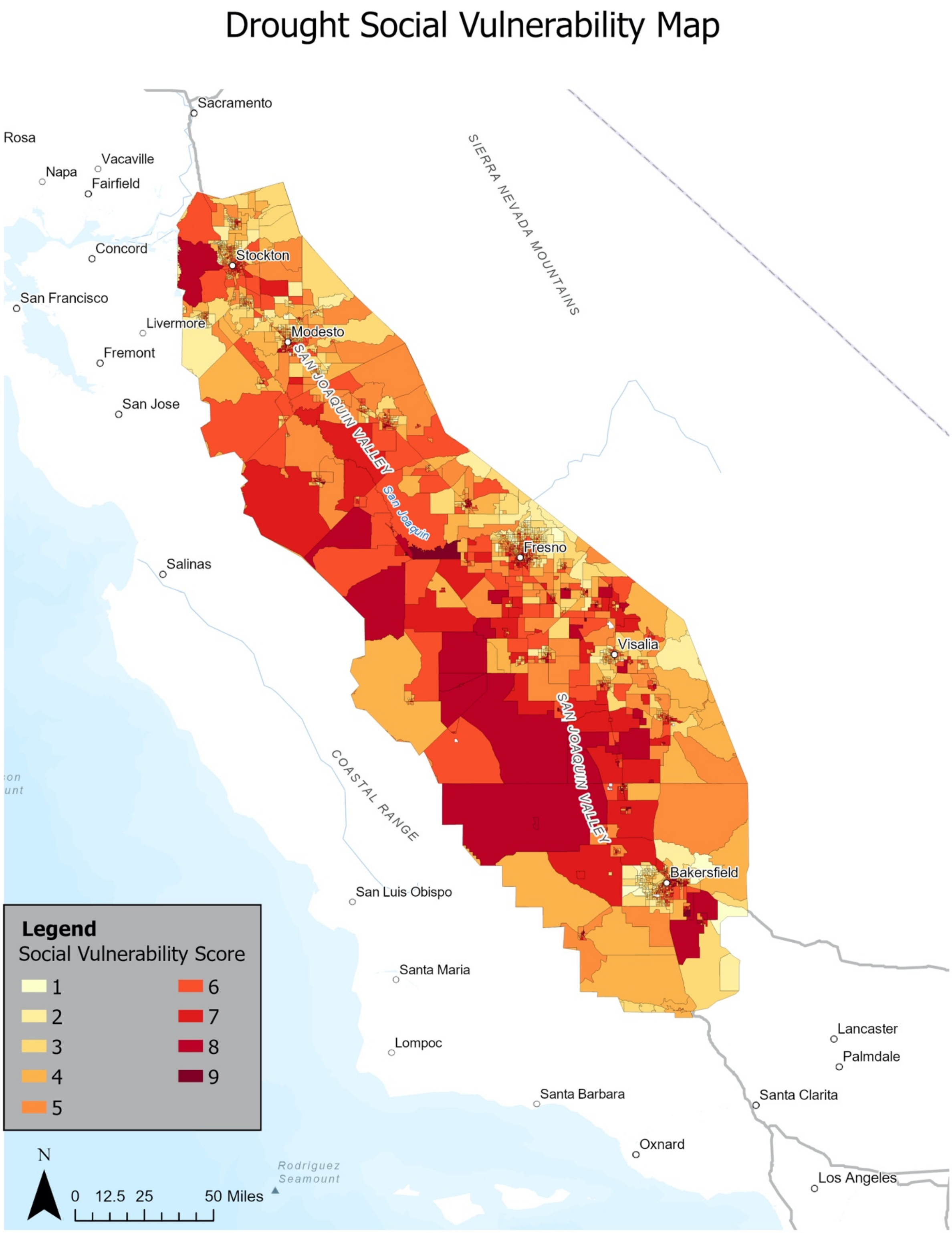

Figure 8: Drought Social Vulnerability Index.

PART II: QUALITATIVE ASSESSMENT

Methods

To gain insights on how local practitioners currently use state and other information resources to support local drought planning, I conducted key informant interviews. Key informant interviews are a widely used qualitative interview methodology for their utility in gaining in-depth insights and recommendations from diverse members of a community that would not otherwise be captured by surveys (UCLA, 2023). Saturation for key informant interviews typically occurs at a sample size of 12 (Guest et al., 2006).

Key informant interviews have helped develop key insights for improving environmental management, from watershed management (Elmendorf and Luloff, 2006) to payment-for-ecosystem services policies (Allasiw et al., 2016). Key informant interviews were selected in this study specifically for their ability to capture in-depth and candid answers from local experts about their use of state resources and their recommendations to improving the way the State supports local planning with information.

Participant Recruitment

The proposed participant population was co-developed by myself and OPR, and included technical professionals working in community- and/or locally-based environmental organizations (e.g., town/city planners, technical experts in environmental non-profits) in the SJV. We also included professionals and/or community members that are active in local environmental work in the SJV but do not work for a formal environmental or community organization in our proposed participant population. Participant recruitment began in November 2023. Participants were recruited for the study in two main ways: 1) we emailed participants directly or 2) participants passed along recruitment information to colleagues they felt would be a good fit for the study ("snowball recruitment"). We identified participants to recruit using the following inclusion and exclusion criteria:

Inclusion Criteria:

- works for a community- or locally-based organization in the SJV (e.g., environmental non-profit, community development non-profit) engaged with drought/water management;
- works for local government in related sector in the SJV (e.g., water resources management, community development);
- works for county government in related sector in the SJV (e.g., water resources management, community development);
- works directly with and/or has connections/partnerships with local organizations working to support water management/drought resilience in the SJV;
- is involved in resilience/adaptation work in the SJV as a community member, rather than professionally, but would still be interfacing with technical data/tools.

