ABSTRACT

HAYS, ALEXANDRA ROSE. Scale Considerations for Analysis of Food and Water Insecurity: A Review and Focused Study of California's Central Valley (Under the direction of Dr. Justin Baker).

This thesis assesses the drivers of food insecurity among farmworker communities in California's Central Valley in an effort to project food insecurity outcomes under various water shortage and agricultural land retirement scenarios, pursuant to the goals outlined in the Sustainable Groundwater Management Act (SGMA), and considering the increased frequency and intensity of extreme weather experienced in this region. To accomplish this, the thesis synthesizes previous literature on water and food security, with a focus on the impact of scale considerations on study outcomes. The review contextualizes the circumstances facing farmworkers in the Central Valley; this paper also conducts an extensive literature review of food and water insecurity studies. These studies identify causal factors, offer historic and political context, explain and critique preeminent data collection and management methods, and project future outcomes. This paper includes studies conducted at the global, national (U.S.), and local (Central Valley) scales, as the experiences felt within the Central Valley relate to a complex network of interconnected food and water systems, which must be discussed to fully understand the unique issues facing this paper's population of interest. Comparing the findings from these studies, this study identifies limitations to food and water insecurity data, primarily, a tradeoff between scale of analysis, political relevance, and accuracy.

Then, drawing from this synthesis review, this thesis develops an econometric approach to establish links between agricultural employment, productive cropland acres, and food insecurity outcomes within the Central Valley. Specifically, this thesis develops a series of fixed effects regressions using a two-stage least squares framework to explore how physical and

socioeconomic factors drive food security estimates. Results from the regression framework are then used to project job loss and food insecurity outcomes by 2040.

This thesis makes several contributions to the literature. First, the synthesis chapter incorporates local knowledge gleaned from qualitative, local-scale, studies, which rely on testimonials from farmworkers living in the Central Valley to establish the drivers of food and water insecurity in these communities. The findings from these studies inform the conceptual model that guides this paper's regression analyses and predictive model. As such, our results seek to incorporate the voices of those most often excluded from data and policy. Additionally, this paper fills a significant gap in the research surrounding drought and policy impacts on California's agriculture sector. While many studies assess economic ramifications, providing estimates for job, land, revenue, and biodiversity loss, none have ventured to quantify impacts to household-level metrics of wellbeing, such as food security, within the Central Valley region.

The regression analyses find a positive and statistically significant relationship between agricultural employment and acres of productive cropland, and a statistically significant and negative relationship between food insecurity and agricultural employment. These findings are in keeping with the existing literature, and facilitate the predictive modeling exercise. This model projects a wide range of food insecurity outcomes under five potential scenarios, adapted from two seminal hydro-economic modeling papers, Hanak et al. (2019) and Medellin-Azuara et al. (2022). These scenarios range from optimistic to 200% of the business-as-usual outlook, reflecting worsening climatic conditions. Food insecurity outcomes range from an increase of 3.31% to 9.27% by 2040, demonstrating that policy affecting agricultural productivity will produce downstream effects on food insecurity through connections to agricultural employment and employment. Given SGMA's decentralized and highly flexible implementation framework,

along with preliminary assessments that find lacking inclusivity within mitigation plans and board member representation, this thesis discusses the need for monitoring frameworks or secondary policy mechanisms to limit impacts of SGMA on historically marginalized, already vulnerable, communities.

Scale Considerations for Analysis of Food and Water Insecurity: A Review and Focused Study of California's Central Valley

by
Alexandra Hays

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APPROVED BY:

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Dr. Justin Baker	Dr. Jason Delborne
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Dr. Christopher Galik	

BIOGRAPHY

I attended Columbia University for my undergraduate education, earning my Bachelors of Arts in Economics, with a Special Concentration in Sustainable Development. My interests in economics, environmental sustainability, and social equity led me to pursue graduate-level research on food insecurity with the Baker Lab. As a graduate research assistant, I have developed a broader skillset in data collection and management processes, statistical and economic analysis, and predictive modeling methods. I have gained exposure to a broader set of disciplines than I had access to as an undergraduate, learning from my coworkers in the Baker Lab, as well as my classmates. Following graduation, I plan to leverage these skills to pursue a career in sustainable finance and/or policy analysis.

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CHAPTER 1: INTRODUCTION

The terms food and water insecurity encompass a broad range of issues, affecting households and individuals across the globe. These issues present differently depending on factors unique to each impacted household, community, and country. Literature addressing food and water insecurity issues in the developed world is severely lacking, as it is generally assumed that these problems have largely been eradicated within more affluent countries. While the developing world is disproportionately impacted by food and water insecurity issues, to assume that these problems do not exist within developed nations is incorrect and ignores distributional inequities present within countries.

Global studies consistently find near perfect rates of food and water security among developed nations. While useful to compare macro trends across countries, these studies fail to capture the experiences of historically marginalized populations, who face chronic underrepresentation in national datasets. In the U.S. context, these populations tend to be of low socioeconomic and/or racial/ethnic minority status, and subsequently more susceptible to food and water insecurity. This paper uses a mix of qualitative and quantitative analysis methods to reveal and explain these shortcomings of highly aggregated data, comparing findings from studies conducted at the global, national, and local scales to identify methodological drivers of these inaccuracies related to scale of analysis.

Despite being a net-exporting agricultural producer and the wealthiest country in the world, the United States struggles with food insecurity among its most vulnerable populations. Rural frontline communities tend to be most heavily affected by food and water insecurity in the U.S., despite their spatial proximity and significant contributions to major agricultural production (Pannu, 2018; Rodriguez et al., 2015; Greene, 2018). This paradox is illustrated perhaps nowhere

more clearly than in California's Central Valley, which is home to a socioeconomically diverse population; from highly affluent urban and suburban centers, to low-income rural communities, home to a significant portion of the area's farmworkers (CCSCE, 2019; Alkon et al., 2011; Matias et al., 2020; Wirth et al., 2007). This region is among the most productive in the world, supplying the majority of specialty crops consumed within the U.S. and relying heavily on farm labor to do so. An estimated 50-75% of these farmworkers are undocumented, and all rely heavily on the agriculture sector for the majority or totality of their household income, leaving them with very little negotiating power as an employee and virtually no backup plan in the event of job loss (Minkoff-Zern, 2014; Center for Farmworker Families, 2023; Ornelas et al., 2022, Alkon et al., 2011). As the area experiences longer and more intense periods of drought, along with the onset of environmental policies, such as the Sustainable Groundwater Management Act (SGMA), it is crucial to consider the socioeconomic impacts to these historically marginalized and chronically underrepresented populations.

Objectives

The objectives of this thesis are to (1) understand local and global drivers affecting food and water insecurity in California's Central Valley, a key agricultural production region in the U.S., (2) to provide spatially downscaled food insecurity estimates for farmworker communities in the Central Valley pursuant to various water restriction scenarios, and (3) to call attention to both the unique challenges facing undocumented farm workers in California's Central Valley and the need to consider historically marginalized populations in policy development processes moving forward.

Key Contributions

This study runs a series of fixed effects regressions, using a two stage least squares approach, to establish and estimate the relationships between food insecurity and employment in the agriculture sector, controlling for food price, household income, and participation in the Special Supplemental Nutrition Assistance Program for Women, Infants, and Children (WIC). These regression results are then used to estimate the effects of various water restriction scenarios on agricultural land-use, job loss, and food insecurity. While the risks to California's agriculture sector have been assessed in various studies looking at water restriction scenarios and subsequent land, revenue, and job loss estimates, the extra step of quantifying the subsequent food insecurity impacts on farmworkers has not yet been taken.

The regression analyses are developed using a conceptual framework, which adapts causal relationships identified by the existing literature. The regression models are designed to reflect food insecurity experiences unique to farmworker communities, using data sources that reliably represent even undocumented farmworkers in the region. The paper relies on the existing body of qualitative, interview-style, data specific to farmworker communities in the Central Valley to guide the construction of the regression framework used, as well as the discussion of results, to ensure our analyses reflect the local knowledge gleaned from these studies.

Relying on causal links established in community-scale studies conducted for the Central Valley, we add to a growing, but presently lacking, body of research focused on food and water insecurity within high-income countries. The literature review discusses how U.S.-focused literature, in both the food and water insecurity spaces, lags behind similar studies conducted for other nations, primarily developing nations, and how this can be tied to a historic failure to recognize distributional inequities that engender unique struggles among historically

marginalized communities. As such, this paper aims to highlight vulnerabilities faced by chronically underrepresented populations and contribute to discussions surrounding equitable representation in data collection, aggregation, and policy development processes.

Methods and Background

This study uses Stata to construct and run a series of fixed effects regressions. The results from these regressions are then used to inform the predictive model, built and run in Excel, which estimates changes in food insecurity subject to various water restriction scenarios. These scenarios reflect future water shortages, and subsequent land fallowing, related to drought or other natural phenomena, environmental policy, such as the Sustainable Groundwater Management Act, or some combination of the two. The model is constructed using a series of fixed effects regressions and a two stage least squares approach to estimate the statistical relationships between water availability, land-use, employment, and food insecurity. The first-stage regression model defines employment as a function of land-use, time, crop type, precipitation, and temperature. The second stage regresses food insecurity on employment, instrumented by each of the explanatory variables included in the first-stage regression. The coefficient estimates from these two regressions are then used to project job loss and food insecurity outcomes from land fallowing estimates, adapted from two seminal hydro-economic studies focused on water shortage and land use change in the Central Valley.

This regression framework derives from a conceptual model based on primary drivers of food insecurity identified by existing studies. This conceptual model primarily draws on qualitative data collected at the individual- and household-scales for communities within the Central Valley. These studies rely on interviews with food and water-insecure individuals from communities primarily made up of immigrant farmworkers, some of whom are undocumented, to

identify problems unique to these populations. As such, this paper aims to incorporate the voices of marginalized and at-risk communities, who have long been underrepresented in quantitative research.

Key Findings

The first-stage regression analysis finds statistically significant and positive relationships for both the acres in production and quadratic precipitation variables. Meanwhile, the second-stage IV regression finds a statistically significant and negative relationship between agricultural employment and food insecurity. The first-stage regression results establish statistical relationships for both variables' impact on agricultural employment, indicating that as either water availability or total acreage in production decline, so too will employment in the agriculture sector. The results from the second-stage IV regression demonstrate the sensitivity of food insecurity to changes in agricultural employment, whereby increased job loss will result in higher food insecurity rates. The predictive modeling exercise uses the coefficient values from these regressions to project job loss and food insecurity outcomes under various water restriction and subsequent land loss scenarios. This exercise estimates a range of food insecurity impacts, from 3.31% to 9.27%, depending on the assumptions underlying each water restriction scenario. The results suggest that impacts to the productive capacity of the agriculture sector, whether from policy or climate change, will produce downstream effects on food insecurity.

Roadmap

Chapter 2 reviews food and water insecurity literature at the global, national, and local scales. This chapter identifies limitations to the existing literature, which drive issues of underrepresentation and ineffective policy design. Chapter 3 transitions the paper to a discussion of this study's food insecurity analyses. This section discusses the conceptual framework that

guides the regression analyses and predictive modeling exercise, and includes an overview of the data sources and methodology. Chapter 4 discusses the results of these analyses, along with policy implications, guided by the findings from the predictive modeling exercise. This section also includes a brief overview of the limitations faced by the regression analyses. Finally, chapter 5 concludes the paper, reiterating broad themes and lessons learned throughout the research process, along with the paper's contribution to the body of existing food and water insecurity research.

CHAPTER 2: LITERATURE REVIEW

This chapter provides an overview of preeminent food and water security literature and includes studies conducted at the global, national, and local levels. While this study is ultimately concerned with the implications to food and water insecurity from sustainable policy interventions in California's Central Valley, inclusion of studies at each scale provides context necessary to understand the complex system dynamics that perpetuate such insecurities and the inequitable distribution of effects from resource limitations and policy decisions among historically marginalized and disadvantaged populations. Further, these studies reveal trends in food and agriculture policies, both at the global and national scales, offering insight into how the entire spectrum of food insecurity effects, from hunger to obesity, persist among developed and developing nations.

This review includes a broad range of topics pertaining to food and water insecurity, both causal factors and outcomes, in an attempt to demonstrate the complex and interdependent nature of these issues. However, given the high volume of relevant literature related to these topics, our goal is not to provide a comprehensive review of all relevant studies in the field. Instead, this review employs a snowballing approach to identify the most relevant papers, ultimately drawing inference from a subset of studies in the food and water insecurity literature. The first round of studies derived from a broad keyword search in Google Scholar. I then reviewed the reference sections to identify more relevant papers based on titles and content cited, and repeated this process multiple times. I read through the abstracts of each paper to determine whether the information would contribute to the goals of the review. At the global scale, included studies discuss the role of globalization in international food and water availability. At the national scale, the literature relates to distributional patterns, causal links between minority communities and

food or water insecurity, and common coping mechanisms among individuals experiencing food or water insecurity. The only criteria for community-scale studies was a focus solely on the Central Valley, CA, or a portion of the region, such as the San Joaquin Valley.

Central Valley - Case Study Background and Justification

The Central Valley is a major food production hub, whose water and subsequent agricultural production shortages have been felt at the global and community scales. Globally, a combination of trade liberalization policies and longer supply chains have increased the risk of food insecurity, particularly among low-income nations (Zhu, 2016; James, 2015). A growing reliance among the developing world on food imports has exacerbated their vulnerability to exogenous supply-side shocks, as evidenced by the recent food insecurity spikes in low-income and net-importing countries amidst global supply chain disruptions associated with the COVID-19 Pandemic and the War in Ukraine (FAO, 2022; Workie et al., 2020; Alibi & Ngwenyama, 2022; Laborde et al., 2020; Hassen & Bilali, 2022; Savary et al., 2020). These global trends are mirrored within net-exporting countries, where these longer supply chains have created a spatial disconnect between regions of agricultural production and consumption (Walker et al., 2010; Alkon et al., 2011; Neff et al., 2009; Long et al., 2020; Morris et al., 1992; Minkoff-Zern, 2014). In the U.S., rural communities tend to be most heavily affected by food and water insecurity in the United States, despite their spatial proximity and significant contributions to major agricultural production (Alkon et al., 2011; Minkoff-Zern, 2014). This paradox is illustrated perhaps nowhere more clearly than in the Central Valley, home to a socioeconomically diverse population, including many low-income rural communities primarily composed of farmworkers (CCSCE, 2019; Alkon et al., 2011; Matias et al., 2020; Wirth et al., 2007). An estimated 50-75% of these farmworkers are undocumented (Minkoff-Zern, 2014; Center for Farmworker Families,

2023; Ornelas et al., 2022), and all rely heavily on the agriculture sector for the majority or totality of their household income, leaving them with very little negotiating power as an employee (Alkon et al., 2011; Ornelas et al., 2022). Some studies argue that California's agribusiness sector exercises market power to minimize labor costs without sacrificing yields, boosting profits at the expense of workers' food and water security (Alkon et al., 2011). The increasing frequency and intensity of drought conditions, along with the onset of sustainable water use policies, compound these social vulnerabilities, as future employment prospects become increasingly uncertain.

Water equity issues in the Central Valley have motivated a class of studies focused on identifying issues unique to disadvantaged communities (DACs), particularly those that are also unincorporated. Disadvantaged unincorporated communities (DUCs) are located outside the boundaries of incorporated cities. As such, they lack their own municipal governments and must instead rely on county governance structures to include them in decision-making processes (Safe Water Alliance, 2014; Pannu, 2018; Flegal et al., 2019). While the U.S. Census accounts for some of these unincorporated areas, or Census Designated Places (CDPs), about 2.8 million California residents lived in unincorporated areas not recognized by the Census as of 2014, leaving them largely invisible to policymakers (Safe Water Alliance, 2014; Flegal et al., 2019). Within the San Joaquin Valley alone, less than a third of DUCs are accounted for by U.S. Census Data (Safe Water Alliance, 2014). This gap in national- and state-level datasets underscores broader issues of underrepresentation in policymaking processes, and explains, in part, how such severe water insecurity issues persist, despite commitments to end water insecurity and the adoption of a human right to water in the California Constitution (Safe Water Alliance, 2014).

While systemic disparities of infrastructural divestment and neglect must still be addressed in these communities, steps have been taken to improve access to water throughout the state by reducing unsustainable groundwater withdrawal rates, primarily from the agriculture sector (Hanak et al., 2019; Alexander & Esteli, 2021; Lewis & Rudnick, 2019). The passage of the Sustainable Groundwater Management Act (SGMA) in 2014 set a broad goal to attain

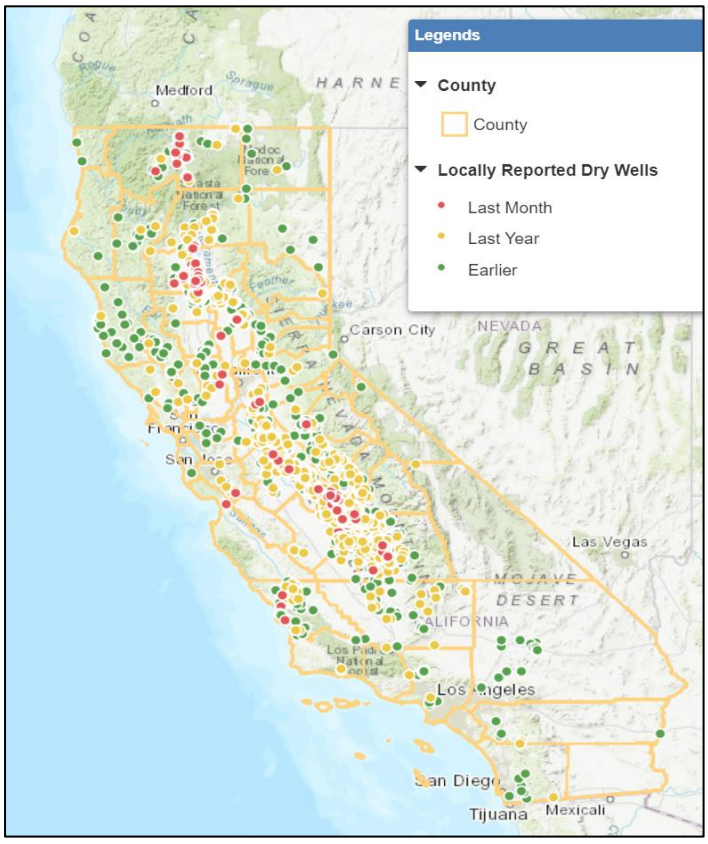


Figure 2.1 Recent Reports of Dry Wells, showing reports of dry wells as of January, 2023. Source: California Natural Resources Agency SGMA Data Viewer.

sustainable groundwater extraction rates within 20 years of implementation. SGMA mandates the creation of Groundwater Sustainability Agencies (GSAs) and Groundwater Sustainability Plans (GSPs) by 2020 for groundwater basins designated as “high-priority”, or those most severely overdrafted (Rudnick et al., 2016; Leach et al., 2021; Lewis & Rudnick, 2019). In this sense, SGMA provides some framework through which communities can address water inequity

issues; however, the loose implementation structure introduces high uncertainty regarding distributional effects (Rudnick et al., 2016).