Exclusion Criteria:

- does not have at least some geographic focus on the SJV (i.e., organization can have multiple regions they focus on but state-wide is too broad);
- would not have reason to or benefit from interface with climate information in their work (e.g., they are more focused on organizing; other methods of supporting communities to build resilience);
- is not focused on water management or drought resilience in some capacity;
- has not worked in the SJV in the last 3 years (i.e., if a person has moved professional positions but could still provide very recent information they could be included, but if they have been working somewhere else, they may not have recent information on this area).

Broad targets:

- diversity of sectors: community-based organizations, local government, water management organizations, etc.
- diversity of communities they work with: local communities (e.g., farmworkers, landowners, farmers), other municipalities or departments, other organizations; with communities from different geographic areas of the Valley.

I generated a list of potential participants for the study. OPR also provided suggestions and recommendations for participants for interviews, namely participants whom they have engaged with on resilience work. However, OPR was not a part of the recruitment process nor were they aware of the final list of participants. OPR's suggested list was merged with my own, and tiers of interview candidates were created. The first participant tier was composed of priority participants who were contacted first. The second tier served as replacements in the case that first tier participants were unavailable/unresponsive. First tier participants were selected based on their fulfillment of inclusion criteria and to fulfill a diversity of participants. I contacted participants only, through email, in accordance with our IRB protocol (2024-0044 Bliska).

Ultimately, nine key informants participated in the study, from a variety of professional backgrounds (Table 3). Interviews took place from January-March 2024 over Zoom. Audio transcripts were obtained from Zoom recordings for analysis.

Table 3: Breakdown of participants by professional background.

Professional space	Sample size
Community- or locally-based organization in the SJV engaged with drought/water management	2
Local government in related sector in the SJV	3
Works directly with or has connections/partnerships with local organizations working to support water management/drought resilience in the SJV	4

Interview Analysis

I analyzed the nine interview transcripts in NVivo 14 Software. NVivo is a popular Computer Assisted Qualitative Data Analysis Software (CAQDAS) that aids researchers in identifying key themes in qualitative data through coding capabilities (Zamawe, 2015). I developed a codebook before coding the interview transcripts with 14 codes; 6 codes were added during the process from newly identified themes and one code was removed for overlap with another code (total codes=19; Appendix A).

Results

Vulnerability Factors

Participants were asked a variety of questions surrounding community vulnerability to drought (Appendix B). From participant responses, four main factors of vulnerability were identified: water resources infrastructure, environmental, social, and economic.

Water Resources Infrastructure Vulnerability

Participants identified water resources infrastructure vulnerability as a key factor to consider in identifying communities susceptible to the impacts of drought (n=8). Notably, participants identified communities with small water systems (n=2) and domestic well users (n=8) as particularly vulnerable. One concept identified in the interviews was the impact of municipal services on informing community vulnerability to drought; several participants explained that rural communities that do not have access to municipal water systems or municipal wells are vulnerable to drought (n=4). Participants also noted that domestic well users are particularly vulnerable to drought. One participant explained "when they have that kind of single source…it means it's that well or nothing…groundwater from wells is their only option." Interviews elucidated the intersections between water resources infrastructure vulnerability and environmental vulnerability. One pertinent intersection was the prevalence of domestic wells with poor water quality, which amplifies community vulnerability to drought. One participant noted "a lot of these smaller local farmers rely on their wells…[and] a lot of their wells are contaminated."

Environmental Vulnerability

Participants also identified environmental factors that pose communities particularly vulnerable to drought (n=8). For example, participants spoke to the impact of agriculture on water availability in the SJV. Notably, orchards, almonds, vineyards, and other high-value and high-water intensity crops were mentioned as crops that require more water during times of drought. One participant alluded to California's natural drought cycles that produce a "cyclical nature of…water supply" and how this characterizes vulnerability to drought in the SJV. Further explained was how groundwater extraction during times of drought has impacted groundwater availability, and the difficulty of replenishing that environmental resource; one participant explained that "it takes decades for them [groundwater levels] to recharge to holistic levels." Another environmental vulnerability factor for drought identified from the interviews was groundwater quality (n=5). Participants noted that agricultural runoff combined with low groundwater levels during times of drought amplified water insecurity for communities near agricultural production.

Social Vulnerability

Interviews highlighted the diversity of communities in the SJV. One participant noted that “there is an incredible diversity of farmer types in the SJV in their identities and backgrounds.” One key takeaway from interviews was how social identity intersects with power in the SJV, and how this subsequently informs drought vulnerability. One participant explained this dynamic by saying “it’s not that they [farmworker communities] don’t have advocates, they don’t have power.” When discussing who in the SJV is most vulnerable to drought, participants raised the vulnerability of community members with undocumented status (n=2). Participants learned of the challenges faced by community members with undocumented status from their community-based work and relationships with community members. Participants spoke to the inability of undocumented workers to access aid during drought events, particularly due to fear. One participant illustrated this fear, saying that among the communities they work with “there was a rumor going around that if you access any kind of aid that would stop [you from] becoming a citizen in the future,” while another noted that among the communities they work with “they [undocumented community members] were afraid CPS [child protective services] was gonna get called if they called and said, hey, my home has no water.”

Renter status was another social identity amplifying drought vulnerability mentioned by participants (n=2). One participant explained that aid structures during drought in some cases required landlords, not renters, to request help, making renters particularly vulnerable. Another noted that because of this dynamic, among the communities they work with “renters felt like if they got involved with that [aid programs] they might be kicked out,” which made them less likely to engage with aid programs during drought. Similar to renter status, living in an unincorporated community was also identified as a social factor contributing to drought vulnerability by participants.