While attractive for its seemingly rapid response to groundwater shortage, promising sustainable withdrawal rates over a 20-year timespan, SGMA implementation has been delayed due to incomplete and inadequate GSPs. Figure 2.1, representing dry well reports as of January 2023, shows that the Central Valley continues to struggle with groundwater shortage and dry wells. Despite this slower rollout, the agriculture sector will face major challenges in the coming years. There are a wide array of potential adaptation methods to reduce groundwater withdrawal rates, including state- and basin-wide water trading schemes, altering irrigation methods and crop patterns to maximize water use efficiency (Fernandez-Bou et al., 2022; Hanak et al., 2019; Alexander & Esteli, 2021). Regardless of the methods employed, a substantial portion of currently productive agricultural land will likely need to be fallowed to attain sustainable withdrawal rates (Hanak et al., 2019; Medellin-Azuara et al., 2022; Sumner et al., 2021; Bryant et al., 2020; Mall & Herman, 2019). This presents a potential issue for food insecurity in the Central Valley, as reduced agricultural productivity could result in job loss among already vulnerable farmworker communities.

A significant portion of Central Valley residents rely on domestic wells to meet their household water needs. While domestic wells outnumber agricultural and public wells in the region, they are relatively shallower and have smaller pumping capacities (Pauloo et al., 2020). Historic analyses of drought and subsequent groundwater overdraft find that these wells run dry and face contamination long before their publicly managed counterparts (Pauloo et al., 2020). During drought periods, the agriculture sector's consumptive shift from surface to groundwater has been widely recognized as the primary driver in over-pumping the region's groundwater

resources (Greene, 2018; Safe Water Alliance, 2014; Hanak et al., 2019; Alexander & Esteli, 2021; Lewis & Rudnick, 2019; Medellin-Azuara et al., 2022; Howitt et al., 2014). Thus, competition between farms and residents in the Central Valley has also been cited as a major contributor to water insecurity among the same communities (Fernandez-Bou et al., 2022, Pauloo et al., 2020). The Central Valley and its residents present a unique case study to assess the interdependencies and tradeoffs that exist between sustainable policies, food and water security, and socioeconomic well-being among historically marginalized and underrepresented populations.

Chapter Outline

The remainder of this paper consists of a literature review of over 100 papers relevant to food and water insecurity topics at the global, national, and local scales. While the ultimate focus of this review is on the food and water insecurity implications of sustainable policy interventions in California's Central Valley, inclusion of studies at each scale provides context necessary to understand the complex system dynamics that perpetuate such insecurities and the inequitable distribution of effects among historically marginalized and underprivileged populations. Further, these studies reveal trends in food and agriculture policies, both at the global and national scales, offering insight into how the entire spectrum of food insecurity effects, from hunger to obesity, persist among developed and developing nations.

Globalization and Food Insecurity

Studies that explore the relationship between globalization and food insecurity present contradictory findings. While forward-looking studies find potential reductions in global hunger rates under scenarios of increased trade liberalization (Janssens et al., 2020), others use empirical data to show how existing global trade policies have left developing nations disproportionately

vulnerable to food insecurity impacts (Zhu, 2016; James, 2015; Smith et al. 2017; Grimaccia & Naccarato, 2019). The latter set of studies links globalization to a lack of resilience in the global food system, finding that exogenous shocks limiting production in one region often lead to ubiquitous price hikes (Beckman et al., 2020), as a few major production hubs export a significant portion of global food supply (Vos et al., 2021; Eldridge, 2020).

Empirical studies find that increased liberalization has reduced global resilience to exogenous supply-side shocks, leaving low-income and net-importing developing nations particularly vulnerable. While the theory behind globalization of food markets asserts that reducing barriers to trade should increase both the quantity and variety of food items available to all participants, disparities between net importing and exporting countries complicate this theory (James, 2015). Developed nations, such as those in the E.U. and U.S., house the majority of large-scale agricultural producers. Consequently, these countries have considerable comparative advantages in agricultural production, which drive down commodity prices in the global markets (Janssens et al., 2020; Zhu, 2016). Small- and medium-sized operations, particularly those in developing countries, cannot compete with the prices of these larger operations and are consequently driven out of business as globalization reaches domestic markets (Zhu, 2016). While these trends initially increase purchasing power among low-income consumers, national income per capita may suffer in the long term as local agriculture sectors shrink, costing jobs and income (Zhu, 2016; Birchfield & Corsi, 2010). Heavy reliance on imports also disincentivizes investments in productive capacity, thereby increasing vulnerability to exogenous supply shocks (such as drought or pandemics), which could adversely affect supply stability and affordability, two of the four pillars of food security outlined by the FAO (FAO, 2015). In short, when a country becomes reliant on agricultural imports, food security depends on highly volatile and

external factors, such as foreign trade policies, extreme weather events, and global market fluctuations. Without self-sufficient and resilient domestic agriculture sectors, national governments can lose the ability to dull demand-side effects from international price and/or quantity shocks. When these shocks do occur, consumers take a direct hit to purchasing power and elevated food insecurity rates follow, as evidenced by the response to recent supply shocks set off by the COVID-19 Pandemic and War in Ukraine (Workie et al., 2020; Alibi & Ngwenyama, 2022; Laborde et al., 2020; Hassen & Bilali, 2022; Savary et al., 2020).

Multinational institutions, such as the World Trade Organization, have been criticized for their role in constructing current vulnerabilities and inequities in the global food system, and failure to address these shortcomings (James, 2015). National and domestic food and agriculture policies tend to allocate subsidies to cereals and animal proteins, leaving out specialty crops (FAO, 2022; Vos et al., 2022; Hamerschlag, 2010). Not only do specialty crops, such as fruits and vegetables, receive less direct funding relative to staples, but their production is actually penalized in various low-income nations (FAO, 2022). The decision to withhold subsidies from specialty crops results in higher commodity prices, fueling access disparities among individuals based on their socioeconomic status (Hamerschlag et al., 2010). Inadequate access to fresh produce among low-income individuals is a commonly cited cause of food insecurity, particularly in high-income nations, where overconsumption of processed foods has been linked to high incidence of non-communicable diseases (Liu & Eicher-Miller, 2021; CDC, 2020; Wolfson & Leung, 2020). This example clearly illustrates the inextricable link between policy decisions made at the highest scales of governance and individual food insecurity outcomes.

Few studies interrogate this question of why large-scale policy measures often fail to comprehensively address food insecurity; even fewer consider the confounding effects of the

term's nonspecific and fluid definition. The definition of food security is highly variable, depending on socioeconomic and demographic characteristics unique to each country, community, and even household in question. While developed countries place heavier emphasis on preserving domestic production, low-income countries that are self-sufficient may struggle to provide adequate quantities to stave off malnutrition (Chatterjee & Murphy, 2014). As such, addressing food insecurity takes on different meanings based on the challenges faced in each country. While certain countries may require investments in distributional infrastructure to transport food from production hubs to newly developed urban centers, others require a restructuring of subsidies to promote equitable access to nutritious foods (Chatterjee & Murphy, 2014).

To accommodate this inherent heterogeneity, globally accepted definitions of food insecurity are broad and fluid, with the term being redefined five times since 1974. Figure 2.2 illustrates the evolution of the term from first being defined at the 1974 World Food Summit, to the UN's 2001 State of Food insecurity. While each iteration converges on capturing the term's inherent nuance, none move away from highly ambiguous/non-specific language. While these definitions ensure a level of inclusivity, in theory facilitating global efforts to eliminate the issue altogether, they fail to guide policymakers toward effective solutions. In fact, these loose definitions have allowed the governments of net-importing and exporting countries to implement non-complementary policies that distort the global markets and exacerbate food insecurity (OECD, 2021; FAO, 2022). When considering the language used in the early definitions, an emphasis on ensuring adequate quantities of food at affordable prices can justify some of the market-distorting tariff policies specifically condemned by the OECD and FAO studies. While the idea of health is introduced in the World Bank's 1986 definition, there are no accompanying

criteria or examples of what constitutes a “healthy life”. Developing specific and targeted definitions could foster a global policy environment that builds resilience into food systems, rather than the fragmented system that currently pits exporting and importing countries against one another (Chatterjee & Murphy, 2014; OECD, 2021; FAO, 2022).

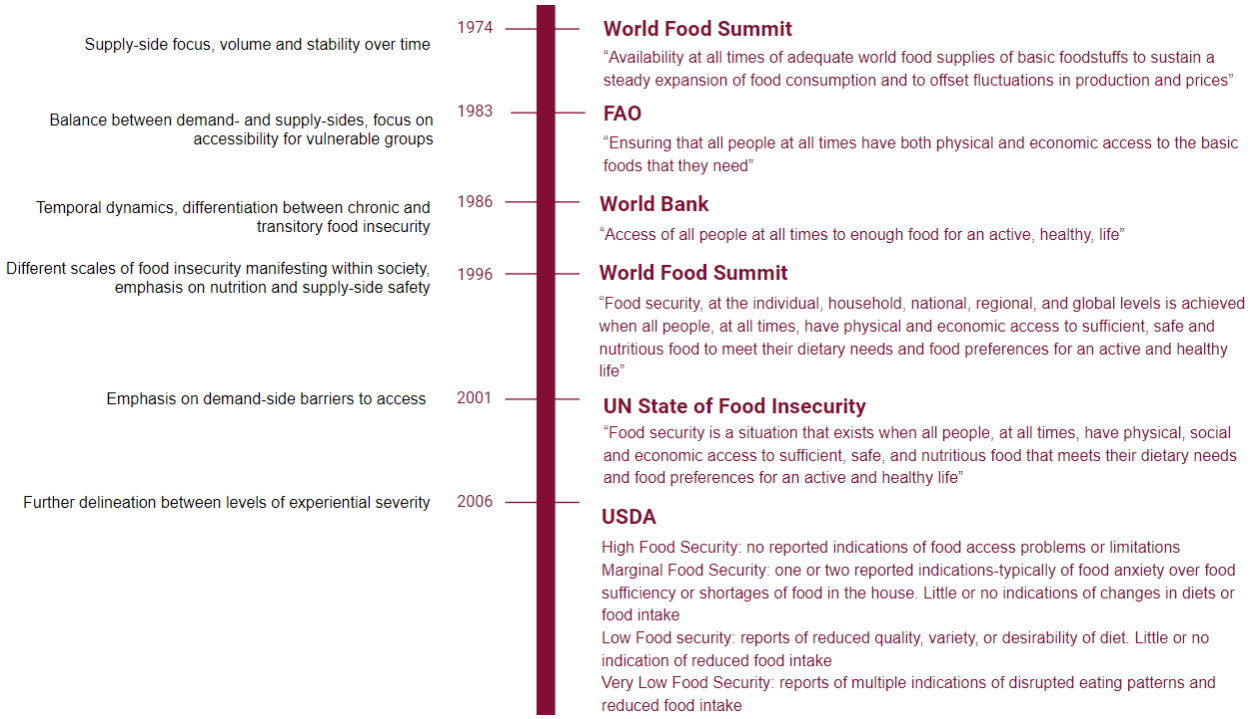


Figure 2.2 Food Insecurity Definition Evolution, illustrating the changes among globally accepted food insecurity definitions, from 1974 through present day.

Globalization and Water Insecurity

Water is a vital input for agriculture and energy, as well as a fundamental component of prosperous, sanitary, and equitable societies. The term water insecurity is fairly new, first used in 2000, and, as shown by Figure 2.3, constantly evolving. There is no widely accepted definition for this term, nor the terms water stress and water scarcity, which are often used interchangeably by policymakers despite their technical distinctions (Wang et al., 2021). Water scarcity generally refers to an inadequate physical supply of freshwater resources, whereas water stress considers

the suitability of available freshwater to meet human and ecosystem demands in terms of quantity, quality, and accessibility (Wang et al., 2021). To further complicate the field, definitions for consumption and withdrawal also differ slightly, with consumption accounting for the full life cycle of blue water by assuming future reuse, while withdrawal does not. Given the focus on food insecurity, this review will include literature addressing water insecurity related to consumptive use by the agriculture and household sectors.

Two common methods used to assess water consumption and availability at the global and national scales are water footprint (WF) and virtual water (VW) accounting. At the most basic level, the distinction between these two calculations hinge on the scale of analysis they are most commonly applied to. Water footprint accounting, a bottom-up approach, is generally applied to production and consumption processes within a country or region, while virtual water flow analyses operate at international or interregional scales, capturing interdependencies between multiple production and consumption systems (Liu et al., 2019; Wang et al., 2021). Water footprint calculations often serve as inputs for virtual water trading analyses and can be broken out into three distinct categories: blue, green, and gray. Blue water footprints account for freshwater use from surface or groundwater and are generally prioritized by the literature as the most relevant calculation when concerned with water availability and/or scarcity (Liu et al., 2019; Wang et al., 2021; Yang et al., 2013). However, many food and agriculture focused studies incorporate green water supply, defined as water contained in soil, given its importance to rain fed agriculture and implications for reliance on irrigation (Liu et al., 2019; Mekonnen & Hoekstra, 2011; Wang et al., 2021; Yang et al., 2013). Gray water footprints account for water pollution and are rarely included in assessments due to a lack of consensus regarding relevant

pollutants and insufficient industry reporting of pollutant discharge (Wang et al., 2021; Liu et al., 2019).

Global water resources are highly constrained and estimates for population and economic growth predict significant increases in consumptive demand in the coming decades (Wang et al., 2021; Mekonnen & Gerbens-Leenes, 2020). These increases are projected to be most pronounced in developing nations as both population and economic growth suggest increased demand for animal- (Mekonnen & Gerbens-Leenes, 2020) and sugar-derived food products (Rosengrant et al., 2009). Increased demand from agricultural and livestock production sectors, along with the associated land use change, is projected to substantially increase green and blue water consumption (Rosengrant et al., 2009; Ercin & Hoekstra, 2014). When factoring in the impacts of climate change on weather patterns, specifically temperature and precipitation rates, findings estimate an increase in the global water footprint of 22% by 2090 (Mekonnen & Gerbens-Leenes, 2020).

Figure 2.3 Water Insecurity Definition Evolution, illustrating the changes among globally accepted water insecurity definitions, from 2000 through present day.

The severity of these future water consumption projections has given rise to a sizable body of modeling work aimed at quantifying demands under various policy, socioeconomic, diet, and environmental change scenarios. Model-based studies have shown that changes in diets, along with more efficient global water use and reduction of food waste could eliminate unsustainable use of blue and green water resources while meeting energy intake minimums (Ercin & Hoekstra, 2014; Mekonnen & Gerbens-Leenes, 2020). Differences between model input features and assumptions result in high variability between total water footprint (and, by proxy, water insecurity) estimates. Ercin & Hoekstra (2014) find that global water footprints increase under all scenarios of population growth and trade liberalization, however, increases are minimized for scenarios characterized by relatively small population increases and reduced consumption of meat and dairy products. Meanwhile, Vanham et al. (2013) find that reducing meat intake in the E.U. could generate water savings for the region without altering total caloric intake per capita, nor the proportion devoted to protein, implying that even incremental dietary shifts could attain sustainable blue and green water footprints. Overconsumption of sugar, oil crops, and animal-derived food products (including eggs and dairy), characteristic of the "western" diet, has been identified as the largest contributor to projected increases in the global water footprint (Mekonnen & Hoekstra, 2011; Ercin & Hoekstra, 2014; Rosengrant et al., 2009; Vanham et al., 2013). Convergence of water footprint assessments on the ordinal impacts of various food commodities points to a stability among high-resolution analyses and suggests that data aggregation methods bear responsibility for observed variations (Dietz & Meehan, 2019; Liu et al., 2019).

Water scarcity is increasing globally however, geospatial differences in precipitation patterns, natural water supplies, population demographics, and consumptive demand, result in

uneven distributional effects (Wang et al., 2021; Liu et al., 2019; Ercin & Hoekstra, 2014). Under current globalized trade systems, localized water consumption habits can produce externalities felt across the globe (Yang et al., 2013). Water scarcity issues transcend the context of agricultural production, directly and indirectly impacting public health, economic development, and human rights (Rosengrant et al., 2009; Wutich et al., 2017; Dietz & Meehan, 2019). As such, accurate and dependable water stress measurements and projections are vital to inform global policies that attain equitable and sustainable resource use under conditions of increased demand and constrained supply (Wang et al., 2021; Mekonnen & Gerbens-Leenes, 2020; Rosengrant et al., 2009).

The existing literature employs numerous methods to measure water scarcity at the global scale. Each method is distinct in terms of the types of water use represented and input variables used, resulting in highly variable estimates of water consumption and stress (Wang et al., 2021; Liu et al., 2019; Mekonnen & Gerbens-Leenes, 2020). Considering this paper's interest in assessing how current systems of globalization and intensive agricultural production in high comparative advantage regions (like the Central Valley) influence water insecurity, the remaining review will focus primarily on the concept of virtual water trade and the water savings estimates informed under assumptions of free and global trade.

Virtual water trade has been touted as the solution to simultaneously accommodate the scale crop and pastureland expansion necessary to keep pace with consumptive demand while attaining sustainable blue and green water footprints (Mekonnen & Gerbens-Leenes, 2020; Chapagain et al., 2006; Liu et al., 2019). Virtual water trade, in theory, would create a system where water-rich nations and regions produce the most water-intensive crops, due to their comparative advantage, and export to water insecure areas. This would alleviate water stress

from extremely water insecure countries and regions (Ercin & Hoekstra, 2014; Mekonnen & Gerbens-Leenes, 2020), economically benefit exporting economies, and generate global water savings that would benefit food and water security (Vos & Mena, 2014). Studies employing water consumption and scarcity calculations under assumptions of virtual water trade find that global water savings are possible (Oki & Kanae, 2004), however, these findings assume that flows occur from regions of high to low water productivity (Liu et al., 2019). In practice, this is not always the case, as the most powerful determinants of virtual water trade flows have been identified as macroeconomic variables, such as national GDP (Oki et al., 2017; Vos & Mena, 2014) or technically advanced agriculture sectors (Liu et al., 2019), rather than physical scarcity. Similar to trends identified in globalized food and agriculture trade policies, outcomes have favored nations with the greatest purchasing power and multinational agribusinesses rather than countries and households facing the highest burdens of water insecurity (Vos & Mena, 2014; Oki et al., 2017). Critiques of virtual water analyses have referenced these shortcomings, arguing that the literature currently lacks policy relevance due to its failure to relate virtual water trade flows to water scarcity (Yang et al., 2013).

Without careful and intentional implementation, virtual water trade has the potential to weaken local and regional water security in the long-term, as importing water-intense foods removes incentives to improve local water productivity and creates a heavy reliance on food exporting countries that are likely to reduce exports as global scarcity increases (Liu et al., 2019). Further, virtual water trade may not attain global water savings if production does not shift to countries with the highest water productivity and could create externalities, such as increased pollution and subsequent water insecurity in high-comparative advantage regions like the Central Valley (Liu et al., 2019; De Fraiture et al., 2004; Wang et al., 2021; Yang et al., 2013). These

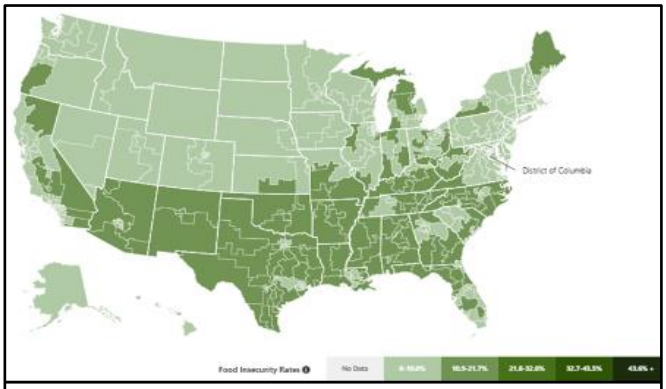
global-to-local considerations and market dependencies are often neglected in localized studies on water insecurity and deserve increased attention in contexts like the Central Valley.