Economic Vulnerability

Economic vulnerabilities were also discussed by participants in interviews as factors contributing to drought vulnerability (n=8). Notably, farmworkers and growers that lacked capital to replace dry wells or water resources during times of drought were cited by participants as vulnerable to the impacts of drought. The interviews illuminated that drought is exacerbated not only for communities that cannot afford to substitute their water resources but also for those who face economic consequences when farming labor is reduced during times of drought. One participant noted, “farmworkers did experience some of these impacts on their…general livelihood.” There were pertinent intersections between economic vulnerabilities and water resources infrastructure vulnerabilities identified in participant responses. For example, one participant noted that mobile home parks and community parks are not placed on municipal infrastructure in part because it is cost prohibitive to run water lines to these communities, which are often in rural locations. Another important intersection between water infrastructure and economic vulnerability to drought was that of the cost of new domestic wells. One participant noted that “a new well can cost upwards of $60,000 for some of these homes.” While renting is common among these communities, the cost of wells is a significant barrier for landlords to improve water security for renters. Notably, there is no state or federal law requiring landlords to provide access to drinking water for renters (Vad, 2023).

Information Sources and Types

Participants spoke to using a variety of data types in understanding drought vulnerability in the SJV. Notably, crop data was mentioned by several participants (n=2), particularly for its ability to provide insights as to water demand. One participant noted that their organization often obtains crop data from DWR. Hydrologic data was also used and obtained by participants in a variety of ways, including from projections and allocation estimates developed by State Water Masters, as well as via local well monitoring.

Many participants relied on state resources for information to inform drought planning or projects. Participants often cited DWR as a key information source (n=7). One participant specifically mentioned using the well monitoring tool developed by DWR, which the participant uses to communicate with members of their community about groundwater levels in real time. Other participants mentioned the use of information sources produced by OPR. Notably, Cal-Adapt was mentioned, and one participant is involved in the Fifth Climate Change Assessment. One participant specifically noted that their department uses Cal-Adapt to gather demographic data for particular areas.

Many participants belonged to organizations that collect their own local data or information (n=6). For example, one participant mentioned that their organization relies on local knowledge, noting "we need to have our ears on the ground with the local communities to find out what their specific challenges are." Similarly, other participants' entities collected their own groundwater data via well monitoring to have accurate understandings of groundwater levels on the local scale.

Barriers to Use of State Resources for Climate Information

Barriers to using state resources for information to inform projects were classified into two categories: usability and applicability (i.e., usefulness).

Usability

Several participants identified usability barriers in regard to using state resources for information (n=6). For example, participants spoke to the difficulty of accessing all of the data they need in a central location. One participant noted that "all that information is not going to live in one central place." Another participant mentioned that their organization relies on consultants to gather data from different state sources and provide the technical expertise needed to interact with the data.

Other participants spoke to challenges with usability regarding the format of data disseminated by the State. For example, one participant mentioned that their organization often wants to use raw data in their analyses, but the challenge is transforming data "into a useable format" given "lack of metadata that made it difficult to understand exactly what was being presented." This challenge is certainly a barrier to data use by organizations, as organizations want to be able to determine that the data they use are reliable and up-to-date.

Another usability challenge mentioned by participants was the challenge of distinguishing between all of the different state resources and tools. One participant noted "there's a lot of tools and maps, and they all have really similar names, and it's hard to assess which is the most relevant or should be used." Notably, participants mentioned the need to parse and sift through resources was a barrier to their use.

While interview questions focused on identifying barriers for technical users (participants), participants still spoke to usability issues they see preventing community members (non-technical users) from using state resources to understand drought. Notably, limited knowledge of the available resources in the community was cited as a barrier, as was usability issues related to internet access and language translation.

Applicability

Some participants spoke to the idea that state resources were, in some cases, not relevant or applicable to their work (n=5). For example, some participants' work was more focused on developing or supporting drought projects in conjunction with local communities, rather than from a data-driven process, which would require climate information. One participant spoke to this idea of a diverse set of stakeholders and users, highlighting "state agencies are building resources and tools on a particular topic that may not be applicable to someone." Additionally, one participant mentioned that while they might not find the resources applicable to their work, they do point the resources they are familiar with out to communities or partner organizations.

As previously mentioned, participants cited their need for fine-scale local data and information (n=6), which is not always available from the State. In some cases, this made state resources not applicable to participants' planning; for example, one participant felt they needed more fine-scale data (e.g., groundwater level data collected for their municipality) to make decisions than is offered by the State. Another participant needed to directly communicate with community members to understand their current experiences with drought and to understand impacts of potential projects, in addition to using state resources.

A barrier that concerned applicability, in addition to usability, was that of a lack of clarity between a plethora of available resources. Participants noted that the volume and uncertainty of distinguishing factors for resources made it difficult for participants to determine if the resources would be applicable to their work.

Opportunities for Improving State Resources for Climate Information for Local Users

The following section details opportunities specifically mentioned by participants for improving the usability and applicability of state resources to local drought planning.

Aggregation of and Guide to Resources

Participants spoke to aggregating information sources and tools as an opportunity for improving usability for use by local practitioners (n=2). For example, one participant noted that "what would be helpful actually is a…guide and a compilation of the tools." Given extensive comments from participants about the lack of knowledge surrounding the available resources and tools, as well as frustrations that all key information sources are not located in one place, an opportunity moving forward could be to create a carefully guided and annotated aggregation of tools and resources.

New Information Types

Several participants mentioned additional information types that would improve the applicability of state resources to their work in drought planning (n=4). For example, one participant noted that there could be more data available via the State on the economic and labor impacts of drought. This is particularly important given the economic vulnerabilities that intersect with drought vulnerability.

Several participants noted that a key piece of their work in drought planning is connecting local communities to funding for projects or acquiring funding for new projects (n=2). Another participant mentioned their interest in funding opportunities for groundwater recharge projects. Thus, a potential opportunity to improve applicability would be to provide information on and aggregation of funding opportunities for drought planning.

Addressing Uncertainty

One participant noted that it would be helpful to have tools that analyze and communicate uncertainty around drought and different climate conditions. For example, this participant explained that it would be helpful to have models that show "what the different potential outcomes are" given different RCPs. This was supported by another participant, who spoke to the difficulty of understanding long-term projections in surface-water allocations; their experience suggests that additional support in interpreting and planning for uncertainty around drought could be helpful.

Creating User-Friendly Resources

Participants noted that tools developed should have an end-user in mind (n=2). Particularly, the usability of many tools depends on who the "intended audience" is, as one participant noted. It would thus be helpful for the State to provide clear guidance on which users a tool would be best suited for: whether technical users, community members, or others. Additionally, many of the hyper-local projects did not use information from the State, rather, participants collected a variety of local data. These cases highlight that the coarse resolution of state data in some cases does not match the needs of a significant user group: local practitioners.

Synthesis of Barriers and Opportunities

Based on participant responses, there are several usability and applicability barriers to local organizations using state resources for climate information. Importantly, there are several opportunities to alleviate these barriers to make resources more usable and useful, some of which were suggested directly by participants, and others informed by my own analysis (Table 4).

Table 4: Barriers and opportunities for improving access to climate information.

Barriers		Opportunities
Usability	Accessing data in one place	Aggregation of resources
	Technical expertise needed	Providing technical expertise Providing funding for technical support
	Insufficient metadata	Updating metadata

	Need for fine-scale data	Providing funding for the collection and visualization of local-scale data Encouraging municipalities to share local data collected with the State and other municipalities Adding local economic data to resources
	Need for data that represents uncertainty under different climate scenarios	Providing technical support interpreting uncertainty Providing guide to resources that account for uncertainty
	Distinguishing between resources	Providing guide to resources
	Limited knowledge[a]	Increased communication and engagement
	Internet access[a]	Producing hardcopy reports
Applicability	Distinguishing between resources	Providing guide to resources
	Connector, not user, of resources	Providing guide to resources

[a]Suggested in reference to community members and not technical users.

A key takeaway is the opportunity to more clearly **describe and articulate the unique role of state resources**. Several participants spoke to the difficulty of discerning between the tools and resources, and not knowing which would be most useful for their work. Developing a succinct user guide, with hyperlinks, detailing each of the state resources and a short descriptor of their use, could help to alleviate these barriers (see Appendix C for a draft user guide). Additionally, videos and informational sessions could also help clarify the purpose and intended use of state resources. For example, DWR uses YouTube videos to communicate the datasets and tools available from the Department (CA DWR, 2024). For inclusion in future user guides, state resources and tools that were specifically cited by participants for use include: California's Groundwater Live (DWR), ACE Viewer (California Department of Fish and Wildlife), Water Shortage Vulnerability Scoring and Tool (DWR), DWR Crop Data and Contour Maps (DWR), My Dry Well (DWR), Cal-Adapt (OPR), and CalEnviroScreen (OEHHA).

A second key takeaway is the **importance of fine-scale, locally collected data for local planning**. There is an opportunity for the State to develop resources to support access to this fine-scale data by 1) providing funding for local departments to continue collecting and visualizing local-scale data and 2) sharing that locally collected data with other municipalities and the State to increase the amount of fine-resolution data available and increase understandings of local vulnerabilities. This would ultimately promote knowledge-sharing across municipalities, which is critical given the regional impacts of drought.

A third key takeaway is the **opportunity for the State to make current datasets more accessible to local practitioners by providing clear and detailed metadata**. Participants mentioned difficulty in understanding how or when data were collected. Even in the context of tools, more detailed metadata would allow users to more easily understand their intended purpose. The State could set standards for metadata sharing, including requiring column names to be specified, dates and methods of collection, and contact information for users to follow up with if they have questions about the data shared.

Importantly, some of the opportunities detailed in Table 4 may already be resolved by existing resources. Thus, action items for each opportunity should be tailored depending on the current availability of state resources (Table 5). For example, the Adaptation Clearinghouse is a searchable database of resources (tools and data) for users to access state resources in one place (ICARP, 2024). While this resource may sufficiently aggregate resources, participant responses that requested aggregations suggest that further communication of the Adaptation Clearinghouse and instructions for its use are needed to communicate the role of this resource to potential users. Additionally, this recommendation further supports the development of a "Tool Comparison" feature on the Vulnerable Communities Platform, which is intended to allow users to display data from different tools and provide information on what the tools can be used for.

Likewise, OPR's Integrated Climate Adaptation and Resiliency Program (ICARP) provides technical support to users through their Climate Services team, which when accessed could alleviate some of the technical barriers identified by participants. On their website, users can contact Climate Services staff to request assistance with climate change adaptation information and resources (ICARP, 2024). The ICARP Climate Services team could be more explicit about their availability and capability to assist local organizations and departments in working with tools and resources, and advertise this ability to local users. Some participants mentioned that they were interested in using consultancy-produced tools (e.g., well data compilations) or that they used consultants to harness the insights of state tools; in this case, ICARP's Grant Programs should be explicit about if these types of services would be covered under grants to increase usability. The Climate Services team is exploring launching a "Help Desk" feature to solicit requests from practitioners; this could be an ideal venue through which increased technical support could be provided.

Table 5: Opportunities identified from participant interviews and recommended action items for OPR.

Opportunities	Satisfied by existing resource?	Action items
Aggregation of resources	Yes, Adaptation Clearinghouse.	Increased communication with users and support to navigate Adaptation Clearinghouse.
Providing technical support Providing funding for technical support	Yes, ICARP Climate Services for technical support and ICARP Grant Programs.	Increased communication about ability to provide technical support. Increased communication about funding for consultancy services and tools covered under grant programs.
Updating metadata	No	Set policy for metadata.