U.S. Food Systems

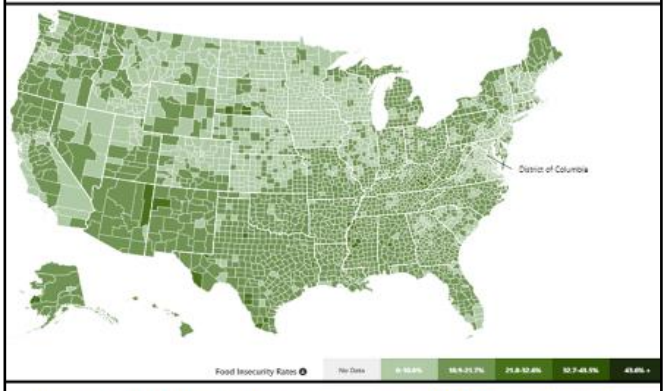
Systemic/Institutional Setting

The U.S. is consistently rated as a highly food secure nation in global scale analyses. While the U.S. is relatively food secure compared to developing and low-income countries, rates of food insecurity among minority groups are high compared to other affluent countries, according to the 2022 Global Food Security Index (UNCCD, 2023). Figure 2.4 compares the district- and county-level findings from Feeding America's Map the Meal Gap food insecurity study, highlighting the variability in food insecurity estimates based solely on the scale of analysis. Food insecurity is a major problem within the U.S. which, consistent with global trends, disproportionately impacts low-income and minority communities. The U.S., however, is somewhat unique in its history of institutional inequities (Bowen et al., 2021). Practices such as redlining, selective zoning regulations, divestment and neglect of minority communities have created pockets of concentrated poverty throughout the nation (Pannu, 2018; Flegal et al., 2019) with heightened levels of food insecurity is just one product of this system. Systemic issues rooted in racial and socioeconomic discrimination are underlying conditions that contribute to inequitable access to adequate and healthy foods in the U.S. (Morris et al., 1992; Walker et al., 2010; Tester et al., 2020; Bowen et al., 2021).

Systemic issues facing the U.S. must be addressed to reduce inequities in food access and foster widespread food security gains. Historic practices of red-lining, restricting access to



Percent of individual food insecurity aggregated to the district-level.
Source: Feeding America Map the Meal Gap



Percent of individual food insecurity aggregated to the county-level.
Source: Feeding America Map the Meal Gap

Figure 2.4 County- vs. District-Level Food Insecurity Rates, a comparison of district- and county-level food insecurity estimates generated by Feeding America's Map the Meal Gap Study.

assets and credit (Nam et al., 2015), and divestment in minority communities have created disparities in access to food retailers (Gosliner et al., 2019; Walker et al., 2010) and safe, well managed, water supplies (Macleod & Mendez-Barrientos, 2019; Safe Water Alliance, 2014; Pannu, 2018). Many studies have established that racial and ethnic minority groups face higher risks of food insecurity relative to white communities in the U.S. (Nam et al., 2015; Burke et al., 2018; Coleman-Jensen et al., 2022; Walker et al., 2010). While no consensus exists in the literature, authors broadly acknowledge that socioeconomic status and racial discrimination coexist as determinative factors for food insecurity (Burke et al., 2018; Nam et al., 2015; Coleman-Jensen et al., 2022). Other identified causal factors include gender (Chilton & Rose,

2009; Morris et al., 1992), number of children in a household (Nam et al., 2015), employment status (Coleman-Jensen et al., 2022), marital status (Chilton & Rose, 2009; Coleman-Jensen et al., 2022), and immigration status (Bowen et al., 2021).

Four key studies have linked immigrant status with heightened risk of food insecurity, particularly among communities of Hispanic and Latinx descent (Phojanakong et al., 2019; Chilton & Rose, 2009; Potochnick et al., 2017; Kalil & Chen, 2008). Each employs different metrics to assess food insecurity, but all three focus on long-term implications of childhood food insecurity. This framing characterizes food insecurity as an intergenerational burden, due to the impacts on childhood cognition and development (Chilton & Rose, 2009; Kalil & Chen, 2008). Thus, while food insecurity can be understood as a transitory phenomenon, which often accompanies economic and environmental cycles (FAO, IFAD and WFP, 2015), these studies help explain how social inequities compound food insecurity issues, prolonging effects for the individual and passing them along to the next generation. Immigrant households are found to face higher risks of food insecurity compared to families with U.S.-born mothers; these effects are heightened for mothers of Latinx ethnicity, with lower educational attainment, and large households (Kalil & Chen, 2008). Maternal experience with racial and ethnic discrimination (Phojanakong et al., 2019) and immigration enforcement agencies (Potochnick et al., 2017) have also been linked to higher food insecurity risk among children. Finally, despite on average healthier conditions at birth, children of non-citizen mothers face higher risks for poor health outcomes (Chilton & Rose, 2009). Each of these findings suggest that a household's sociodemographic characteristics, independent of socioeconomic status, can significantly increase the risk of food insecurity outcomes. This finding is significant, as many studies identifying racial or ethnic characteristics as predictive of food insecurity do not separate the

effects of race from low socioeconomic status. Establishing this causal relationship supports the notion that entrenched bias in U.S. institutions contribute to and perpetuate national food insecurity.

U.S. Food and Agriculture Policy Context

The U.S. and other advanced capitalist countries adhere to neoliberal policy practices that treat food insecurity as an individual problem, beyond the scope of governmental responsibility (Long et al., 2020). Federally funded food aid programs in the U.S. are designed, as indicated by their names, to supplement food items for families at the margin of food insecurity, not to lift those most vulnerable out of food insecurity status. While these programs have been shown to significantly improve outcomes among participants, the majority of highly insecure households remain so despite participation in these programs (Kaiser et al., 2007; Gundersen & Ziliak, 2018; Poblacion et al., 2017).

The Supplemental Nutrition Assistance Program (SNAP) and the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) are two of the most widely used federal food aid programs in the U.S. SNAP is the largest program, serving over 40 million participants per month on average, while WIC ranks third largest, serving roughly 7 million participants per month (Jensen et al., 2019). While similar in their design, these programs differ in the terms of the commodities and individuals eligible for coverage.

SNAP benefits apply to a larger set of food items compared to WIC, as WIC products must meet nutritional requirements for pregnant, postpartum, lactating women, infants and children (Jensen et al., 2019). Despite WIC's relative emphasis on nutrition, studies have found households utilizing either program lack sufficient fruit and vegetable consumption due to the skewed coverage of "shelf" items over fresh produce (Greenwald & Zajfen, 2017; Jensen et al.,

2019). The two programs also differ in their eligibility requirements for participants. WIC-eligible households must have either a pregnant, postpartum, or lactating mother, infant, or child under 5 years old (Jensen et al., 2019). Meanwhile, SNAP eligibility depends on income alone, irrespective of age and/or parental status. SNAP does, however, require proof of citizenship for the primary beneficiary, while WIC benefits apply to households headed by undocumented immigrants, so long as the child is born in the United States (Jensen et al., 2019; Winham & Florian, 2015).

SNAP and WIC are both underutilized by eligible households, with about 55% of food insecure households in the U.S. reporting participation in one or more of the three largest public food assistance programs (Coleman-Jensen et al., 2022). This underutilization is more prevalent among minority populations, particularly Hispanic/Latinx households, despite the elevated food insecurity rates for this demographic relative to the broader U.S. population (Kaiser, 2008; Pelto et al., 2020; Wadsworth, 2016). Within the general Hispanic population, immigrants are at a heightened risk for experiencing food insecurity relative to U.S.-born Hispanics, while undocumented immigrants face the highest risk (Walsemann et al., 2017). Many studies have assessed the causal factors underlying these underutilization issues, identifying misinformation, social stigma, and fear of detection and/or repercussions from other federal entities as key determinants (Minkoff-Zern, 2014; Pelto et al., 2020; Winham & Florian, 2015; Kaiser, 2008; Rodriguez et al., 2015; Gundersen & Ziliak, 2018).

Both WIC and SNAP have been critiqued in the literature, with calls for benefit expansion stemming from the common persistence of food insecurity among users (Kaiser et al., 2007; Gundersen & Ziliak, 2018; Poblacion et al., 2017). SNAP benefits are calculated using the lowest-cost food plan, the “Thrifty Food Plan” (TFP), which does not account for spatial

disparities in food price or cost of living, nor the cost of time and preparation (Ziliak, 2016; Gundersen & Ziliak, 2018; Poblacion et al., 2017). Poblacion et al. (2017) find that 5.31% of participants could become newly food secure if the criteria used to determine SNAP benefits changed from TFP to the next lowest-cost option, the Low Cost Food Plan. WIC faces similar scrutiny for the program's relatively short duration of benefits and restricted commodity coverage (Winham & Florian, 2015; Jensen et al., 2019; Poblacion et al., 2017). Poblacion et al. (2017) propose extending WIC benefits from the youngest child's fifth to sixth birthday, finding that this alone would reduce food insecurity by 1.47% among WIC participating households.

Concurrently high rates of food insecurity and program underutilization among Hispanic households, particularly those headed by immigrants, highlight a severe gap in coverage by public food assistance programs in the United States. While some argue providing benefits for this demographic is beyond the scope of the U.S. government, immigrant workers comprise a significant portion of the U.S.'s labor force, providing services that bolster domestic production, particularly in the agriculture sector. USDA estimates 47% of all salaried and wage-based agriculture workers are immigrants to the U.S. (USDA ERS, 2022). When accounting for informal work and pay arrangements, commonplace in the agriculture sector, studies estimate that 50%-75% of all farmworkers in the U.S. are undocumented (Minkoff-Zern, 2014). In California, these estimates hover more consistently between 60%-75%, although these likely provide lower-bound estimates as undocumented status is self-reported (Center for Farmworker Families, 2022; Cha & Collins, 2022). Considering these populations' contributions not only to the U.S.'s economic prowess, but specifically to U.S. and global food supply, their exclusion from federal food assistance programs presents a paradox. Further, declining trends in H2A Visa

applications suggest these practices are unsustainable; signaling new challenges for the U.S. agricultural production system (USDA ERS, 2022; New American Economy, 2021).

Private and charitable food aid programs have developed vast networks to fill gaps left by public assistance programs, serving an estimated 60 million individuals across the U.S. in 2020 (Feeding America, 2021; Gundersen & Ziliak, 2018; Poppendieck, 1998). While these organizations can have powerful impacts on individuals, they lack the resources and distributional capacity necessary to equitably and effectively address food insecurity at the national and global scales, and often fail to reach those most vulnerable (Minkoff-Zern, 2014; Poppendieck, 1998). Considering the immense scope of food insecurity, much of the existing literature argues for a shift toward government intervention, rather than continued or increased reliance on the private sector and/or non-governmental organizations (Chilton & Rose, 2009; Long et al., 2020).

Food Access Inequities

Food deserts form where communities lack access to supermarkets or large grocery stores, as these retailers offer the highest quality and variety of food items at significantly lower prices relative to small markets and convenience stores (Gosliner et al., 2019; Morris et al., 1992). Food deserts are disproportionately located in low-income, minority, communities that lack ease of mobility, whether rural or urban (Walker et al., 2010; Elliot, 1997; Long et al., 2020). Food desert maps provide a convenient visualization of the trends uncovered in the existing literature, as impacted communities often share socio-demographic characteristics, such as racial/ethnic and socioeconomic status. Impacted communities suffer lower life expectancies and higher rates of non-communicable diseases, such as cardiovascular disease (Liu & Eicher-Miller, 2021), hypertension, and diabetes (Burke et al., 2018; Liu & Eicher-Miller, 2021), as a

result of this geographic isolation from adequate food sources. These links between socioeconomic and racial status, food insecurity, and negative health outcomes have been of particular interest during the COVID-19 Pandemic, which has highlighted the lifelong health disparities that follow inequitable access to healthy foods (Liu & Eicher-Miller, 2021).

Geospatial analyses clearly depict the relationship between food insecurity and proximity to food retailers and reveal socio-demographic trends among communities located in food deserts. Although food deserts are often conceptualized in the context of urban poverty, low-income rural communities face, including those in key agricultural supply regions, fewer options and farther distances to supermarkets relative to socioeconomically comparable urban communities (Morris et al., 1992). Both urban and rural food deserts suffer from reduced variety and quality of fresh produce and animal products, along with higher prices, due to their geographic isolation from supermarkets (Gosliner et al., 2019; Morris et al., 1992). Many residents of food deserts lack access to transportation options that would allow them to travel the far distances to these larger retailers (Morris et al., 1992; Carney et al., 2012; Flores-Landeros et al., 2021; Gosliner et al., 2019). As a result, these communities must augment their diets to rely on the types of foods available at the smaller markets nearby, often substituting nutrient-dense whole foods for calorie-dense, highly processed, foods (Carney et al., 2012; Morris et al., 1992).

U.S. Water Systems

Water Availability and Use

Similar to global studies, water footprint (WF) and virtual water (VW) trade analyses are commonly used to estimate water consumption and availability in the U.S. These studies produce a wide array of estimates based on differences between models, input data, and assumptions used in calculations (Rushforth & Ruddell, 2018), similar to global analyses employing these

methods. While some studies focus solely on blue water footprints (Rushforth & Ruddell, 2018; Tom et al., 2016), others incorporate green footprints (Veetil & Mishra, 2016; Mubako & Lant, 2013) to provide a more comprehensive estimate of national water availability and use, particularly for the agriculture sector. Studies accounting for gray water footprints are generally lacking at the national scale. Some experts do not regard gray water as consumptive use, noting the potential for double counting given the multiple uses for reclaimed and sanitized water sources (Fulton et al., 2014). However, there is no accepted definition of gray water and this distinction is therefore not applied ubiquitously across the literature.

Water footprint studies face criticism for their lack of temporal dynamism; these analyses capture a snapshot in time and are unable to track trends changes in water availability over time or in relation to seasonal weather patterns (Rushforth & Ruddell, 2018). Additionally, water footprint analyses contain a degree of temporal uncertainty; the estimates reflect a time within a given range of years, not a specific year (Rushforth & Ruddell, 2018). This lack of dynamism makes it difficult to assess the impacts of exogenous shocks, such as a major drought. Water systems are highly dynamic systems, sensitive to changes in seasonal trends and constantly evolving over time. This sensitivity is what necessitates the field of study, as climate change effects are bound to significantly impact future water availability.

State-level water footprint analyses reveal high variability based on differences in ecological factors, such as precipitation and evapotranspiration rates, along with socioeconomic variables, such as dominant industries and demographic trends (Mubako & Lant, 2013). To obtain water savings, virtual water trades must flow from areas of relatively low to high water footprint; however, studies estimating virtual water trade flows show that the U.S. engages in highly inefficient trade patterns. Humid, water-abundant, East Coast states receive the largest

water transfers primarily from arid Southwest states, currently suffering from increasingly intense and frequent drought conditions (Mubako & Lant, 2013; Rushforth & Ruddell, 2018). Spatially explicit studies show that urban dependence on rural agricultural outputs drive this unproductive water trade, suggesting that factors such as affluence and urbanization determine national virtual water flows, not physical water scarcity (Rushforth & Ruddell, 2018).

Diet-focused studies of the U.S., similar to global analyses, find that transitioning to a "healthier" diet does not automatically reduce water footprint. Tom et al. (2016) assess the USDA dietary recommendations relative to their blue water footprint, finding that this diet increases the U.S.' average blue water footprint by roughly 16%. The only scenario found to reduce blue water consumption relies solely on reducing caloric intake without altering the current mix of foods consumed. These findings suggest that the water saving benefits of reducing per-capita meat intake could be offset by increased consumption of fruits and vegetables, which have some of the highest blue water footprint index scores, due to their low caloric content and the fact that they are grown primarily in California, one of the driest yet most agriculturally productive states in the nation (Tom et al., 2016). This study introduces an important tradeoff between policies aimed at improving human health conditions and reducing the national water footprint, both of which must be considered to address food insecurity.

Water Insecurity

U.S.-focused water insecurity literature is lacking as the issue has gone largely unrecognized, only recently gaining momentum following major crises, such as Flint, MI. Water insecurity effects are disproportionately concentrated in communities of color and states with relatively lax water quality regulation and monitoring standards (Dietz & Meehan, 2019; Mueller & Gasteyer, 2021; Peeples, 2020). National-scale water insecurity analyses reveal causal factors

similar to those identified by global food and water insecurity studies. Among the most commonly cited characteristics are racial/ethnic, immigration, and socioeconomic status (Dietz & Meehan, 2019; Jepson et al., 2016; Mueller & Gasteyer, 2021).

National-scale water footprint and virtual water trade calculations can mask household-level effects if the scale of analysis is too large. Much of the publicly accessible and nationally representative data required to calculate water use and scarcity for the U.S. are available at the county or census tract scales. Thus, most national studies produce water availability and use data at these scales. Given the high variability between household-level experiences of water insecurity, some studies argue that even the census tract is too coarse a scale to accurately depict water insecurity (Dietz & Meehan, 2019). At any arbitrarily defined political scale, individual experience may be masked by data aggregation methods. Inadequate access to fine-scale input data is therefore a key limitation facing this field (Rushforth & Ruddell, 2018). As such, water footprint and virtual water flow studies have been criticized for masking the true effects of water insecurity, particularly within developed nations like the U.S., where such issues tend to manifest in small and isolated pockets among otherwise water secure communities (Dietz & Meehan, 2019; Young & Miller, 2022). Spatially-explicit and/or spatially-downscaled analyses are necessary to capture water insecurity effects, as there can be high heterogeneity between household access to safe and clean drinking water within the same community.

The U.S. is the wealthiest nation in the world and has invested in national-scale infrastructure to facilitate widespread access to running water and sanitation services. While these factors create the perception of ubiquitous water security, the U.S.'s water infrastructure is rated as "poor" in some studies, due to neglect of maintenance and necessary upgrades (Mueller & Gasteyer, 2021). Continued neglect of these infrastructural issues will exacerbate existing

inequities between communities based on the amount of funding and attention their water systems receive from state and local regulatory agencies (Dietz & Meehan, 2019). Similarly, the passage of federal and state regulatory policies such as the Safe Drinking Water Act (SDWA) and Clean Water Act (CWA) imply strong federal protection and oversight of water supplies. However, both employ patchwork implementation approaches, which allow for substantial disparities between states based on each legislature's approach to monitoring and regulating water quality (Mueller & Gasteyer, 2021).

An estimated 97% of the U.S. population does have physical/infrastructural access to safe drinking water however, this represents just one of four water insecurity pillars (Young & Miller,

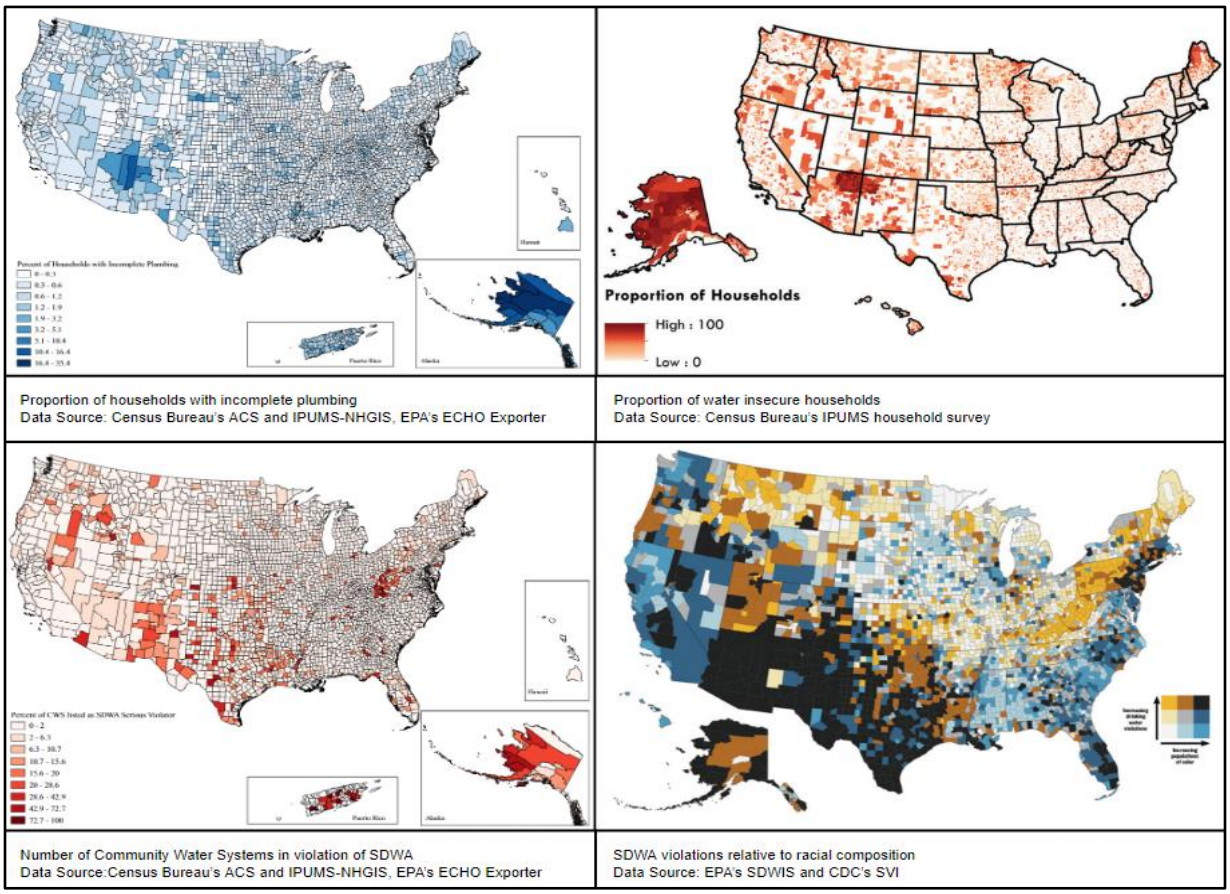


Figure 2.5 National-Scale Water Insecurity Metrics, four maps displaying water insecurity throughout the U.S., each using different metrics for measurement and demonstrating spatial heterogeneity of effects.

2022). Accessibility, use or trust, and stability of these conditions over time are also integral aspects of household water security. Barriers to any of these pillars constitutes water insecurity, manifesting in inability to pay water bills (Young & Miller, 2022; Rosinger, 2022), incomplete plumbing (Dietz & Meehan, 2019; Mueller & Gasteyer, 2021; Jepson & Vandewalle, 2016), and mistrust of tap water sources (Rosinger et al., 2022; Rosinger, 2022; Park et al., 2019). Given that experiences of water insecurity in the U.S. are highly individualistic, presenting among households located within even the most water secure communities, small-scale analyses reveal a far more nuanced picture of water insecurity in the U.S. relative to country-level estimates. As evidenced by Figure 2.4, county-level water insecurity estimates reveal pockets of concentrated water insecurity appearing throughout the nation. However, even high-resolution studies fall short of providing a comprehensive and straightforward estimate of water insecurity in the U.S., as the term encompasses a wide range of experiences. Figure 2.4 illustrates this heterogeneity, showing the differences in location and severity of estimated impacts based on the definition employed to measure these effects in each study.

Despite these inconsistencies, each household-scale study finds that disparate access to complete plumbing and adequate drinking water supplies tend to concentrate among low-income and minority households living in states with lax regulatory standards (Dietz & Meehan, 2019; Mueller & Gasteyer, 2021; Peeples, 2020). These household factors have intensified over time; studies find that a growing number of U.S. adults report reliance on bottled water due to negative perceptions of tap water safety relative to the early 2000s (Rosinger, 2022; Rosinger et al., 2022). Park et al. (2019) find that this mistrust is more heavily concentrated among Hispanic communities relative to non-Hispanic white communities, compounding already elevated water insecurity rates among this demographic.

Case Study Region: Central Valley, CA

Proximity to Food Retailers and Barriers to Equitable Access

As it exists today, the food system in the Central Valley operates such that the communities most directly involved in food production face the steepest barriers to attain food security. At the local scale, a primary factor underlying these inequities is the spatial distribution of different types of food retailers. Gosliner et al. (2019) show that the price and variety of food options depend on the type of food retailers located within their communities. Low-income and minority communities generally have access to convenience stores, while small grocers and supermarkets tend to be located in more urban and affluent areas. This presents a spatial barrier to healthy food access, as there are statistically significant differences between these three store types regarding both the variety and quality of fresh produce options. Residents of these disadvantaged communities (DACs) are concurrently less likely to own a vehicle or have access to reliable public transportation to commute far distances to attain better food options (Gosliner et al., 2019). As a result, these communities face spatial and financial barriers to fresh produce even without supply constraints. Studies based on survey responses from DAC residents find that proximity to food retailers and lack of adequate transportation play determinative roles in shaping perceptions of feasible diets (Carney et al., 2012; Flores-Landeros et al., 2021). Policies incentivizing supply shifts toward healthy diets are unlikely to reach these communities without first investing in the necessary infrastructure to facilitate access, such as grocery stores and public transportation.

Several case studies assess local impacts on Central Valley communities following the 2012 drought (Greene et al. 2018; Rodriguez et al., 2015; Wirth et al., 2007; Carney et al., 2012; Flores-Landeros et al., 2021, Feinstein et al., 2017). Empirical studies use a mix of personal

interviews and survey results to understand the daily effects of food insecurity on impacted communities. Flores-Landeros et al. (2021) interview stakeholders in the San Joaquin Valley regarding food access inequities, among other related topics such as access to water, diet-oriented education, and infrastructure. Results indicate that lack of affordability presents a significant barrier to access, particularly for healthy foods, such as fresh produce. Interviewees describe difficulties with attaining these foods based on limited retailer options. As the effects of drought increase prices throughout the global food system, these impacts are felt most severely by communities already struggling to consume healthy foods. As prices rise throughout the economy, attaining healthy diets becomes nearly impossible. Many low-income residents of the Central Valley work locally in the agriculture sector. As a result, supply constraints in the agriculture sector that result in end-product price hikes coincide with potential loss of work and income for many families in these communities (Flores-Landeros et al., 2021). This dual-reliance on the agriculture sector for employment and food production compounds these inaccessibility issues among residents of DACs in the Central Valley and similar communities.

Agricultural Employment and Food Insecurity

Given that a high proportion of Central Valley DAC residents are employed by the agriculture sector as farmworkers, unemployment data is a reliable indicator of food insecurity. Increased agricultural unemployment signals land use changes that reduce the number of available jobs, whether that be from crop switching or cropland fallowing. Subsequent income loss constrains purchasing power, further limiting food options, particularly among low-income families who spend a relatively high proportion of total income on food and other essentials (Neff et al., 2009). This relationship between agricultural production and employment in Central

Valley communities can be identified through the seasonality of employment numbers, which mimic cycles of harvest and growth (Wirth et al., 2007).

Several studies have established the link between employment and food insecurity among farmworkers in the Central Valley, most notably Wirth et al. (2007). The study focuses on a sample population of 455 Spanish-speaking farmworkers in Fresno County and finds substantial, statistically significant, variations in mean monthly income, rent payments, remittances, and food stamp usage for surveyed households between winter and summer months. Household income and consumption both increase during the summer months, when jobs are abundant, and decline in winter months. Comparing these quantitative results with survey response data shows that individual food insecurity perceptions vary with seasonal changes to income and employment status. In keeping with Gosliner et al. (2019), Carney et al. (2012), and Flores-Landeros et al. (2021), this study identifies affordability and spatial proximity to large grocery stores and supermarkets as key determinants of food insecurity, with rates highest among undocumented migrant workers.

Greene et al. (2018) assess spatial disparities in food insecurity rates in the San Joaquin Valley, which serves as a particularly useful case study region given its spatial disparities in crop production, water management, and segregation of lower- and higher-income communities between the east and west. The study finds that farmers responded to drought by shifting production away from more labor-intensive field crops, to higher-valued perennial crops such as almonds, whose harvest is highly mechanized. This change helped to offset economic losses to farmers in the region, but cost an estimated 24,800 jobs lost in the agriculture sector from 2014-2016. Beyond unemployment implications, the drought and subsequent shift in crop production resulted in reduced donations to food banks from farmers, along with reports of increased food

prices locally, despite a decline in national average food price over the same time horizon. Spatially explicit analyses reveal harsher impacts in the western region of the San Joaquin Valley, which suffered a greater decline in labor-intensive crop production and houses a higher proportion of farmworkers relative to the east, reinforcing the findings of (Wirth et al., 2007).

Water Insecurity in the Central Valley - Drought and SGMA

California's surface water supply relies on runoff from mountaintop snowmelt, which has declined in recent years due to rising year-round temperatures. Simply put, as warmer winters yield less snowpack accumulation, the constant flow of surface water that would supply the region throughout the growing season runs dry earlier. As a result, water consumption pivots from this renewable water source to pumped groundwater, a finite resource. While these water shortages are not unique to the Central Valley, the prominence of agriculture in the region creates high levels of inelastic demand, which has resulted in substantial groundwater overdraft. For this reason, California passed the Sustainable Groundwater Management Act (SGMA) in 2014, which holds California's highest-risk water basins accountable to achieve sustainable groundwater withdrawal rates by 2040 (Rudnick et al., 2016; Leach et al., 2021). The implementation structure of SGMA mandates creation of groundwater sustainability agencies (GSAs) within each basin, which must develop groundwater sustainability plans (GSPs) tailored to meet the specific needs of their community. While this distributed governance style is attractive on its face, it leaves room for high variability between GSAs, along with economic uncertainties and inequitable stakeholder representation (Leach et al., 2021).

While all sectors contribute to California's water shortage issues, agriculture constitutes the bulk of water demand in the Central Valley. California's State Water Board reports that roughly 80% of the state's total water consumption comes from the agriculture sector, which is

increasingly reliant on pumped groundwater as drought conditions limit available surface water (Alexander & Esteli, 2021). Despite the state's relatively constant net water consumption over the last 30 years, groundwater overdraft has nearly doubled to constitute about 15% of total water use (Hanak et al., 2019). These statewide trends are even more pronounced in the Central Valley, due to its high concentration of agricultural producers. Between 1962 and 2003, predating the most recent and severe droughts, groundwater consumption in the Central Valley increased by about 233% (Alexander & Esteli, 2021). Such dramatic increases reflect two defining characteristics of the Central Valley: its highly productive and water-dependent, agriculture sector and increasing vulnerability to climate change-induced drought conditions.

Each of the three basins covering the Central Valley floor-the Sacramento River Basin, the San Joaquin Valley River Basin, and the Tulare Lake Basin-are critically overdrafted. While SGMA does not mandate specific policy interventions to achieve sustainable withdrawal rates, there is general consensus among hydro-economic models that a combination of land fallowing and water trading programs will be necessary to decrease withdrawal rates below recharge rates, particularly in regions such as the San Joaquin Valley, where the average net overdraft exceeds 1.8 million acre-feet (maf) annually (Hanak et al., 2019).

The San Joaquin Valley produces over half of California's total farm output and has the highest net overdraft on average (Hanak et al., 2019; Medellin-Azuara et al., 2022). Existing studies find that implementing a mix of land fallowing, crop switching, and water trading can minimize costs to the agriculture sector while addressing the region's severe overdraft issues (Hanak et al., 2019; Alexander & Esteli, 2021; Medellin-Azuara et al., 2022; Sumner et al., 2021). The severity of economic losses depends on the options afforded to farmers in the form of crop switching and surface water trading. Losses from fallowing productive agricultural land

account for a substantial portion of total economic losses. Estimates for total acreage that must be fallowed in the San Joaquin Valley to attain sustainable groundwater use range from 535,000 to 750,000 acres (Hanak et al., 2019; Alexander & Esteli, 2021). On the lower end, modelers assume valley-wide surface water trading and high flexibility in crop choice, while the upper bound represents a BAU scenario, where trading is constrained to producers within the same basin. With no water trading, this number increases to 780,000 acres (Hanak et al., 2019; Alexander & Esteli, 2021). The economic losses accompanying these scenarios reveal the importance of spatial allocation of land fallowing. Under optimal conditions, economic losses total about $1.3 billion in lost revenue and 9,000 full- and part-time farm jobs. When water trading is constrained to only within-basin allowances, revenue losses increase to $3.5 billion. The difference in revenue losses is attributable to the spatial distribution of land fallowing, not necessarily the total acreage. Without valley-wide trading, land retirement would be concentrated in the southern portion of the valley, where water is more scarce but the crops grown have higher market values. Thus, allowing for valley-wide trade can shift water resources from areas where water abundance is higher or the value of crops are lower to reduce the overall economic toll (Hanak et al., 2019). Flexibility in water trading mechanisms is critical, as the location of the most severe drought impacts has begun to migrate north (Medellin-Azuara et al., 2022; Sumner et al., 2021). However, such regional water markets have not yet been implemented, leaving open the possibility for significant economic losses from land fallowing and sustained drought that limits water supplies, contracts total production and reduces labor demands.

The Central Valley has undergone significant expansion of perennial and orchard crop acreage, which require yearly watering and maintenance to avoid a complete lost investment. Since 2012, field crop acreage has declined by 67%, largely replaced by tree nuts, whose acreage

surpassed that of field crops for the first time in 2021 (Sumner et al., 2021). In dry years, it is relatively simple, logistically speaking, to temporarily fallow acreage devoted to field crops as farmers need only refrain from replanting after a harvest. The perennial crop category encompasses orchard crops, trees and vines, which take a longer time to produce yields but then continue producing each year without significant investment in replanting. If a farmer forgoes watering these crops, they risk losing their entire investment, which could be economically devastating. Thus, an increase in the acreage devoted to perennial crops implies reduced demand elasticity for farmers, as they cannot fallow in dry years (Sumner et al., 2021). Studies assessing the economic ramifications of this reduced elasticity throughout the Central Valley find that annual revenue loss in dry years could increase by 30% given current trends in perennial expansion (Mall & Herman, 2019). However, it remains unclear whether this transition toward higher reliance on perennials might benefit overall environmental health.

As drought conditions intensify, this shift in land-use and subsequent demand rigidity will compound drought vulnerabilities in the Central Valley. Analyses linking water insecurity to crop trends have not quantified the ecosystem services, such as nutrient cycling, soil retention, carbon sequestration, and biodiversity conservation, which accompany expansion of perennials and may offset some of the negative impacts of higher water demand (Mall & Herman, 2019; Bryant et al., 2020). With over 35 wildlife and plant species listed as endangered or threatened in the San Joaquin Valley, along with land subsidence and water quality issues stemming from overdraft and reduced recharge capacity, these co-benefits should receive serious consideration when developing plans for land fallowing and retirement (Bryant et al., 2020). These co benefits are particularly important considering that expansion of perennials and subsequent demand inelasticity limits the potential for land conservation incentive programs.

A combination of record-low precipitation and increased evaporative demand has culminated in 2021 being California's driest year on record. In a preliminary report on the economic impacts of the 2021 drought, Medellin-Azuara et al. (2022) analyze the economic effects of the current drought using 2018 as a baseline, non-drought, year. This study found that about 395,100 acres were fallowed statewide in response to the drought, with the Central Valley accounting for about 385,000 of these acres. This is around 10% less than the 428,000 acres fallowed in 2014, the height of the 2012 drought (Medellin-Azuara et al., 2015). While about 83% of the additional groundwater pumping was concentrated in the San Joaquin Valley, the Sacramento Valley's groundwater levels fell more significantly in 2021 compared to 2014 and this region experienced the highest net shortage relative to the other two basins in the Central Valley. This denotes a spatial transition such that the most drastic drought effects are no longer felt in the southern portion of the Central Valley, which has implications for management techniques and expected economic losses. Total revenue losses for the Central Valley are estimated at $755 million, compared to about $800 million in 2014, potentially reflecting the northern migration of drought impacts, away from the most economically valuable and productive land. Similarly, direct job losses remain lower in 2021, despite a difference in net water shortage of only about 10,000 acre-feet (Medellin-Azuara et al., 2022; Medellin-Azuara et al., 2015).

Table 2.1 Differences between Economic Outcomes from 2014 and 2021 Droughts, presents differences in economic impacts for California's Central Valley from 2014 and 2021 droughts, numbers adapted from Mendellin-Azuara et al., 2015 and Mendellin-Azuara et al., 2022.

Drought Year	Net Water Shortage (maf)	Idled Acreage	Revenue Losses (Direct)	Additional Pumping Costs,	Direct Job Losses (full- and part-time)
2014	1.5 maf	428,000	$800 million	$454 million	6,722
2021	1.48 maf	385,000	$755 million	$184 million	6,114

Water Equity Concerns

California's state legislature passed a human right to water in 2013 however, residents still experience high rates of water insecurity, particularly during periods of drought. With the passage of this right came the acknowledgement that systemic divestment in rural disadvantaged communities (DACs) has created a crisis among populations that regularly lack access to clean, safe, and adequate drinking water supplies (Pannu, 2018). California legislators have not offered guidance on how local governments should approach issues of insufficient water quality or quantity. Further, the patchwork implementation approach fails to account for those disadvantaged unincorporated communities (DUCs), which are most vulnerable to water shortages and contamination issues (Safe Water Alliance, 2014).

Existing studies assessing groundwater management impacts find that DACs bear a disproportionately high burden of water insecurity in California (Pannu, 2018; Macleod & Mendez-Barrientos, 2019; Safe Water Alliance, 2014; Flegal et al., 2019). Macleod & Mendez-Barrientos (2019) show that access to drinking water, along with quality and affordability, are linked to a community's socioeconomic status, with rural DACs of color, bearing the harshest impacts. Many of these communities are located outside the boundaries of incorporated cities; they have no municipal government to regulate water management issues, instead relying on

county officials to address issues of insufficient quality and quantity. Due to their close proximity to farmlands, these DUCs must compete with large producers for water use and live with nitrate and arsenic contamination that accompanies intensive agricultural practices. Historic divestment and neglect, coupled with risk factors linked to agricultural land management trends result in these DUCs bearing the harshest consequences of water insecurity in the state (Safe Water Alliance, 2014).

When farms and households are forced to compete for limited groundwater resources, farms tend to win as they already have the knowledge and resources necessary to quickly adapt to supply constraints (Fernandez-Bou et al., 2022). Excessive groundwater pumping and subsequent land subsidence introduce externalities that compound existing water insecurity issues, disproportionately impacting DACs of color. Land subsidence can contaminate existing groundwater supplies, creating further limitations on an already strained resource. When water tables fall too low, saltwater intrusion can make water unusable for households and agriculture (Lewis & Rudnick, 2019; Medellin-Azuara et al., 2015). Contaminants can also leach into groundwater supplies when over-pumped, creating health risks for local populations (Safe Water Alliance, 2014, Fernandez-Bou et al., 2022).

These health risks apply primarily to disadvantaged unincorporated communities (DUCs), which are often co located in sub-basins with agricultural producers (Fernandez-Bou et al., 2022), rely on private wells for drinking water, and lack access to municipal water supplies (Pannu, 2018; Flegal et al., 2019). These communities continue to suffer from their history of divestment and exclusion; they lack water delivery infrastructure and have no backup supply during intense drought periods. These communities often neighbor farmlands, as many residents work in the agriculture sector as farmworkers and are majority Latinx (Pannu, 2018; Fernandez-

Bou et al., 2022). Regulatory policies aimed at reducing overdraft do not necessarily account for these water equity issues. Without investment in water delivery infrastructure, DUCs will continue to suffer the consequences of water use decisions that never extended to them. As noted earlier, a significant portion of DUC residents are employed by the agriculture sector, implying that stringent water regulation could have downstream unemployment effects on farmworkers, many of whom reside in these DUCs. As such, it is crucial that population demographics be taken into account when developing water regulation policies in the region.