Providing funding for the collection and visualization of local-scale data Encouraging municipalities to share local data collected with the State and other municipalities Adding local economic data to resources	Yes, ICARP Grant Programs.	Ask municipalities to share data and insights generated as a result of ICARP Grant Program funding.
Providing technical support interpreting uncertainty Providing guide to resources that account for uncertainty	Partially, ICARP Climate Services can provide technical support.	Increased communication about ability to provide technical support to interpret uncertainty. Develop guide for supporting organizations/departments in interpreting uncertainty from models with RCPs and how to incorporate uncertainty into planning.
Providing guide to resources	No	Develop user guide summarizing key differences between state resources and intended uses of each.
Increased communication and engagement	Yes, ICARP Climate Services.	Increased local presence and communication with local organizations/departments.
Producing hardcopy reports	No	Make report hard copies available at local libraries for community members to read through and interact with.

Discussion

This project identified key factors in the literature that have been shown to predispose communities to disproportionate impacts to drought in the SJV, including domestic well density, water quality risk, and poverty status, among others. Using these key factors, I identified the spatial location of communities vulnerable to the impacts of drought in the SJV, a major agricultural region of the U.S. Importantly, my geospatial analysis revealed that vulnerability to drought is particularly concentrated outside the City of Fresno, where less densely populated communities have high social and water resources vulnerability. These results highlight the importance of supporting local adaptation and resilience planning in Fresno County, given the significant vulnerabilities to drought present in this region.

Using bivariate visualization, I found that there are distinct differences in vulnerability between the western and eastern regions of the SJV. In particular, the western region of the Valley scored very high for social vulnerability, while the eastern region of the valley scored higher for water resources vulnerability. Researchers have previously noted the diversity and distinctions present between the eastern and western regions (e.g., Greene, 2018). For example, there are different irrigation districts in the eastern and western SJV; the western region is managed by Westlands Water District and the eastern by Friant Water Authority. Irrigation districts are responsible for distributing irrigation water, and their allocations (and subsequent distribution) may differ depending on State guidance from the State Water Resources Control Board (California State Water Resources Control Board, 2024). Additionally, the eastern region has historically produced permanent crops such as citrus and fruit, while the western region has grown annual crops such as tomatoes and cotton (Greene, 2018). The geographies of the western and eastern SJV are also quite distinct. Notably, the eastern region receives more precipitation and snow pack melt due to proximity to higher-elevation mountains and foothills (CSU Stanislaus, n.d.). The eastern region is also more urbanized, with larger cities such as Visalia and Fresno (Figure 5). Thus, it is unsurprising that my findings illustrated differences between the western and eastern regions, and these difference emphasize the importance of tailoring resilience and adaptation strategies to each region.

There are several caveats important to discuss within the context of the results of the geospatial analysis of drought vulnerability in the SJV. First being that some indicators, such as the count of dry wells, may not holistically capture a community's experience with water insecurity during droughts. In particular, not all wells that run dry are reported; from participant interviews, I learned that undocumented individuals may be less likely to report their wells dry for fear of consequences from the State. Additionally, the metric of count of dry wells does not tell us how many people rely on a given dry well, ranging from an individual, to a household, to many households, nor is it adjusted by population density. Therefore, there are ample opportunities to investigate these considerations and potentially improve the metric of count of dry wells to more fully capture this important factor representing water insecurity during periods of drought.

The geospatial analysis relied on American Community Survey data for factors related to social vulnerability, including the percentage of Hispanic community members and the percentage of community members living below the poverty line, among others. The American Community Survey, as a part of the U.S. Census, captures valuable demographic information; in particular, it is noted to have more frequently updated data and better coverage than the U.S. Census (Bazuin and Fraser, 2013). However, it is important to recognize that underreporting, particularly of socially vulnerable communities, is a caveat present in the data. The American Community Survey does not have a 100% response rate (USCB, n.d.) and has been shown to have inaccuracies in sparsely populated neighborhoods (Bazuin and Fraser, 2013). Thus, it is important to recognize that some communities in the SJV, particularly those undocumented, may not be fully represented by American Community Survey data.

Additionally, some of the social characteristics we selected in our geospatial analysis will have different characteristics depending on the geographical context. For example, individuals who are renters in downtown Fresno likely hold much more diverse jobs and incomes compared to renters in smaller, rural towns who are likely to be employed in agriculture. Importantly, a study in 2014 found that ~70% of African Americans and Latinos rented in Fresno County compared to ~31% of Whites (Abood, 2014) suggesting many rural farmworking communities who are predominately communities of color are likely to constitute a large fraction of renters in this area.

Future studies could investigate other indicators for individuals in the SJV that have less agency over their housing and water infrastructure, including those living in mobile homes or vans.

Additionally, the geospatial analysis does not account for the mobility and/or other responses of communities when drought occurs. One of our interview participants specifically noted that there are some farm working communities that are year-round residents in the SJV, while others are mobile agricultural workers who can leave the SJV during times of drought and travel to Washington or other areas for labor. This participant explained that the communities who are not mobile and remain year-round in the Valley are more vulnerable to the impacts of drought. Importantly, this connects to discussions around climate migration, and how the ability of communities to move can reduce their exposure to hazards such as drought (Adger et al., 2018). Therefore, it is important moving forward to understand which communities have lower degrees of mobility, posing them most vulnerable to drought. Future geospatial analyses could investigate mobility via demographic surveys to identify which communities are largely permanent and thus predisposed to disproportionate drought impacts.

Overall, the geospatial analysis of this project identified significant vulnerabilities to the impacts of drought in communities residing outside of metro areas. This provides significant insight as to the factors that could be addressed in resilience and adaptation planning in rural areas. In particular, improving water resources infrastructure in rural and unincorporated communities could aid resilience and adaptation to drought. Key informants discussed the importance of connecting unincorporated and other rural communities to municipal water systems to alleviate water insecurity associated with private wells and small water systems. Importantly, many of the factors identified in the literature review as pertinent to identifying communities disproportionately impacted by drought were corroborated by key informants. For example, participants highlighted how farmworking communities are more vulnerable to drought because of their physical proximity to industrial water users and their economic insecurity during times of drought; working in agriculture was also identified as a vulnerability factor in the literature review. Overall, these insights help us to identify exactly which factors predispose communities to the impacts of drought in this region and where spatially they are concentrated to better support communities in preparing for the impacts of climate change. With this knowledge, the State can support municipalities and local organizations in tailoring drought planning and responses to the areas that need it most.

Given the knowledge this study has produced on vulnerabilities present in the SJV, it is paramount to consider the role of the State in supporting the implementation of solutions to drought vulnerability on the local level. The key informant interviews revealed that local organizations and departments are using a variety of data types and sources to support their work, including those from the State. Interestingly, organizations and departments had different data needs. One key informant's organization was very involved in geospatial analysis, and relied on state resources like DWR to obtain geospatial data on crop types for water studies. Another key informant, who worked for a municipality, employed consultants to harness the demographic and other data available on Cal-Adapt. Other key informants work to build drought resilience from a non-data driven perspective, working directly with community members to develop or support local projects.

Key informant interviews also revealed a plethora of data that is generated locally, both through quantitative and qualitative methods. For example, key informants worked for departments who collected their own groundwater monitoring data or who conducted outreach to community members to learn more about community desires and needs. Interestingly, the diversity of methods for obtaining and using data in drought resilience work prevalent among key informants speaks to the growing movement to integrate local knowledge and perceptions *with* scientific evidence of climate impacts (Alexander et al., 2011; Pelling, 2010; Shrestha et al., 2019).

I identified usability barriers that prevent more in-depth use of state resources in our key informant interviews. Notably, key informants raised issues with being able to distinguish between all of the different state resources and tools, and that a lack of knowledge and similar naming conventions made them hard to discern which tools and resources would be most helpful to their work. Community-engaged user surveys and feedback sessions could help to understand how naming conventions of tools could be improved and how local users would most prefer to receive information about the available tools and resources. There is ample guidance in the literature to support the design of such community-engaged surveys (Harrison et al., 2021). Based on key informant interviews, one such suggestion for improving communication about the different roles of state tools and resources could be the development of an accessible guide detailing distinguishing characteristics of the tools and their location on the internet (see Appendix C). Notably, internet access was raised as a barrier to community members (not local practitioners) in utilizing tools and resources. Therefore, ICARP could consider developing hard copies of this report for review at local libraries and, where possible, make tools and resources available via computers for interaction with at local libraries. This recommendation aligns well with feedback ICARP has received from workshop participants that displays for the Vulnerable Communities Platform should be made available at local libraries.

Importantly, the key informants had diverse data needs for their drought planning work, suggesting that there are many different user types for climate information in the State of California. This finding speaks to the importance of understanding *who* potential users are of state resources and what their information needs are. Stakeholder analysis is a well-practiced methodology for identifying key stakeholders for engagement (Bridges, 2010; Schmeer, 1999; Brugha and Varvasovszky, 2000; Varvasovszky and Brugha, 2000; Preskill and Jones, 2009). Stakeholder analysis could be used by the State to learn more about the different types of local users and their data needs to inform state resources, and then focus subsequent engagement through surveys or feedback on covering a diverse representation of user types.

I also found that there were applicability barriers for participants in utilizing state resources and tools. For example, some participants relied on collecting local data rather than using data offered by the State because they need data at a fine scale (e.g., within a municipality). It may be the case that these practitioners represent a subset of climate information users that simply will continue to rely on municipal data and are not an ideal user population for state resources and tools. However, it is also possible that the State could work to make their information more applicable for local practitioners, increasing their potential use. For example, OPR could help to convene and share local practitioners' data, encouraging cross-municipal learning. One possible avenue for this action would be to ask municipalities who implement projects with OPR funding to share their data and insights back to the Office, who could then upload these insights to one of their public data tools, such as the Vulnerable Communities Platform. Additionally, OPR could conduct more local level case studies, like the process undertaken in this report, to produce and share fine scale vulnerability data with local practitioners.

My analysis determined that there are many opportunities to improve usability and applicability of state resources and tools to support local drought adaptation and resilience planning, in addition to those discussed so far. One centers around the opportunity for ICARP Climate Services to better communicate and/or expand their offerings of technical support. Technical support could not only help improve local user's usability to state resources and tools, but it could also support the collection of more rigorous, local data. The Federal Emergency Management Agency has increased its technical support for disadvantaged communities interested in resilience planning through their BRIC (Building Resilient Infrastructure and Communities) Direct Technical Assistance program (FEMA, 2024). In this program, the Agency offers support to disadvantaged communities in developing hazard risk assessments and grant applications, and reviewing data and planning efforts (Griner, 2022). ICARP Climate Services could emulate this process by further expanding technical assistance to local departments and organizations, providing training and expertise in the state tools and resources available.

This recommendation aligns well with ICARP's plan to enhance technical assistance, documented in their recent Technical Advisory Council Staff Report (ICARP, 2024). In this report, ICARP outlines their goal to pilot new technical assistance programs in 2024 that help provide support to local practitioners. While technical assistance usually provided by ICARP is in direct relation to grant program development, ICARP may choose to expand its offerings to include technical support, which would include providing technical support independent of grant development to local practitioners.

Conclusion

This project illuminated the ways in which the State is currently supporting drought planning in local organizations and departments in the SJV, and provided actionable recommendations for ways to improve this support. Nine key informant interviews revealed that there was knowledge and use of state resources among local organizations and departments planning for drought, but that there was ample opportunity to improve the usability and applicability of these state resources for local users. Key recommendations for OPR include developing a guide to help users distinguish between multiple state resources and understand their unique utilities for their work, and to increase communication about the ability of state grants to support technical assistance and data collection for practitioners involved in drought resilience work.