Water trading schemes pursuant to SGMA may yield negative externalities for DACs, as well as the diversity of California's agriculture sector. Assigning water use allocations to communities based on historic consumption levels could perpetuate existing water inequity issues for DACs, whose constrained access is not indicative of actual demand. Residents of these communities have struggled to survive during dry years, forced to rely only on bottled water or go without when wells run dry and groundwater contamination from nearby agricultural land use makes water unusable (Alexander & Esteli, 2021; Safe Water Alliance, 2014). These schemes could also skew the distribution of small, family-owned, farms in California by incentivizing these operations to cease crop production, instead maximizing profits from water sales (Alexander & Esteli, 2021). Under stringent water restrictions, larger farms with the capital to purchase additional water allowances can maintain revenues, albeit under slimmer profit margins. Smaller farm operations without this financial leverage will see revenues decline, potentially to the point where operations are no longer profitable (Alexander & Esteli, 2021). Similarly, larger farms have both the human capital and financial sway to influence GSP decision-making processes (Rudnick et al., 2016). It is crucial that GSAs account for these power

dynamics when formulating policies to attain sustainable groundwater use to avoid disproportionately impacting small farms and DACs.

Given that the earliest deadline for GSP implementation is 2020, relatively few papers have assessed policy outcomes. Early assessments of these implementation schemes have raised equity concerns based on representation on GSA boards and within GSP strategies. Rudnick et al. (2016) present accounts from three farmers, operating small, medium, and large-scale farms to assess equity implications across agricultural producers based on operational scale. The paper draws on interviews with these producers to extrapolate broad-scale challenges to production capacity and assess information on surface and groundwater improvements, financing new infrastructure, and representation of various water user and resource needs. Leach et al. (2021) analyze implementation efficacy from the perspective of GSAs, recording survey responses from a much larger sample population of 134 GSAs. While Rudnick et al. (2016) focused more on the experience of farmers trying to implement strategies to comply with SGMA groundwater regulations, Leach et al. (2021) assess perceptions of success among policymakers involved in GSP formation to identify problem areas in GSP development and implementation. Dobbin (2018) offers insight into the inclusivity of GSPs with respect to disadvantaged communities (DACs) and unincorporated areas (DUCs). This analysis conducts geospatial analyses to establish the presence of these communities within GSA boundaries, finding that nearly half of the states' DACs and DUCs fall within one or more GSA jurisdictions. Despite their prevalence, these communities are severely underrepresented, both as GSA board members and within GSP implementation strategies. The study reports that only 55% of small DACs are included on interested parties lists submitted by GSAs, while this rate falls to 10% for DUCs. These numbers alone suggest that GSAs systematically exclude those most vulnerable to food and water

insecurity impacts, mirroring exclusionary practices characteristic of state- and national-scale policies, despite their localized nature. Given that DACs and DUCs rely almost exclusively on private groundwater wells to meet household water demands, this oversight on the part of GSAs becomes increasingly problematic.

Discussion

Study results regarding food and water insecurity impacts, along with their causal factors, vary based on the scale of analysis and population of interest. Effective and comprehensive policies must consider these differences to fully account for the range of potential externalities accompanying proposed interventions; thus, each scale of analysis has its merits. There are, however, inherent tradeoffs between scale and specificity that complicate problem and intervention identification processes. Current policies, implemented across scales of governance, fail to incorporate localized knowledge captured in bottom-up, community-level studies, relying instead on data derived from top-down approaches, which sacrifice nuance for generalizability. In part, these gaps between global, national, and localized perspectives explain the persistence, and recent intensification, of food and water insecurity, despite national and multi-national commitments to end these issues.

Data Collection and Management Methods

Global studies generally produce country-level estimates of food and water insecurity, which run the risk of obscuring distributional disparities at the sub-national level, thereby misrepresenting real vulnerabilities (Caifero et al., 2022). Food and water system dynamics are highly variable and largely reliant on localized hydrologic, socioeconomic, and political factors. International virtual water trade assessments generally rely on bilateral trade data from FAOSTAT, due to its detailed accounts of directionality in trade flows and political relevance

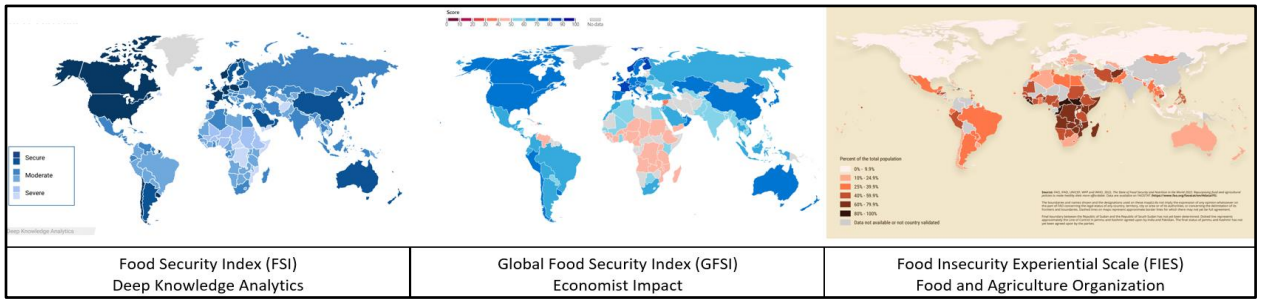


Figure 2.6 Global Food Insecurity Metrics, comparison of three widely used global food insecurity measurements, each employing different methodologies, data collection methods, and measurement scales.

(Liu et al., 2019). This data is, however, available only at the national level, which constrains output data to the same scale. Similarly, global models of food trade present results at the country or regional level, rarely accounting for within-country distributional patterns and thus masking inequities among sub-populations (Caifero et al., 2022; Janssens et al., 2020).

The global studies that capture both between- and within-country food and water insecurity information utilize individual-scale survey data, disseminated across a globally representative sample population through Gallup Inc.'s World Poll. These data are the Food Insecurity Experience Scale (FIES), the Individual Water Insecurity Scale (IWISE), and the Household Water Insecurity Experience Scale (HWISE). Partnership with Gallup Inc. has allowed these bottom-up surveys to capture data from a sufficiently large and diverse sample population to facilitate analyses at the national and global levels without masking inherent heterogeneity (Young et al., 2019). Each survey employs Rasch item response theory to code qualitative responses into numeric data for use in quantitative analyses (Young et al., 2019; Caifero et al., 2022; Smith et al., 2017; Grimaccia & Naccarato, 2019). Studies utilizing these datasets can identify and analyze determinants of individual food and water insecurity and study cross-country disparities relative to characteristics such as development status. One key limitation of these data is their inability to capture directionality/causality in the relationships

they identify (Smith et al., 2017; Stoler et al., 2021). Thus, while these studies present novel and highly useful data, additional quantitative analyses must be employed to ensure policies are targeted toward behaviors and actors in violation of sustainable and equitable resource allocation.

These distinctions between the data collection and aggregation methods employed by each global study produce some divergence in country-level food insecurity estimates. Additionally, these methodological differences result in different measurement scales, complicating cross-study comparisons and interpretability. As shown in Figure 2.6, each of the three global food insecurity studies produce slightly different results, with notable differences between findings using FSI and GFSI data and those produced from FIES data in sub-Saharan Africa, China and Russia. However, it is difficult to even compare results across these three studies, as FSI qualitatively categorizes food security, while GFSI uses a 0-100 score, and FIES estimates the proportion of each national population experiencing food insecurity.

Methodological Differences

Water footprint and virtual water trade analyses allow researchers to infer causality and directionality, as these studies employ trade flow data, which details the origins and destinations of traded products (Liu et al., 2019). These analyses can be used to compare trade flows between or within countries. High uncertainty exists across studies due to lacking standardization of basic definitions and methodological approaches (Wang et al., 2021). Studies differ in their water footprint metrics, methodological approaches, models and assumptions, and chosen scale of analysis (Yang et al., 2013; Wang et al., 2021; Liu et al., 2019); each of which contributes to high variability among results.

Wang et al. (2021) provide a detailed and critical review of water savings studies, finding that employment of numerous methods to measure savings and losses, along with different models, creates high levels of uncertainty in the results. The authors identify the most popular methods for calculating global water savings; these are input-output (IO) and multiregional input-output (MRIO) tables and water footprint accounting (WFA). IO and MRIO are "top-down" methods, which account for flows between production and consumption throughout entire supply chains, enabling large-scale water footprint calculations. Contrarily, water footprint accounting takes a bottom-up approach to assess water management practices, and is primarily used in the context of food and agricultural production.

Water footprint accounting includes for blue, green and gray water use, making it among the more comprehensive estimates (Wang et al., 2021). Water footprint accounting can be used to compare the consumptive demand and/or efficiency between different regions but can also be used as input data to estimate virtual water trade flows (Mubako & Lant, 2013). Flow estimations are useful to assess water use efficiency as they provide insight on directionality and spatial dependencies between nodes within a supply chain. While clearly a versatile and useful tool, water footprint analysis faces substantial limitations that warrant attention, particularly from policymakers relying on these data for decision-making processes. Water footprint data lack temporal dynamism and contain temporal uncertainties (Rushforth & Ruddell, 2018). Additionally, these quantitative data do not independently communicate water scarcity information (Veetil & Mishra, 2016; Fulton et al., 2014), representing water productivity rather than physical limitations and therefore limiting its policy relevance (Liu et al., 2019). Finally, while the bottom-up approach to water footprint accounting helps to capture supply- and demand-side heterogeneity between units of analysis, the spatial scales are often still too large

due to input data constraints, and therefore mask effects at the basin and sub-basin scales (Rushforth & Ruddell, 2018). Similarly, reliance on annual input data leaves water footprint studies unable to convey seasonal variability (Rushforth & Ruddell, 2018), an important factor in determining water availability and security. Hydro-economic and related modeling techniques can help overcome the limitations of water footprint analyses by representing system dynamics and temporal variation in resource availability/demands, but such computational approaches often require spatial or population-scale aggregation, limiting their usefulness in contexts where specific population groups face water security challenges (Baker et al., 2021).

Qualitative data are useful to assess water scarcity and insecurity and identify issues prevalent among marginalized populations, particularly those for whom national statistics may not be available, such as undocumented immigrants. These studies tend to rely on small sample sizes, resulting in a lack of scalability, which ultimately limits their political relevance (Yang et al., 2013). However, the relatively recent validation of the Household Water Insecurity Experiences (HWISE) and the Individual Water Insecurity Experiences (IWISE) scales, two globally disseminated household- and individual-level surveys, has helped to bridge this divide between political relevance and accuracy (Young et al., 2018). These surveys belong to the same project as FIES, and face similar drawbacks, namely their inability to establish directionality/causality between variables (Stoler et al., 2021). Additionally, while both scales have been validated for low- and middle-income countries, they have yet to be validated for high-income countries, which also experience individual- and household-level water insecurity (Young et al., 2019). No water insecurity experience scale has been validated for the U.S. or developed nations as a unit, marking a significant gap in the literature (Rosinger, 2022).

In addition to these competing calculation methods, various models exist to estimate water consumption, flows, and project future availability under various climate and economic scenarios. Differences between model inputs and assumptions produce highly variable estimates of virtual water consumption (Mekonnen & Hoekstra, 2020; Mekonnen & Gerbens-Leenes, 2020; Liu et al., 2019; Rushforth & Ruddell, 2018; Fulton et al., 2014), again, creating uncertainty that hinders effective policy design. This paper proposes a standardization of common definitions to facilitate a more congruous body of water savings estimations that will be better equipped to inform policy decisions moving forward.

Table 2.2 Methodologies and Analytical Scales, commonly employed by existing literature to measure issues relating to food and water insecurity.

Study Focus	Quantification Method	Analytical Scale(s)	Literature
Water Security	HWISE Scale	Global	Brewis et al., 2020; Stoler et al., 2021
	IWISE Scale	Global	Brewis et al., 2020; Bethancourt et al., 2022
	National Health and Nutrition Examination Survey (NHANES)	National	Rosinger, 2022; Rosinger et al., 2022
	American Community Survey (ACS)	National	Mueller & Gasteyer, 2021
	In-person/telephone Interview	Community	Greene, 2018; Feinstein et al., 2017
Industrial/National Water Footprint	Blue, Green and Gray Water Footprint	Global, Regional (Multi-national), National, State	Ercin & Hoekstra, 2014; Mekonnen & Hoekstra, 2011; Vanham et al., 2013; Fulton et al., 2014
	Blue and Green Water Footprint	Regional (Sub-state)	Veettil & Mishra, 2016
	Blue Water Footprint	Global, National	Mekonnen & Hoekstra, 2020; Rushforth & Ruddell, 2018; Tom et al., 2016
Virtual Water Flow/Water Savings	Blue Water Footprint and International Trade Data	Global	Rosengrant et al., 2009; Oki et al., 2017; de Fraiture et al., 2004; Dabrowski et al., 2009
	Blue and Green Water Footprint and Intranational Trade Data	National	Mubako & Lant, 2013

Table 2.2 (Continued).

Hydro-economic Modeling	SWAP and IMPLAN Models	State, Regional (Sub-state)	Hanak et al., 2019; Medellin-Azuara et al., 2015; Medellin-Azuara et al., 2022
	SWAP and remote sensing data	State	Howitt et al., 2014
	SWAP, COMET, LUCAS models	Regional (Sub-State)	Bryant et al., 2020
Food Security	In-person/online survey	National, State, Regional (Sub-State and Multi-State), Community	Rodriguez et al., 2015; Chilton & Rose, 2009; Wolfson & Leung, 2020; Flores-Landeros et al., 2021; Carney, 2012; Wirth et al., 2007
	Current Population Survey Food Supplemental Survey (CPS-FSS)	National	Potochnick et al., 2017
	NHANES	National	Rodriguez et al., 2021
	FIES	Global	Caifero et al., 2022; Grimaccia & Naccarato, 2019; Smith et al., 2017
Food Access	Geospatial Analysis	National, State	Gosliner et al., 2019; Morris et al., 1992

Scale of Analysis

National-scale studies generally place greater emphasis on disparities between groups based on socioeconomic, racial/ethnic status, and gender when identifying causes of insecurity. Regression analyses are typically employed to identify statistically significant relationships between a set of suspected causal variables and the food or water insecurity outcome variable. Of the 14 studies focused on identifying disparities between sub-populations, 8 employ some

combination of individual-level survey data with regression analyses to establish causal links between food insecurity and racial/ethnic minority status (Burke et al., 2018; Phojanakong et al., 2019; Dietz & Meehan, 2019; Jepson & Vandewalle, 2016; Rosinger, 2022; Mueller & Gasteyer, 2021; Park et al., 2019; Wutich et al., 2021). Racial/ethnic minority status (Mueller & Gasteyer, 2021; Burke et al., 2018; Phojanakong et al., 2019; Deitz and Meehan, 2019), immigrant status, particularly those of Hispanic/Latinx descent (Chilton & Rose., 2009; Potochnick et al., 2017; Jepson & Vandewalle, 2016), and low socioeconomic status (Mueller & Gasteyer, 2021; Jepson & Vandewalle, 2016; Chilton & Rose., 2009) are among the most influential predictive characteristics identified. These studies build on existing knowledge that minority groups suffer the greatest food insecurity risks in the U.S., going a step further to identify factors beyond race and ethnicity that contribute to vulnerability. Group-specific studies offer insight into extenuating and compounding inequities, providing valuable insight into root causes that must be addressed to solve food and water insecurity among these subgroups.

Interview-style research conducted at the community level is best suited to center the experiences and voices of minority groups, as these studies employ a bottom-up approach to causal factor identification. These studies allow respondents to identify the factors that contribute to their food insecurity through loosely-structured interviews and then transform these responses into qualitative surveys for wider dissemination (Greene et al., 2018; Wirth et al., 2007; Flores-Landeros et al., 2021; Carney et al., 2012) or quantitative data (Feinstein et al., 2017) for further analyses. This process is distinct from much of the work done at the national level, where researchers take a top-down approach, starting with a set of causal factors and relying on sample selection to isolate effects on marginalized groups. While these studies are foundational in identifying issues and relative impacts on DACs, this style of research faces a set of

shortcomings that limits its scope of influence. After reviewing the 6 Central Valley focused surveys, three recurring trends were identified: (1) experimental design issues, (2) results fail to identify intervention points, (3) the input data are too subjective and/or the framing of the research too broad.

Community-level survey studies face issues related to experimental design that limit the scalability of results. A common failure among these studies to use random sampling methods leaves their findings open to questions of bias. Samples are often selectively chosen based on characteristics that identify these communities as being most vulnerable (Flores-Landeros et al., 2021; Carney et al., 2012). In each of these three studies, the selected sample populations share socioeconomic, demographic, and employment characteristics and are the sole participants in each study. While this a priori selection method ensures that historically marginalized and underrepresented populations are represented in the literature, failure to provide a heterogeneous study population makes it impossible to tease out the factors that contribute to heightened vulnerability among these communities. These studies take as given that communities of color, farmworker communities, and low-income communities bear harsher burdens of food insecurity. While these links have been established by previous studies, this method leaves studies vulnerable to omitted variable bias, whereby related factors not controlled for in the analyses would skew results. Wirth et al. (2007) specifically address their convenience sampling method as a limitation to the paper. This strategy, which lacks control groups or significant diversity between experimental groups, limits the applicability of results.

Sample size is also an important determinant of scalability; small sample sizes yield results that lack broad representativeness. While sample size sufficiency depends on the population of interest, few studies in this domain could apply findings beyond the few

communities they study. With sample sizes ranging from n=22 (Flores-Landeros et al., 2021) to n=454 (Wirth et al., 2007), each study provides data specific to their study areas. These results offer little insight into county-level trends, much less Central Valley or statewide patterns in food and/or water insecurity. The narrow scope of these results inhibits their political relevance, as findings do not directly translate to policy interventions. That said, these studies facilitate localized knowledge generation and problem identification, which should be used to inform future data collection efforts.

Studies conducted at these fine spatial scales incorporate the voices of historically underrepresented populations to identify key issues and establish causal relationships, facilitating the creation of highly accurate and comprehensive estimates of food and water insecurity. Few, however, suggest policy-oriented solutions to address these issues. There is a fundamental gap in the literature between studies aimed at centering voices of underrepresented and exceedingly vulnerable populations and those that provide quantifiable data and policy recommendations. Feinstein et al. (2019), Gosliner et al. (2019), and Greene et al. (2018) deliver community-specific problem identification and policy-oriented analyses by employing a combination of quantitative and qualitative analytical techniques. All three studies employ qualitative data collected using interview and survey methods to identify issues specific to communities of interest and establish basic causal chains. They also perform quantitative analyses regarding crop production (Greene et al., 2018), water system functioning (Feinstein et al., 2019), and food retailers (Gosliner et al., 2019) to substantiate qualitative findings. Gosliner et al. (2019) and Greene et al. (2018) produce spatially explicit data, particularly useful to showcase the Central Valley's socioeconomic and demographic heterogeneity. Visualizing the spatial distribution of

food insecurity relative to these population data demonstrates not only the region's extreme wealth disparities, but the paradox between agricultural productivity and food insecurity.