This project also provided valuable insights as to where communities most vulnerable to disproportionate impacts of drought are located by generating two unique indices, informed by the literature, that are able to identify communities vulnerable to drought. Using these indices, significant vulnerability to drought was identified in communities just outside of the Fresno Metropolitan area (approximately 50-mile radius). These results speak to the importance of the State supporting drought resilience work in Fresno County. Given the location of communities vulnerable to drought outside of metro areas, the results suggest the importance of focusing on drought resilience work in unincorporated and other rural areas, and considering policy and project measures that may support water infrastructure improvements in these areas, increasing water security during times of drought. Other key insights from the geospatial analysis were the differences in vulnerability factors in the western and eastern regions of the SJV: the western region had much higher social vulnerability, while the eastern region had much higher water resources vulnerability. These insights can help to inform tailored resilience and adaptation solutions in these regions.

Ultimately, this project supports the work of the Climate Services team of ICARP and the development of their Vulnerable Communities Platform by providing a fine-scale look at the spatial distribution of vulnerability to a particular hazard – drought – in an important agricultural region of California. It also further positions ICARP to aid communities must vulnerable to the impacts of climate change by providing actionable recommendations as to supporting local users with state resources and information.

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Appendices

Appendix A: Codebook

Codebook

Parent Codes (top-level)	Child codes	Definition	Inclusion criteria	Exclusion criteria	Inclusion example	Exclusion example	Added during coding process
Vulnerability	Social vulnerability	Anything involving comments of how identity or other social characteristics make a community more vulnerable to drought	Describe race/ethnicity, immigration status	Describes income	"Farmworking communities with members from Mexico are more vulnerable"	"Not having enough stable pay during drought poses households vulnerable"	
	Environmental vulnerability	Anything involving comments of environmental factors that make a community more vulnerable to drought	Describe environmental factors such as water quality, agriculture or other land use	Describes water infrastructure	"Agricultural communities have water quality issues, which makes drinking water unsafe"	"Domestic wells are not maintained by the State"	
	Economic vulnerability	Anything involving comments of how poverty or other economic factors make a community more	Describe income	Describes social vulnerability	"Not having enough stable pay during drought poses households vulnerable"	"Farmworking communities with members from Mexico are more vulnerable"	

		vulnerable to drought					
	Water resources vulnerability	Anything involving comments of water infrastructure vulnerability that make a community more vulnerable to drought	Describes water infrastructure	Describes water quality	"Domestic wells are more vulnerable to drought because they are not used by the State"	"Agricultural communities have water quality issues, which makes drinking water unsafe"	X
Information sources	Department of Water Resources	Anything involving resources that the DWR produces or distributes	Describe tools or websites produced by DWR	Describes general water resources	"We have used the tool on DWR's website that allows us to see the count of dry wells"	"We like to use data on groundwater levels"	
	Community knowledge	Anything involving locally gathered knowledge (interviews, family)	Describes knowledge generated by community members, locally collected data	Describes academic research	"We ask community members what their main concerns are"	"In my dissertation, I interviewed local farmworkers"	
	Researchers	Anything involving academic researchers or think-tank research	Describes knowledge generated by academic research	Describes knowledge generated by community members	"In my dissertation, I interviewed local farmworkers"	"We ask community members what their main concerns are"	
	State resources	Anything involving a product produced by the State of California	Describes a tool or information source produced by the State, like Cal-Adapt or the Adaptation Clearinghouse	Describes data collected by local municipality	"We use Cal-Adapt to find demographic data."	"We collect our own local data to inform our projects"	X
Information types	Geospatial data	Anything involving geospatial data	Describes geospatial data (parcels, etc.)	Describes data points that are not	"We use GIS data to prioritize places to work"	"We want to know where the dry wells are"	

				associated with spatial features			
	Hydrologic data	Anything involving hydrology data	Describes dry wells, water tables, etc.	OK if describes GIS data, but should not describe other types (crop)	"We use data on groundwater levels"	"We use data on the types of crops grown, such as oranges vs. almonds"	
	Crop data	Anything involving the distribution of agriculture	Describes crop data	OK if describes GIS data, but should not describe other types (hydrology)	"We use data on the types of crops grown, such as oranges vs. almonds"	"We use data on groundwater levels"	
Barriers	Accessibility barrier (later updated to **usability** barrier)	Anything involving ease of use as a barrier	Describes difficulty accessing, finding, or understanding what the data is (no metadata)	Describes lack of financial resources (this is not a publicly available resource, then)	"We do not have the resources to use that type of data"	"We cannot afford ArcGIS Pro"	
	Applicability barrier	Anything involving relevancy to work or if organization uses data	Describes resources as not being relevant to work, helpful; Describes a lack of data use by the organization as a whole	Describes difficulty accessing, finding, or understanding what the data is (no metadata)	"We don't find that data relevant to our work"; "Our organization does not use data to inform our projects"	"We do not have the resources to use that type of data"	
Ideas	Aggregation of data	Anything involving having all information in one place	Describes desire to have aggregated data	Describes difficulty finding resources	"We would like to be able to go somewhere and find the data all in one place"	"I can't find the data I want right now"	
	User friendly	Anything involving more user-specific tools	Describes desire to have more user-specific tools	Describes lack of applicability to work	"We would like tools more designed for our specific need"	"We don't find that data relevant to our work"	
	Address uncertainty	Anything involving products that address different climate scenarios	Describes needing to plan under different RCPs, or needing help deciphering action	Describes difficulty of making long-term plans	"We want to be able to plan for uncertainty under different allocations, but we	"We want to make long-term plans"	X

		or help plan under uncertain drought futures	items under uncertain allocations		have trouble doing this with the information we have"		
	Consultancy	Anything involving using consultancy products or using consultants	Describes use of consultants to decipher and use state resources or desire to access consultancy-designed products	Describes using a state resource for technical support	"We hired consultants to use Cal-Adapt"	"We need the State to provide more help in using these tools"	X
	Diversity of data types	Anything involving adding different forms of data or information less prevalent	Describes desire to access different types of data or to find other forms of information	Describes wanting to use other forms of data but they are already available	"We cannot access economic data, which would be very helpful for understanding the impacts of droughts on our community."	"We want to move toward using social vulnerability data to focus our well monitoring"	X
	Funding information	Anything involving information about funding	Describes desire for funding or need to understand funding opportunities	Describes own funding program	"We need more information on funding opportunities from the State to share with our local communities"	"We provide grants to local communities"	X

Appendix B: Interview Guide

[Informed consent verbal request]: You received the informed consent information over email, but now I'll ask you to confirm verbally that you consent to being interviewed, and then we can proceed. Do you consent?