There are merits to exploratory analyses whose primary objective is knowledge generation. Wirth et al. (2007), Carney et al. (2018), Feinstein et al. (2019) conduct loosely structured interviews before designing surveys for data collection, allowing the lived experiences of community members to guide their research. Interview topics cover barriers to food access (Wirth et al., 2007), coping mechanisms among food-insecure households (Carney et al., 2018), along with water insecurity and co-occurring health affects (Feinstein et al., 2019). Each study provides a platform for residents to share full, personal, accounts of food and water insecurity on their own terms, not guided by pre-developed questions, nor aggregated into broader categories that remove nuance and authenticity. These results rely on the interviewee's self-perceptions of food and water insecurity. Surveys ask interviewees to rate their consumption during the drought (Feinstein et al., 2019) or the 2007 Financial Crisis (Carney et al., 2018) relative to "normal", which is never clearly defined. While the merits of self-perceived, experiential, data are well established in the field (Smith et al., 2017; Coates, 2013), certain indicators of food and water insecurity are highly subjective and may result in skewed data (Grimaccia & Naccarato, 2019). Relevance and reliability of survey data are therefore highly variable depending on the design and methodology employed.

Water equity studies face barriers to data collection and experimental design, as patterns of institutional discrimination and neglect drive under response among DUC residents, particularly those of Hispanic/Latinx nativity (Pannu, 2018; Flegal et al., 2019). DUCs lack a singular definition or set of criteria, which contributes to under-identification, while complicating problem identification within recognized areas. Water systems in the Central

Valley operate at localized scales, serving county and community populations. As a result, water insecurity issues manifest differently based on circumstances unique to each water system, and bottom-up problem identification strategies are therefore necessary to accurately and comprehensively address insecurity within each DUC. Five studies outline relevant water equity issues experienced by rural communities in the Central Valley, each identify key issues and recommend policy interventions to address them. Three of these papers provide policy suggestions that offer insight into the unique set of circumstances contributing to water insecurity in DUCs and directly outline steps toward remediation. Fernandez-Bou et al. (2022) and Hanak et al. (2019) conduct quantitative analyses for potential land retirement scenarios to understand how different stakeholders may experience costs and benefits under SGMA water restriction scenarios. Both of these studies focus on water outcomes from various land fallowing scenarios pursuant to SGMA groundwater withdrawal goals. While Fernandez-Bou et al. (2022) place a heavier emphasis on analyzing costs to low-income, rural, communities, Hanak et al. (2019) primarily explore outcomes for the agriculture sector and include a brief discussion of how water quality improvements could benefit DACs. While this discussion acknowledges the possibility for hydro-economic models to include water equity considerations, a failure to quantify and include these benefits in the main cost-benefit analyses conducted indicates these issues remain secondary to more tangible economic variables of interest (e.g. total costs and benefits).

CHAPTER 3: DATA AND METHODS

This chapter transitions from an assessment of food and water insecurity literature and scale considerations to an empirical analysis of food insecurity drivers, specific to the Central Valley. The chapter develops a simple conceptual model, used to frame the econometric modeling approach, and describes the primary datasets used, along with the regression framework and related robustness tests. The discussion closes with a description of the simulation exercise, designed to project food security outcomes from changes to agricultural employment, stemming from policy or environmental change factors that reduce agricultural crop area in the Valley.

Conceptual Model

The regression framework employed in this paper is guided by a conceptual model, developed using causal links identified by existing food and water insecurity literature. Each link in the model draws on a mix of qualitative and quantitative research, from hydro-economic analyses to in-person interviews, which identify agricultural and economic trends specific to the Central Valley. As illustrated in Figure 3.1, the regression analyses assumes that water availability, employment, and food insecurity are correlated among farmworkers in the Central Valley. The evidence for these relationships has been well established by other papers in the field, particularly this link between employment and food insecurity, which serves as a fundamental assumption for the Map the Meal Gap Study, whose analytical framework this paper borrows from.

Employment status is consistently identified as a predictor of food insecurity among vulnerable U.S. households (Coleman-Jensen et al., 2022; Nam et al., 2015; Kaiser, 2008). Considering farmworker communities, household food insecurity has been linked to seasonal

variations in employment status, which affect household income and subsequent purchasing power (Wadsworth et al., 2016; Kaiser et al., 2007; Rodriguez et al., 2015). In the Central Valley, this vulnerability among farmworkers is compounded by the heightened risk of food insecurity among immigrants of Hispanic descent (Walsemann et al., 2017; Winham et al., 2015; Alkon et al., 2011; Minkoff-Zern, 2014; Kaiser et al., 2007). Supply-side coping mechanisms that lower job numbers and crop production also translate to reduced farm-to-food bank donations, further constraining food options among local farmworker communities (Greene, 2018; Manalo Le-Clair, 2014; Rodriguez et al., 2015). Each of these factors culminate to make employment, specifically in the agriculture sector, a uniquely strong determinant of food insecurity among farmworkers in the Central Valley.

Although the regression analysis only considers the effect of agricultural employment on food insecurity, the two variables have a bidirectional relationship. Studies on farmworker communities in the Central Valley consistently find that food-insecure households face geospatial and financial barriers to accessing fresh produce (Carney et al., 2012; Flores-Landeros et al., 2021; Rodriguez et al., 2015; Wirth et al., 2007). These dietary shortcomings are common among low-income, food-insecure, individuals in the U.S., who often substitute calorie-dense and highly processed food items for more nutrient-dense but expensive foods (Carney et al., 2012; Rodriguez et al., 2015; Flores-Landeros et al., 2021). These dietary trends have also been linked to high incidence of non-communicable diseases, such as cardiovascular disease, hypertension, and diabetes (Burke et al., 2018; Liu & Eicher-Miller, 2021; CDC, 2020; Wolfson & Leung, 2020).

Food insecurity can both cause and exacerbate these issues; as food insecurity worsens, it may inhibit an individual's capacity to manage their disease and perform workplace responsibilities (Liu & Eicher-Miller, 2021; Wolfson & Leung, 2020). The strong connection between household income, employment status, and food insecurity sets the stage for a positive feedback loop that compounds socioeconomic and health-related vulnerabilities among at-risk populations.

Figure 3.1 Conceptual Model, constructed using causal links identified by local-scale literature and used to guide regression analysis.

Working backwards, agricultural employment outcomes flow from land use decisions, both in the form of crop switching and land fallowing, largely determined by water availability. Again, this relationship between employment and land use in the Central Valley has been extensively documented by the existing literature (Greene et al., 2018, Flores-Landeros et al., 2020, Rodriguez et al., 2015; Minkoff-Zern, 2014; Manalo-LeClair, 2014; Wirth et al., 2007; Nord & Prell, 2014). Each paper employs loosely structured interviews with farmworkers in the Central Valley to establish this link. Greene et al. (2018), go further, analyzing agricultural employment statistics alongside qualitative data collected during interview sessions, to establish a relationship between crop-switching practices and unemployment among farm laborers in the San Joaquin Valley.

While these studies consider the effects of water restrictions spurred by drought rather than policy, both drivers employ similar mechanisms to restrict water allocations. During periods

of drought, water is diverted from agricultural producers by their respective water delivery utilities, as would be the case under SGMA regulations (Howitt et al., 2014). California relies heavily on surface water runoff from mountain snowpack melt, not necessarily rainfall (Lewis & Rudnick, 2019). Thus, water shortages derive from reduced runoff during the growing season as a result of reduced snowpack accumulation during the wet season. In other words, crop production primarily relies on delayed surface water deliveries via runoff, rather than precipitation. As such, drought-induced water shortages are somewhat foreseeable, likening the water restriction scenarios of natural drought to those imposed under sustainable water use policies. Even accounting for the longer period of planning and preparation that accompanies policy-induced water restrictions, the outcomes are the same; attaining sustainable water withdrawal rates in the Central Valley will require retirement of productive agricultural lands (Hanak et al., 2019; Medellin-Azuara et al., 2022; Hagerty, 2021; Lewis & Rudnick, 2019; Bryant et al., 2020). No amount of foresight can alter this reality. What is subject to change, however, is the magnitude and timing of water restriction policies.

SGMA's decentralized implementation framework leaves room for high variability in outcomes based on decisions made by each GSA. Although basins deemed "high priority" were required to pass GSPs by 2020, only eight have been approved, while 39 are incomplete or inadequate, and the remaining 70 are under review (CA Department of Water Resources, 2023). Many of the 39 plans deemed incomplete or inadequate have been denied by the state for lacking adequate mitigation plans that draw from incorrect or ambiguous water budget calculations (CA Department of Water Resources, 2023). It is, therefore, evident that any measurable effects of the SGMA are yet to be seen and the range of potential outcomes remains uncertain. As such, this model considers five water restriction scenarios, each assuming alternative positions on these

questions of quantity, timing, and distributional priorities, which manifest in various land fallow estimates. From these estimates, we estimate subsequent employment and food insecurity impacts.

The land fallow estimates underlying each scenario derive from two key papers: Hanak et al. (2019), which estimates the acres of irrigated agricultural land that must be retired to meet sustainable withdrawal rates in the San Joaquin Valley by 2040, and Medellin-Azuara et al. (2022), which uses remote sensing data to assess the magnitude and spatial distribution of effects from the 2021 drought across the entire Central Valley.

Data Description

This study aims to provide food insecurity estimates that reflect the unique experience of food insecurity among farmworkers in the Central Valley. As such, the food insecurity model relies, to the greatest extent possible, on spatially downscaled data, collected using bottom-up processes, most likely to include historically marginalized populations, such as unincorporated community residents and undocumented immigrants.

The Central Valley produces the majority of the U.S. fruits and vegetables and as such, the region relies more heavily on human farm labor relative to other agricultural hubs (Alkon, 2011). The Central Valley is consequently home to a large population of migrant workers, whose livelihoods depend directly on their employment on farms (Alkon, 2011; Minkoff-Zern, 2014; Rodriguez et al., 2015; Wirth et al., 2007; Greene, 2018; Manalo-LeClair, 2014). Building from these studies, this paper assumes that unemployment and experiences of food insecurity are closely related among farmworkers in the Central Valley. As such, these employment data are used to estimate impacts on individual farmworkers and food insecurity rates within each county. This model uses employment data maintained by California's Employment Development

Department, which provides monthly agricultural employment estimates from 1990 through the present day. These estimates are categorized by NAICS code and aggregated to represent the Sacramento and San Joaquin Valleys. Since these data are available at the region-level and each region consists of multiple counties, these estimates are weighted by the proportion of productive agricultural land recorded for each year and county relative to the entire Central Valley. This land area information comes from another reference dataset, the Pesticide Use Report Data, and the weighting process is detailed in the following section.

To assess changes to agricultural land use over time, this paper relies on Pesticide Use Report (PUR) data recorded by the California Department of Pesticide Regulation. These records capture high-resolution land use data, used to assess the relationship between crop-switching tactics, employment, and food insecurity. The PUR dataset contains detailed attribute information on pesticide application at the land plot level. This study considers two attributes: crop type and acres treated from 2009 to 2018. These data are downloadable using a GIS query tool developed by the AGIS Lab at UC Davis. The data are then summarized such that each record has unique values for crop type, county, and year. This summarized data facilitates weighting for each county by the total acres devoted to agricultural production, or the acres treated variable. Weights are assigned to each county based on the proportion of total productive agricultural land in a given year. This weight is then used to generate employment estimates, spatially downscaled from the region- to the county-level.

Further, this study uses Map the Meal Gap data from Feeding America to estimate the relationship between increased unemployment and food insecurity in the Central Valley. This dataset provides estimates for annual food insecurity, both the food insecurity rate and the estimated number of food insecure people, along with meal cost at the county level. This paper

uses the number of food insecure people to estimate food insecurity, as this unit aligns with the agricultural employment and WIC variables, which estimate the total number of farmworkers and program participants, respectively. Map the Meal Gap was chosen over other similar food insecurity measures due to its methodological and conceptual overlap with this study. The study provides community-level estimates of food insecurity in an effort to improve data coverage and accuracy. As referenced throughout this thesis, underrepresentation of marginalized groups has been an issue for more highly aggregated datasets. Map the Meal Gap does not use income as a determinative factor in sample selection, as many food-insecure households in the U.S. do not fall below the federally defined poverty threshold. Additionally, the data assume a direct link between food insecurity and employment, race/ethnicity, and socioeconomic status, in keeping with the assumptions of this thesis. This study considers overall food insecurity and childhood food insecurity rates from 2009 to 2018. These historic food insecurity observations are used to establish relationships between employment status and food insecurity. Food insecurity outcomes are then projected using these estimates under various water restriction scenarios in the Central Valley.

To control for macroeconomic conditions that affect employment and individual purchasing power, the model uses county-level statistics on meal cost and per-capita income. Meal cost data also comes from the Map the Meal Gap dataset and are available at the county level on an annual time step. These cost data offer a spatially explicit estimate of food price inflation within the Central Valley, which is a useful control when assuming food insecurity is a function of a household's socioeconomic characteristics, such as employment and income, along with external macroeconomic conditions. Controlling for food price inflation ensures that exogenous stressors on household purchasing power are considered when estimating food

insecurity outcomes that stem from more direct drivers of socioeconomic well-being, such as employment. While research establishing the link between food price and food insecurity in the U.S. is generally lacking, this paper assumes a causal relationship between the two, following the results of (Gregory & Coleman-Jensen, 2013).

Data on income per-capita comes from the U.S. Census Bureau's American Community Survey (ACS). ACS is a household survey, distributed continuously throughout the year in an effort to keep pace with the nation's rapidly changing demographics (U.S. Census Bureau, 2020). Data collected throughout the year are pooled to obtain annual estimates. The temporal and geographic scale of the ACS data allows for spatiotemporal variation that other variables, such as national or state GDP, would not. Of particular interest for this study, the bottom-up and randomized data collection methods employed result in an equal likelihood of undocumented households being selected relative to both authorized and U.S.-born households (Pope, 2016; Amuendo-Dorantes & Arenas-Arroyo, 2017). It is, however, worth noting that the sampling process relies on the Census Bureau's official inventory of known housing units in the U.S., which Flegal et al. (2019) have shown drastically underestimates units in DUCs. As such, the relationship between household income and food insecurity acts as a lower-bound estimate, as unobserved household incomes are likely lower and more volatile relative to the observed population.

In an effort to account for variations in household food insecurity, this study includes a variable measuring participation in the Special Supplemental Nutrition Assistance Program for Women, Infants, and Children (WIC). This data is available at the county-level on a monthly time step from 2010-2021. The monthly frequency of the data aligns with the agricultural employment estimates, allowing this study to consider the effects of program participation on

seasonal food insecurity. This paper uses data on WIC participation, as opposed to the Supplemental Nutrition Assistance Program (SNAP), as utilization rates are higher among Hispanic households, particularly Hispanic immigrant households. This is primarily due to the fact that WIC does not require proof of citizenship for the household heads, whereas SNAP does. Undocumented immigrants are eligible to participate in WIC as long as the household has a child under 5 years old born in the United States (Jensen et al., 2019; Pelto et al., 2020; Winham & Florain, 2015). WIC data are downloaded from the California Department of Health and Human Services Open Data website.

Since agricultural production in California is highly sensitive to climatic factors, specifically drought, this study controls for annual temperature and precipitation averages for each county in the Central Valley. These climate control data come from the PRISM Climate Group at Oregon State University, which provides high-resolution climate data available at a monthly timescale, in keeping with the temporal resolution of the agricultural employment and crop production data.

Table 3.1 Regression Variables - Descriptive Statistics, description and summary statistics for variables considered in first- and second-stage regressions.

Variable	Unit	Description	Data Source	Mean	SD	Min	Max
Agricultural Employment	**Count of Employed Individuals**	Agricultural employment estimates by county and year	CA Employment Development Department	13,511.39	28746.38	0	152,130
Production Acres	**Acres**	Number of acres in use for crop production, defined for each land plot in use	CA Department of Pesticide Regulation	93,400.67	705,654.30	0	12,600,000
Precipitation	**Inches**	Monthly precipitation averages by county	PRISM Climate Group at Oregon State	17.63	11.32	2.37	105.29
Temperature	**Degrees Fahrenheit**	Monthly temperature averages by county	PRISM Climate Group at Oregon State	59.74	6.10	42.20	67.40
Food Insecurity	**Count of Food-Insecure Individuals**	Annual food insecurity estimates by county	Feeding America	58,584.54	66,818.00	310	242,460
Meal Cost	**Dollars**	Average amount spent by a food-	Feeding America	3.00	0.41	2.26	4.20

Table 3.1 (Continued).

		secure household on a single meal by year and county					
Income Per Capita	**Dollars**	Income per capita estimates by year and county	U.S. Census Bureau's American Community Survey (ACS)	38,408.19	8,252.62	24,808.00	77,233.00
WIC Participation	**Count of WIC Participants**	Number of participants in the Federal WIC Program by county and year	CA Department of Health and Human Safety	16,582.93	18,016.70	391	61,785

Data Transformations:

To spatially downscale the agricultural employment data to the county level, the original region-level data is weighted based on the total productive acreage in each county and year. This weight is calculated using a simple pivot table in Excel, which calculates total productive acreage in each county and year, using the PUR data, and divides this sum by the grand total across all counties in the Central Valley. The respective proportion of acreage in agricultural production for each county serves as its weight term, which is then multiplied by the number of agricultural jobs estimated for each region. The resulting variable provides monthly agricultural job estimates at the county-level.

At this stage, each county contains many records for a given month and year. To declare the dataset as panel data, each record must have a unique combination of county, month, year, and crop category values. In other words, no duplicates are allowed. To achieve this, the original data containing observations for each land plot and crop type must be aggregated to the crop category level. Three distinct crop categories are defined: high-value annual, low-value annual, and perennial. These distinctions are important given the relationship between crop type and labor intensity. Multiple studies have identified crop-switching practices as a common coping mechanism employed by farmers seeking to reduce input costs during periods of drought (Hagerty, 2021; Mall& Herman, 2019; Alexander & Esteli, 2021; Sumner et al., 2021). These changes, however, tend to reduce the number of jobs and/or hours available to local farm laborers, and therefore directly affect agricultural employment. Quantitative analyses assessing crop-switching tactics in response to drought in California validate these anecdotal data (Wirth et al., 2007; Greene et al., 2018; Medellin-Azuara et al., 2022; Medellin-Azuara et al., 2015).

Visual assessment of the agricultural employment data utilized for this study, shown in Figure 3.2, clearly reflects these job loss trends.

The literature identifies higher market value of perennial crops as a primary driver of crop switching decisions. As such, this paper considers the relative costs of land fallowing and replacement, in addition to biological properties of each crop when generating categories, consistent with (Mall & Herman et al., 2019). Category values are assigned to each unique crop type using the numeric crop code, provided by the PUR data. Once all observations are categorized, Stata's collapse command is used to aggregate the observations by category, county, month, and year. This aggregation process trims the data from over 10,000 observations to only 800, but allows the dataset to be defined as panel data and facilitates the use of a fixed effects regression framework.

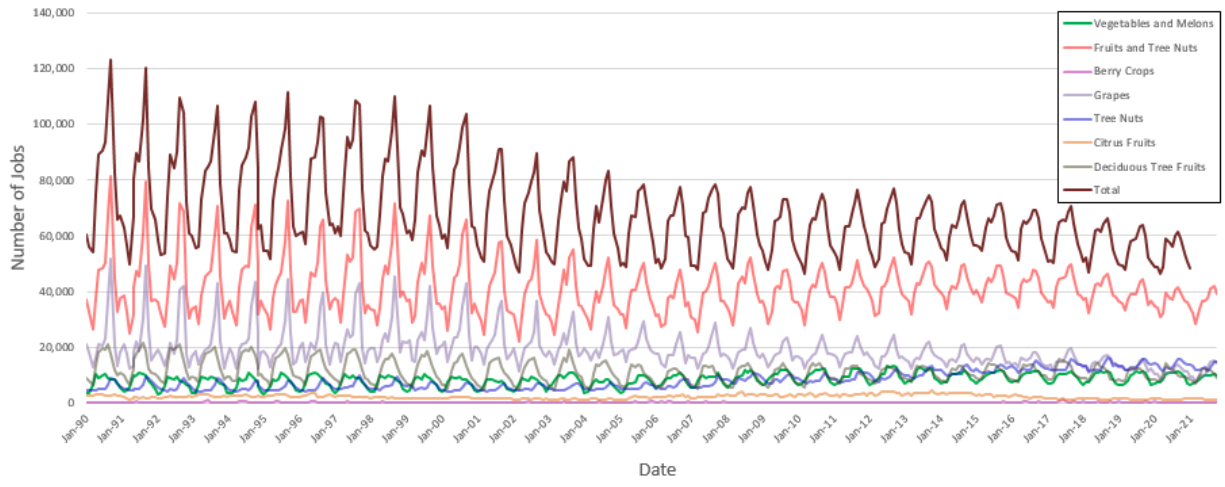


Figure 3.2 Agricultural Employment by Crop Type – San Joaquin Valley, visual representation of trends in agricultural employment in the San Joaquin Valley by crop type, from January 1990-January 2021.

Since the agricultural employment data are only available at the regional level, this paper initially includes all 32 counties contained within or intersecting the Central Valley. Given that agricultural production is concentrated among a few key counties, many counties record zero, or

close to zero, agricultural jobs across all months and years once the weight term is assigned to the region-level employment estimate. Because this analysis hinges on the relationship between agricultural employment and food insecurity, these counties are dropped to avoid downward bias in the estimates. Ultimately, the analysis considers 17 counties that consistently employ farmworkers for at least one crop category, reducing total observations from 800 to 460.

Methods

This study runs a series of fixed effects regressions, using a two stage least squares approach, to determine whether a statistical relationship exists between food insecurity and employment in the agriculture sector, controlling for food price, household income, and WIC participation.

The two-stage least squares framework is employed due to the potential bidirectional (endogenous) relationship between food insecurity and agricultural employment. Essentially, food insecurity can influence agricultural employment, just as agricultural employment affects food insecurity among the population of interest. The food insecurity model employed in this analysis solely considers the effects of agricultural job loss on food insecurity. However, as explained by the conceptual model (see Figure 3.1), negative health outcomes common among food-insecure individuals could inhibit future employment and set off more intense food insecurity experiences, as evidenced during the COVID-19 Pandemic (Liu & Eicher-Miller, 2021; Tester et al., 2020; Rodriguez et al., 2021; Wolfson & Leung, 2020).

Instrumenting agricultural employment using variables that are not directly correlated to food insecurity facilitates accurate estimation of the relationship between agricultural employment and food insecurity, despite this potential correlation among error terms. The first-stage regression defines agricultural employment as a function of productive acres, season, year,

crop category, precipitation, and temperature. While these climatic and temporal variables can drive food insecurity outcomes within developing countries, where agricultural supply is directly related to consumption, these variables do not have the same influence over food insecurity outcomes in the U.S. context.

As discussed throughout the literature review, food insecurity effects in the developed world, particularly within net-exporting countries such as the U.S., derive from causal factors that differ from those impacting developing nations. Food insecurity in developed countries often arises from demand-side distributional patterns that constrain individual purchasing power. The most commonly-cited determinants of food insecurity in the U.S. are socioeconomic and employment status, race and ethnicity (Burke et al., 2018; Nam et al., 2015; Coleman-Jensen et al., 2022; Tester et al., 2020; Bowen et al., 2021), and citizenship status (Phojanakong et al., 2019; Chilton & Rose, 2009; Potochnick et al., 2017; Kalil & Chen, 2008). Closely related to these individual sociodemographic characteristics are features of the built environment, such as proximity to food retailers (Gosliner et al., 2019; Morris et al., 1992; Long et al., 2020; Walker et al., 2010) and transportation options (Morris et al., 1992; Carney et al., 2012; Flores-Landeros et al., 2021; Gosliner et al., 2019), which contribute to heightened experiences of food insecurity. Supply-side issues, on the other hand, rarely translate into heightened food insecurity in the U.S. and other developed nations that benefit most from the globalized food system (Long et al., 2020; Morris et al., 1992). Supply-side constraints do, however, engender food insecurity within net-importing, developing, countries due to the inequities baked into the globalized food system (James, 2015; Zhu, 2016; Workie et al., 2020; Alibi & Ngwenyama, 2022; Laborde et al., 2020; Hassen & Bilali, 2022; Savary et al., 2020). Thus, while the parameters chosen to instrument agricultural employment in the first-stage regression may be highly correlated with food

insecurity outcomes for developing countries, the literature supports their use in the U.S. context.

The first-stage regression, equation (1), defines agricultural employment as a function of productive cropland acreage, season, year, precipitation, and temperature, along with two interaction terms measuring the effect of growing season and crop category in each year.

$$employment_{\mathrm{nt}} = \lambda + \gamma_1 * acres_{n,t-1} + \gamma_2 * growing\ season_{n,t-1} + \gamma_3 * year_{n,t-1} + \gamma_4 * (year * growing\ season)_{n,t-1} + \gamma_5 * (year * category)_{n,t-1} + \gamma_6 * precipitation_{n,t-1} + \gamma_7 temperature_{n,t-1} + \gamma_8 (precipitation)^2{}_{n,t-1} + \gamma_9 (temperature)^2{}_{n,t-1} + \eta_{n,t-1} \quad (1)$$

The second-stage regression then defines food insecurity as a function of the instrumented agricultural employment term, along with meal cost, income per capita, and WIC participation.

$$FI_{\mathrm{nt}} = \alpha + \beta_1 * \widehat{employment}_{\mathrm{n,t-1}} + \beta_2 * meal\ cost_{\mathrm{n,t-1}} + \beta_3 * income_{\mathrm{n,t-1}} + \beta_4 * WIC_{\mathrm{n,t-1}} + \varepsilon_{\mathrm{n,t-1}} \quad (2)$$

where α and λ represent the intercept values, $\varepsilon_{n,t}$ and $\eta_{n,t}$ are error terms for each county and year, and β_n and γ_n are the respective parameter estimates for each year.

These regressions are run using Stata. Once all of the data were loaded, the variables for productive acres and agricultural employment estimates were aggregated by crop type, month, year, and county name using the collapse command. The group command in Stata was then used to create a unique identifier variable for each combination of crop category and county FIPS code. Defining this unique identification variable using the county FIPS code enables the model to incorporate county-level fixed effects, which controls for unobservable differences between counties. Specifically, this study is concerned with differences in population and industry size following periods of prolonged drought and job loss. Controlling for county-level population ensures that the regressions do not detect changes in sociodemographic trends unrelated to food insecurity. Manalo-LeClair (2014) and Rodriguez et al. (2015) have noted significant fluctuations in the populations of farmworker communities following periods of sustained drought and subsequent job loss, as families are forced to move in search of work. Controlling

for county-level population ensures that the regressions do not mistake emigration for food insecurity trends. This identifier variable is used, along with the time variable, representing each month and year, to declare the panel data.

The regressions also employ robust standard error terms to account for the heteroskedasticity concerns addressed above. Robust standard error terms incorporate non-constant variance into the standard error calculation, producing confidence intervals and p-values that reflect the model's heteroskedasticity. Traditional OLS standard error estimators assume homoskedasticity and as such, may inaccurately represent parameter significance, and are therefore unreliable. Robust standard errors not only facilitate reliable significance tests, but tend to err on the conservative side, generating larger values relative to other calculation methods. As such, the significance of our parameter estimates is reliable and strong.

Model Specification

The two-stage least squares framework relies on three key assumptions: (1) normality of the dependent variable, (2) homoskedastic data, and (3) linear relationships between independent and dependent variables. Upon visual inspection, it is clear not all of these assumptions hold. First, the distribution of the dependent variable, food insecurity, is consistently left-skewed, having a significant concentration of low values with a few high outliers. More importantly, both the WIC and agricultural employment variables violate the homoskedasticity and linearity assumptions. This analysis uses log-transformed values for the food insecurity, agricultural employment, and WIC participation variables, a common method employed to correct non-normal and heteroskedastic data (Gelman & Hill, 2007).

As discussed earlier, wide variations across county populations yield substantial differences between the raw data for agricultural jobs, WIC participation, and food insecure

individuals. Additionally, it can be assumed that the relationship between food insecurity and both WIC participation and agricultural employment is multiplicative given the study area and population of interest. This analysis estimates food insecurity impacts among a highly vulnerable population. By design, any marginal changes to the socioeconomic wellbeing of this population, approximated by the dependent variables, will yield significant changes in their food security status. It has been shown, for instance, that even small changes in purchasing power, impacted by each of the independent variables, will increase food insecurity among marginalized groups (Gregory & Coleman-Jensen, 2013; Morris et al., 1992; Nam et al., 2015; Rodriguez et al., 2015; Wolfson & Leung, 2020; Wasleman et al., 2017; Poblacion et al., 2017; Gundersen & Ziliak, 2018). This, coupled with the seasonality inherent to both agricultural employment and WIC participation, introduces heteroskedasticity concerns. Considering the homoskedasticity assumption helps improve the accuracy of estimated coefficient values, this data must be log-transformed to generate reliable and accurate parameter estimates. Taking the natural log of these variables transforms their relationships from multiplicative to additive, which reduces heteroskedasticity by stabilizing variance from proportional- to constant-variance (Gelman & Hill, 2007).

While this study considers results from various log-transformed regressions as robustness checks, the results section draws on estimates from the log-log model. This specification not only accounts for normality and heteroskedasticity concerns among the dependent and independent variables, but provides an intuitive interpretation for parameter estimates. The values generated using the log-log approach communicate the elasticity of the dependent variable with respect to the independent variables. Thus, the second-stage regression results estimate the percentage

change in food insecurity given a one percent change in agricultural employment within the Central Valley.

Water Restriction Scenarios

This analysis draws on land fallow estimates generated by Hanak et al. (2019), which projects the total acreage of irrigated agricultural land that must be temporarily or permanently retired to attain sustainable withdrawal rates by 2040, pursuant to SGMA. Hanak et al. (2019) focus on the San Joaquin Valley, so we also look to Medellin-Azuara et al. (2022) for recent estimates of irrigated cropland retirement across the entire Central Valley, along with region-specific breakdowns, following the most recent 2021 drought.

Hanak et al. (2019) project land retirement under three scenarios: local water trade, valley-wide surface water trade, and the "optimal" supply and demand portfolio. The local water trade scenario serves as the closest to a business-as usual, or baseline scenario, while the valley-wide scenario assumes expansion of current water trading infrastructure and relaxation of existing water policies, neither of which have been expressly outlined by any GSA or legislative body to date. This thesis relies on two of the three scenarios, the local and valley-wide trade scenarios, as the assumptions underlying the optimal scenario are beyond the scope of this study. It is worth noting that even the local water trade scenario assumes more efficient and frequent utilization of existing water trade schemes, while the other two scenarios presume significant changes to current infrastructure, policy, and GSA cooperation, which even Hanak et al. (2019) acknowledge as optimistic. For this reason, along with some of the more recent climate phenomena impacting the state, from extended wildfire seasons to unprecedented levels of rainfall and inundation, this paper estimates two additional scenarios, more pessimistic relative to the Hanak et al. (2019) estimates. These scenarios represent 150% and 200% growth of fallowed

lands relative to the local trading scenario.

Given that Hanak et al. (2019) project land fallow outcomes within the San Joaquin Valley, the estimates represent only a portion of the acreage that will be retired throughout the Central Valley. We draw on results from Medellin-Azuara et al. (2022) to determine the proportion of agricultural land retired within the San Joaquin Valley following the 2021 drought. Medellin-Azuara et al. (2022) estimate the water shortages and subsequent retirement of cropland experienced during the 2021 drought, the driest year in California's history, using hydro-economic analyses along with remote sensing data to assess the magnitude and spatial distribution of water shortages. This study is unique in its employment of remote sensing to detect the spatial distribution of both groundwater shortage and retired agricultural lands, offering a highly accurate and timely analysis of current drought effects. The study finds that the harshest drought impacts have migrated north, relative to historic drought conditions. Whereas the San Joaquin Valley has experienced the harshest physical and economic consequences of drought in the past, these effects were felt more acutely in the Sacramento Valley during the 2021 drought, likely reflecting a combination of climate change effects and shifts in crop production. Medellin-Azuara et al. (2022) estimate that the San Joaquin Valley accounted for only 36% of the Central Valley's fallowed agricultural land. As such, we assume the Hanak et al. (2019) estimates represent just 36% of the total acreage that must be retired throughout the Central Valley to attain sustainable withdrawal rates by 2040.

Hanak et al. (2019) project retirement of between 725,000 and 750,000 acres by 2040 under valley-wide and local water trading schemes, respectively. The "optimal" scenario assumes valley-wide surface water trading, along with storage and conveyance systems developed to increase the efficiency of water imports based on productive capacity and relative

value of the land. In this scenario, land fallow estimates fall to 535,000 acres. Expanding these projections to include the Sacramento Valley, retirement of agricultural land ranges from 1,481,843 acres under the optimal scenario assumptions to 2,077,338 acres under valley-wide trading. To account for potentially worsening drought conditions, this paper includes estimates for 150% and 200% of the local water trade scenario, which would yield 3,116,007 and 4,154,676 acres retired, respectively. These estimates are multiplied by the coefficient value for the acre parameter, found in this paper's first-stage regression analysis, to project the rate of annual job loss. We then multiply the annual job loss estimates by the coefficient value for agricultural employment found in the second-stage regression to assess food insecurity outcomes. We use the rate of annual job loss, rather than the total jobs lost over the 20-year period, since the preferred specification is a log-log transformed model. As such, the percentage change in food insecurity is informed by the rate of agricultural job loss, not the total number of jobs lost over the 20-year period, and thus likely represents a lower-bound impact.

Relying on the coefficient values generated using the log-log specification, outlined in equations (1) and (2), this study finds that food insecurity could increase from 3.3% to 9.3% by 2040. This wide range of potential food insecurity outcomes reflects the uncertainty driven by climate change induced natural phenomena, SGMA implementation strategies, and innovations and investments in water trading capacity. Considering the data limitations faced by this study's model, which likely result in undercounting of households in DUCs and undocumented people, those most vulnerable to food insecurity outcomes, these estimates represent a lower bound for food insecurity rate increases.

CHAPTER 4: RESULTS AND DISCUSSION

Main Estimation Results

First-Stage Regression

Table 4.1 presents results from the first-stage regression, which establishes a relationship between the acres of productive cropland and agricultural employment for a given year and county, controlling for climatic and temporal variations. The results find a statistically significant and positive relationship between the total acres of productive cropland and agricultural employment. This finding, while supported by the literature, is important to substantiate given the discussion surrounding crop-switching practices, particularly perennial crop expansion and efficiency gains in crop production, which has coincided with a reduction in total agriculture sector jobs in the region (Wirth et al., 2007; Greene et al., 2018; Hagerty, 2021; Mall & Herman, 2019; Alexander & Esteli, 2021; Sumner et al., 2021).

This regression model is also used to instrument the agricultural employment term in the second-stage IV regression. This instrumenting process addresses the potential endogeneity issue introduced by correlation between the error terms for agricultural employment and food insecurity. The explanatory variables included in this first-stage regression reflect the unobservable factors that may drive endogeneity between food insecurity and agricultural employment in the U.S. context. These variables, while uncorrelated with food insecurity in the U.S. context, directly influence agricultural employment in the Central Valley. Instrumenting the agricultural employment term using these variables allows the second-stage regression to reliably estimate the relationship between agricultural employment and food insecurity.

Table 4.1 Agricultural Employment Effects, presents results from the first-stage regression, instrumenting the agricultural employment variable and controlling for seasonality and climatic variables. *t* statistics in parentheses, $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

	Standard Model
Production Acres	5.45e-09*** (3.11)
Year	0.012 (0.17)
Growing Season	0.606* (1.83)
Precipitation	-0.149*** (-3.69)
Temperature	0.672 (1.46)
Precipitation Squared	0.001*** (2.91)
Temperature Squared	0.001 (0.13)
Constant	-59.72 (-0.44)
N	446

The coefficient value for the productive acres variable estimates a linear relationship between the number of acres in production and available agricultural jobs. For each acre of agricultural land removed from production, agricultural employment declines by $5.45*10^{-7}$%. When considering the scale at which agricultural land must be taken out of production to attain sustainable withdrawal rates in the Central Valley, this coefficient value yields high job loss estimates.

The coefficient values for each of the other six explanatory variables have similar interpretations; a unit increase in the variable of interest yields an increase or decrease in

agricultural jobs equivalent to the parameter estimate. For example, agricultural hobs increase during the growing season, consistent with seasonal labor demands. The linear precipitation term has a negative and significant correlation with agricultural jobs, but a positive quadratic effect, indicating additional labor demands as precipitation (and presumably productivity) increases above a certain threshold. Aside from the precipitation and production area effects, no other coefficient values are statistically significant in the first-stage regression.

This analysis considers quadratic temperature and precipitation terms in an effort to account for non-linearity in the relationship between these variables and agricultural productivity (and hence employment). Higher temperatures benefit agricultural employment up to a point, after which crop production suffers and job loss ensues. As such, this analysis refers to the coefficient values generated for the squared climate terms. The squared precipitation term suggests that water availability plays a deterministic role in agricultural employment, whereby increased precipitation yields higher agricultural employment.

Second-Stage IV Regression

The second-stage regression presents the primary model of interest in this analysis and establishes a relationship between the food insecurity metric and agricultural employment. Table 4.2 presents coefficient estimates for the impact of agricultural employment changes on county-level food insecurity in the Central Valley. Each column represents an alternative specification of the same empirical model with county-level fixed effects. Models (1) and (2) use the instrumented agricultural employment parameter while (3) and (4) employ an instrumented farm labor variable. Models (2) and (4) take the natural logarithm of the positive count variables in the model: agricultural or farm employment, WIC participation, and the response variable, food insecurity. These log-log specifications account for the data's heteroskedasticity, non-normality,

and multiplicity issues, discussed in greater detail in the Data & Methods section. Additionally, the coefficient values generated using this specification communicate the percentage change in the food insecurity rate, rather than the increase in food-insecure individuals, which facilitates the water restriction simulation exercise. As such, model (2) is this paper's preferred specification.

The results of the second stage IV regression reveal a negative and statistically significant relationship between county-level agricultural employment and food insecurity, indicating that as agricultural employment declines, county-level food insecurity rises. This finding has implications for policies, such as SGMA, which will affect productivity in the agriculture sector. Additionally, the WIC participation and meal cost parameters are statistically significant at the 95% confidence level, while income per capita is also significant, but at the 90% level. According to model (2), for every percent increase in agricultural job creation, food insecurity decreases by about 0.01%. For every percent increase in WIC participation, food insecurity increases by .19%, while a percent increase in meal cost yields a 0.31% decrease in food insecurity.

These results broadly affirm the findings from preeminent U.S. food insecurity research, particularly studies interested in Hispanic/Latinx, immigrant, and farmworker communities (Wirth et al., 2007; Greene et al., 2018; Minkoff-Zern, 2014). The agricultural employment parameter establishes the second statistical relationship required for the analysis of food insecurity outcomes under various water restriction scenarios, covered in the next section.