INTRODUCTION

1. Tell me a bit about what you do and how you're involved in the San Joaquin Valley community. *And when we say community, we mean folks who live and work there.*
2. What type of work does your organization currently do to address drought?
    a. *Probes:* water use planning, water retention projects.

SECTION 1: DROUGHT VULNERABILITY

1. How do you see drought impacting the San Joaquin Valley community?
2. Who do you think is most affected by drought in the San Joaquin Valley community?
    1. How will this change in the future (e.g., 10, 50, 100 years from now)?
3. What intersections, if any, do you see between drought vulnerability and other types of vulnerability in this community?
    1. *Probes*: what about social, economic vulnerabilities?

SECTION 2: BARRIERS FOR CLIMATE INFORMATION ACCESS AND USE

General:

1. What information is most helpful for your organization when planning drought mitigation projects?
    a. *Probes:* do you use local knowledge, information from the government?
2. Do you **use** any climate information from the State to inform drought planning?
    a. If the response is YES, move to Questions 3-6.
    b. If the response is NO, move to Question 6-7.

Climate Information Access and Use:

3. What kinds of climate information from the State **do you use** and why?
    a. *Probes:*
        i. *Types*: Crop, groundwater planning, social vulnerability, water access data.
        ii. *Sources:* Cal-Adapt (for modeling scenarios and data in the analytics platform), California Climate Change Assessment (for climate change projections), Department of Water Resources information.
            1. *Type out in chat*
4. On a scale from 1-10, how **accessible** are the information sources you mentioned above?
5. What information do you find most **useful** and why?
    a. What information is most useful for communicating with communities about drought impacts and/or implementing local projects?
6. What barriers or challenges limit the **access and use** of climate information in your organization's drought planning?
    a. What challenges exist for using climate information to develop plans or projects to be implemented locally or in conjunction with community members?
7. Where do you **access** other key climate information for your work to mitigate drought?

SECTION 3: OPPORTUNITIES FOR SERVICES/TOOLS

1. Have you used services and/or tools made by the State before in planning for drought? If so, which ones? Why? If not, why not?
    1. Are any related specifically to climate information? If so, which ones?
        - *Probes:* Cal-Adapt, Adaptation Clearinghouse (ResilientCA.gov), TAGs, CDFA tools, DWR tools.
            - *Type out in chat.*

            a. If the response is YES, move to Questions 2-3.

            b. If the response is NO, move to Questions 4-5.
2. Which of those services or tools have you found **most helpful** for drought-related projects or programs?
3. What services or tools **could help you** better inform drought vulnerability planning with climate information from the State?
4. What types of services or tools **have you used** to better plan for drought impacts in your community? Which are the most helpful?
    1. *Probes:* Community Water Center resources (e.g., Drinking Water Tool), other resources from local/regional organizations.
5. What services or tools **could help you** better inform drought vulnerability planning with climate information from the State?

CLOSING:

- Anything else you'd like to add?

Appendix C: Draft User Guide

State of California Information Sources and Tools (non-comprehensive list)

1. Cal-Adapt: designed to allow users to explore peer-reviewed data portraying how climate change might affect California at the state and local level.
    a. Local Climate Change Snapshot Tool: provides climate projections for temperature, precipitation, and wildfire at a given location.
    b. Maps of Projected Change: projected changes for annual averages of maximum temperature, minimum temperature and precipitation rate in California, data available for RCP 4.5 and RCP 8.5.
    c. Others: Extended Drought Scenarios, Projected Changes in Snowpack.
    d. Data download for the Fourth Climate Change Assessment.
2. California Climate Change Assessment (Fourth available, Fifth underway): assessment to understand climate-related vulnerability at the local scale and inform resilience actions, while also directly informing state policies, plans, programs, and guidance to promote effective and integrated action to safeguard California from climate change.
    a. San Joaquin Valley Regional Report: includes climate science, impacts, and adaptation information for the region.

    b. Technical reports on water resources (e.g., drought, groundwater management).
    c. Cal-Adapt (listed above) is the best source for accessing the Fourth Assessment's data and using tools to visualize.
3. Adaptation Clearinghouse: consolidated searchable database of resources for local, regional and statewide climate adaptation planning and decision-making.
    a. General search: can search for San Joaquin Valley and find relevant reports and tools.
    b. Case studies: explore case studies of adaptation in the San Joaquin Valley.
    c. Resources by topic: can select water and view state and local reports and documents related to water (e.g., California Water Plan, California State Water Resilience Portfolio).
    d. Tools & data: search for tools related to a keyword (not all are developed by the State, some by partners like The Nature Conservancy, other partnerships).
4. Department of Water Resources:
    a. Groundwater Live: mapping tool for latest groundwater information.
    b. SGMA Data Viewer: mapping tool for groundwater datasets organized by SGMA and GSP.
    c. Water Data Library: data collected by DWR regional offices on 35,000+ wells in CA.
    d. California Statewide Groundwater Elevation Monitoring (CASGEM): information for wells and their elevation readings.
    e. Central Valley Model: develops and uses a number of modeling tools to support water management statewide and in the Central Valley.