Table 4.2 Food Insecurity Effects, presents results from the second-stage IV regression, where food insecurity is the dependent variable. *t* statistics in parentheses, $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

	(1) Standard Ag	(2) Log-Log Ag	(3) Standard Farm	(4) Log-Log Farm
Total Ag	0.00687 (0.25)			
Meal Cost	10824.0 ** (2.15)	-0.306*** (-13.12)	12086.0** (2.50)	-0.301*** (-10.65)
Income	-1.905*** (-3.74)	-0.00000525* (-1.69)	-1.918*** (-4.00)	-0.00000591* (-1.78)
WIC Participation	1.718*** (3.38)		1.721*** (3.98)	
Log Ag		-0.0106*** (-2.63)		
Log WIC		0.188*** (2.78)		0.171** (2.51)
Total Farm			-0.499*** (-3.13)	
Log Farm				-0.0576 (-1.62)
Constant	73844.6*** (4.13)	9.900*** (14.02)	77768.0*** (4.84)	10.46*** (14.00)
N	387	379	387	387

While the parameter estimates for the meal cost and WIC variables are relatively high in magnitude and statistically significant, the sign is counter-intuitive across model specifications. In the case of meal cost, the coefficient value implies that lower costs result in higher food insecurity rates. While the literature consistently finds that increased purchasing power reduces food insecurity, this confounding result is not uncommon among studies focused on low-income and minority populations. A few explanations have been offered for this finding. Socioeconomic and racial/ethnic status are well-established determinants of the types of food retailers located

within a community (Gosliner et al., 2019; Walker et al., 2010; Long et al., 2020). Therefore, a spatially explicit food cost variable may not reflect greater affordability, but inadequate access to food retailers offering fresh and affordable produce (Greenwald & Zajifen, 2017; Matias et al., 2020). Beyond questions of quality, the relatively low cost of food options in low-income communities is unlikely to offset the financial constraints driving food insecurity (Gundersen & Coleman-Jensen, 2013). When considering rural communities in particular, lacking transportation options and longer distances between food retailers on average compound issues of inadequate access and optionality (Kaiser et al., 2007; Minkoff-Zern, 2014; Matias et al., 2020).

Similarly, the coefficient value for WIC participation implies greater participation rates drive higher food insecurity when the opposite should be true. Again, this finding is common among literature interested in federal food assistance programs, and is often attributed to endogeneity issues. Gregory & Coleman-Jensen (2013) explain that a household's decision to enroll in a federal nutrition assistance program may be driven by unobservables correlated with food insecurity. Sampling bias may also play a role in these paradoxical findings; since these assistance programs are voluntary, severely disadvantaged households likely enroll at disproportionately high rates (Jensen et al., 2019; Rodriguez et al., 2015; Gregory & Coleman-Jensen, 2013).

Some argue that program benefits are structurally flawed, as they rarely suffice to alleviate food insecurity among participating households. A primary critique of federal food assistance programs, such as SNAP, is that benefit determinations do not vary across geography. As a result, benefits do not capture any differences in cost of living, travel time, median household income, or demographic characteristics across the U.S. This calculation method may

result in higher rates of non-participation among eligible households in high-cost areas of the country (Gundersen & Ziliak, 2018; Gregory & Coleman-Jensen, 2013). Essentially, households in more expensive areas may perceive the real benefits as too low to justify the time and effort required to apply for a program, resulting in a paradoxical relationship between participation in federal nutrition programs and food insecurity (Gundersen & Ziliak, 2018).

Other studies find that foundational datasets underestimate participation among the broader U.S. population. Specifically, underreporting of food aid receipts in recent Current Population Survey (CPS) data has been cited as a potential driver of these paradoxical treatment effects (Meyer et al., 2015). This finding is particularly relevant to this analysis, given the reliance on the Map the Meal Gap study, which employs CPS data to inform county-level food insecurity estimates.

In the context of the Central Valley, inadequate access to affordable food retailers and lacking transportation options could reasonably explain the paradoxical treatment effects found for the meal cost parameter (Gosliner et al., 2019; Carney et al., 2012; Flores-Landeros et al., 2021). Considering the WIC coefficient value, substantial underutilization has been observed among Hispanic/Latinx populations (Winham & Florian, 2015; Walsemann et al., 2017), particularly for immigrant households, regardless of documentation status (Minkoff-Zern, 2014; Pelto et al., 2020). As such, these confounding parameter values likely reflect selection bias, as only the most food-insecure households enroll in federal food assistance programs (Rodriguez et al., 2015).

Discussion

Water Restriction Scenarios

In an effort to contextualize the first- and second-stage regression findings, and in keeping with the framing of Hanak et al. (2019), this paper assesses potential food insecurity outcomes under various water restriction scenarios pursuant to the regulatory goals outlined by SGMA. This application of the results from the two-stage least squares regressions provides tangible estimates of food insecurity outcomes, which anchor the findings in practical outcomes and a relevant discussion surrounding distributional inequities stemming from well-intentioned, even progressive, policies.

Table 4.3 displays the projected land retirement, agricultural employment, and food insecurity outcomes under four potential water restriction scenarios, pursuant to the goals of SGMA, to end unsustainable groundwater withdrawals by 2040. This analysis finds increased county-level food insecurity rates ranging from 4.48% to 9.27%, driven by the loss of an estimated 143,719 to 297,350 agricultural jobs over the 20-year period.

Two of the scenarios are adapted from Hanak et al. (2019), which estimates the long-term land retirement implications from attaining sustainable withdrawal rates by 2040, as outlined by SGMA. This analysis includes two additional scenarios, which diverge from the assumptions underlying demand-side efficiency gains in water usage, along with liberalization of current water trading policies, made by Hanak et al. (2019). The two scenarios introduced in this analysis assume a continuation of current water trading policy norms, along with increased intensity and frequency of extreme climatic phenomena, consistent with observed trends in the region. This second assumption follows from the recent intensification of drought and wildfire, along with unprecedented rainfall and flooding, experienced within the Central Valley (Hatchett

et al., 2023; Safford et al., 2022; Huang & Swain, 2022; Zamora-Reyes et al., 2022). These two scenarios use the Hanak et al. (2019) local water trade scenario as a baseline, estimating 150% and 200% increases in land retirement by 2040.

Table 4.3 Food Insecurity Outcomes by 2040, presents estimated impacts of various water restriction and land retirement scenarios, annual and total employment losses, and percent change in county-level food insecurity within the Central Valley by 2040. *t* statistics in parentheses, $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Scenario	Acres Fallowed	Annual Employment Loss	Total Employment Loss	% Change County-Level Food Insecurity
Local Trade (BAU)	-2,008,094	-7,186	-143,719	4.48
Valley-Wide Trade	-2,077,338	-7,434	-148,675	4.64
150% BAU	-3,116,007	-11,151	-223,013	6.96
200% BAU	-4,154,676	-14,868	-297,350	9.27

This simulation exercise provides a range of feasible job loss and food insecurity estimates pursuant to SGMA. The estimated job loss numbers are supported by those projected in Hanak et al. (2019), as well as those observed by Medellin-Azuara et al. (2022) in their assessment of the 2021 drought. This agreement in job loss estimates across these two hydro-economic studies bolsters confidence in the accuracy of this paper's regression results, estimating the relationship between acres of agricultural land, agricultural employment, and food insecurity. Despite the methodological differences between these hydro-economic studies and this empirical analysis, we converge on similar job loss estimates, which speaks to the robustness of the findings across differing assumptions and methodological approaches.

Policy Implications

The simulation results indicate that food insecurity is highly sensitive to changes in agricultural land use and employment. It follows, then, that policy with the potential to impact the agriculture sector's productive capacity may have downstream effects on food insecurity. While the risks to California's agriculture sector have been quantified in various studies assessing water restriction scenarios and consequences for land fallowing, revenue, and job loss (Hanak et al., 2019; Medellin-Azuara et al., 2022; Howitt et al., 2014; Medellin-Azuara et al., 2015; Fernandez-Bou et al., 2022), the extra step of quantifying subsequent food insecurity impacts has not yet been taken. Establishing this relationship between agricultural land loss and food insecurity highlights the vast sphere of influence that policies impacting agricultural productivity, such as SGMA, might have. Beyond the economic implications accompanying land retirement and reduced agricultural productivity, significant impacts at the individual- and household-scales must also be considered when developing implementation strategies.

Under the business-as-usual (BAU) scenario, future restrictions of agricultural water allocations pursuant to SGMA could result in a loss of 143,719 jobs, which would translate to an increase in food insecurity of approximately 4.48% by 2040. Assuming that water trading policies remain unchanged and accounting for changes to environmental conditions that exacerbate existing constraints on agricultural production, food insecurity could rise between 6.96% and 9.27%. These effects are substantial, particularly when considering the heightened vulnerability among this study's population of interest.

Farmworkers in the Central Valley, particularly undocumented DUC residents, lack access to welfare programs and job mobility, leaving them uniquely vulnerable to food insecurity outcomes (Flores-Landeros et al., 2021; Wadsworth et al., 2016; Alkon et al., 2011; Manalo-

LeClair, 2014; Safe Water Alliance, 2014). When these individuals experience job and income loss, they do not have the range of coping strategies that other Americans do. Often, these individuals are forced to emigrate in search of other agricultural employment opportunities, or return to their home countries (Manalo-LeClair, 2014; Rodriguez et al., 2015). Food insecurity impacts within these communities are not experienced as marginal sacrifices. Qualitative studies of food-insecure households in the region uncover extreme coping strategies, limiting both quality and quantity of food consumed within already constrained households (Minkoff-Zern, 2014; Rodriguez et al., 2015; Winham & Florian, 2015). Meanwhile, assessments of the federal and private food aid programs identify failures to infiltrate these same communities, highlighting the lacking resilience in local food systems (Minkoff-Zern, 2014; Kaiser et al., 2007; Kaiser, 2008). These outreach gaps, coupled with barriers to access driven by citizenship requirements, stigma and rumors (Minkoff-Zern, 2014; Pelto et al., 2020; Winham & Florian, 2015; Kaiser, 2008; Rodriguez et al., 2015; Gundersen & Ziliak, 2018), along with inadequate access to transportation, and food retailers (Gosliner et al., 2019; Carnet et al., 2012; Flores-Landeros et al., 2021) compound to situate the Central Valley's farmworker communities in a uniquely precarious situation, with little recourse in the event of underemployment or job loss.

This paper does not argue that the costs associated with heightened food insecurity outweigh the benefits of attaining sustainable water use in the Central Valley. From biodiversity conservation (Beckman et al., 2020) to water equity (Safe Water Alliance, 2014; Fernandez-Bou et al., 2022; Pauloo et al., 2020), the benefits of ending groundwater overdraft have been well documented. Regardless of policy, continued overuse of water resources cannot sustain agricultural production; if groundwater recharge is not prioritized, the source will eventually run dry as the persistent intensification of climate change effects exacerbates existing surface water

shortages (Medellin-Azuara et al., 2014; Hanak et al., 2019; Hagerty, 2021; Mall & Herman, 2019). This paper does argue that the effects on food insecurity are non-trivial and should be considered when developing and implementing policies that impact agricultural productivity. Particularly in a state like California, whose legislature takes pride in pioneering progressive policies, steps must be taken to incorporate the experiences of highly marginalized groups and ensure that these communities are not disproportionately impacted by any negative externalities that arise from implementation.

While the food insecurity estimates produced in this study do not fully account for the severe outcomes that farmworkers in the Central Valley are likely to face in the coming decades, this analysis takes a step toward filling a substantial gap in coverage. The economic importance of the region's agricultural production is reflected by the existing research, however, little attention is paid to household-level welfare. SGMA-oriented policy analyses have fallen short in addressing the full scope of potential policy outcomes. This shortcoming likely derives from the failure of the bill itself to address such issues. When considering the breadth of potential outcomes from a policy like SGMA, household-level wellbeing must be considered both by policymakers and by the research community, particularly when the affected population is already vulnerable and lacks access to traditional social safety net programs.

SGMA does not require special considerations for DACs or DUCs, which will be disproportionately impacted by the policies enacted by GSAs. While SGMA requires GSAs to "consider the interests of all beneficial uses and users of groundwater", analyses of proposed GSPs find that DACs and DUCs are severely underrepresented, both as members on GSA boards and in the intervention strategies proposed by GSPs. Only 55% of small DACs were accounted for in the interested parties list submitted by GSAs, despite their high reliance on groundwater

and relative prevalence within GSA boundaries (Dobbin, 2018). DUCs face even higher rates of exclusion, with only 10% of DUCs included as members of the GSAs they reside within (Dobbin, 2018). This underrepresentation could be attributed to a number of factors, but the invisibility of DACs and DUCs within foundational datasets cannot be overlooked as a driver of their exclusion. To hold GSAs accountable for incorporating these communities into their GSPs, they must be visible to policymakers, meaning they must be represented by the data. The coverage gaps within foundational datasets, along with the vague language employed in SGMA, facilitate these exclusionary outcomes, offering GSAs an excuse of ignorance, whether genuine or not.

Without improved representation in input datasets and policies that integrate special consideration for historically marginalized and vulnerable groups, policy outcomes will continue to evade communities most in need of intervention and food and water insecurity will persist, recognized or not. Even studies, such as this one, aimed at accurately representing a single marginalized population, will continue producing negatively biased estimates as long as input data systematically undercounts these communities.

The limitations faced by this study reinforce a primary theme discussed throughout the literature review, that inadequate and inequitable representation in commonly used datasets facilitates policy outcomes that disproportionately impact historically marginalized and vulnerable communities. Despite the efforts undertaken in this analysis to isolate food insecurity effects among farmworker communities, input data limitations produced estimates that mask the severity of outcomes. As such, this paper suggests that steps be taken toward remediating chronic underrepresentation of DUCs and undocumented farmworkers in foundational datasets to facilitate more accurate analyses moving forward. Without adequate input data, even well

intentioned policies may engender negative outcomes and perpetuate existing inequities among those most vulnerable.

While the decentralized implementation framework of SGMA allows for local knowledge to guide GSP development, the findings from Dobbin (2018) reveal systematic underrepresentation of DACs and DUCs located within GSA boundaries. While many GSPs have been rejected as incomplete or inadequate, the reasons provided tend to address inaccurate water budget calculations or insufficient mitigation strategies. According to the SGMA portal, none have been denied for failure to "consider the interests of all beneficial uses and users of groundwater". Given the high incidence of DAC and DUC exclusion, along with these communities' heightened vulnerability to food and water insecurity, this paper suggests that an accountability framework be drafted to ensure GSPs and GSAs are truly inclusive of all stakeholders.

Robustness Checks

This study considers results from alternative model specifications as robustness checks. The paper re-estimates the second-stage regression using the childhood food insecurity rate and total farm (rather than total agricultural) employment estimates for both standard and log-transformed models.

Childhood food insecurity is considered as an alternative response variable, since these estimates trend higher than adult and overall food insecurity rates in the U.S., on average (Gundersen & Ziliak, 2018; Coleman-Jensen et al., 2022; Wolfson & Leung, 2020). This variable also comes from the Map the Meal Gap data, using the same data collection and aggregation methods as the overall food insecurity estimates.

Table 4.4 presents the parameter estimates found using childhood food insecurity as the dependent variable. These estimates maintain the same statistical significance across each variable compared to the specifications that assess overall food insecurity. While the magnitude of estimates also remains relatively stable across the employment, meal cost, and income parameters, the effect of WIC participation is substantially higher when childhood food insecurity is the dependent variable. Considering WIC benefits last only until the youngest child's fifth birthday, it makes sense that childhood food insecurity would be more heavily influenced by program participation.

In addition to agricultural employment, this study considers the relationship between total farm labor and food insecurity. The results from these specifications are presented by models (3) and (4) in Tables 5 and 7. These estimates are available through the California Economic Development Department, the same source as the agricultural employment estimates. Total farm employment estimates, however, are available at the county-level, rather than the region-level. The two employment estimates are distinct in terms of the jobs represented, with farm labor estimates encompassing livestock and dairy, pasture and rangeland, aquaculture, and management, whereas agriculture refers to workers employed directly by crop production. Thus, while the total farm data do not require the manual weighting that the agricultural jobs do, they may include professions that fall beyond the scope of this paper.

The parameter estimates differ based on model specification, with the standard models producing statistically insignificant parameter estimates for agricultural employment, but statistically significant values for farm employment. This is reversed for the log-log transformed model; agricultural employment is a statistically significant predictor of general and childhood food insecurity, while farm labor is not.

Table 4.4 Childhood Food Insecurity Effects, presents results from second-stage IV regression, where childhood food insecurity is the dependent variable. *t* statistics in parentheses, $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

	(1) Standard Ag	(2) Log-Log Ag	(3) Standard Farm	(4) Log-Log Farm
Total Ag	-0.00432 (-0.56)			
Meal Cost	1866.7* (1.74)	-0.0985*** (-2.17)	2449.6** (2.33)	-0.109*** (-2.25)
Income	-0.450*** (-3.64)	-0.00000124* (-3.52)	-0.452*** (-4.14)	-0.0000127* (-3.32)
WIC Participation	1.378*** (11.27)		1.379*** (13.49)	
Log Ag		-0.00789*** (-3.12)		
Log WIC		0.521*** (9.89)		0.496** (8.97)
Total Farm			-0.262*** (-3.92)	
Log Farm				-0.0423 (-1.38)
Constant	15473.0*** (3.13)	5.646*** (10.23)	17471.3*** (4.34)	6.211*** (10.91)
N	387	379	387	387

Limitations

This study faces several input data limitations, which inhibit the spatial and sociodemographic specificity of the results. First, this study's scale of analysis is constrained by three key datasets, whose measurements are available only at the county or region scales. As discussed throughout the literature review, estimating food insecurity effects at the county-level can often obscure the experiences of historically marginalized populations, particularly in a

region as socioeconomically diverse as the Central Valley (CCSCE, 2019; Alkon et al., 2011; Matias et al., 2020; Wirth et al., 2007). Data on income per capita and WIC participation are only available at the county level, while agricultural employment estimates are measured by region.

The agricultural employment data present another limitation, as these estimates are provided at an even coarser scale. This analysis downscales the region-level data to county-level estimates using a weight term, which is calculated as the proportion of total productive acreage in each county. This transformation of the data assumes a proportional relationship between acres of agricultural land and agricultural employment, which may be flawed given the variations in required maintenance and human labor across crop types (Greene et al., 2018; Wirth et al., 2007).

Beyond issues of spatial scale, this study relies on data from the U.S. Census Bureau, which has been shown to substantially undercount DUCs in the Central Valley (Flegal et al., 2019). This finding is significant and relevant to this study, given the heavy reliance on American Community Survey (ACS) and Current Population Survey (CPS) data. The Map the Meal Gap food insecurity and meal cost data use CPS and ACS data to measure county-level population and income, and the income per capita variable employed in this analysis is also sourced from ACS data. While the ACS is a richly detailed and commonly used data source, the sampling process used to select participants relies on the Census Bureau's official inventory of known housing units in the U.S., which Flegal et al. (2019) have shown drastically undercounts units in DUCs. The underrepresentation issues present in these foundational datasets limit this paper's ability to isolate food insecurity outcomes among those most vulnerable.

CHAPTER 5: CONCLUSION

Distributional inequities, both between and within countries, engender distinct manifestations of food and water insecurity. While global and national datasets successfully identify food and water insecurity where effects present homogeneously across a population, these highly-aggregated studies tend to mask the severity of impacts when experienced as pockets of insecurity among a generally secure population, as is the case throughout the U.S. and, specifically, within California's Central Valley. In the Central Valley, these issues of data aggregation and scale are compounded by the prevalence of unincorporated areas and undocumented residents, as both are severely underrepresented by foundational datasets, such as those maintained by the U.S. Census Bureau (Flegal et al., 2019).

Chapter 2, a review of existing food and water insecurity literature, includes studies conducted at the global, national, and local levels. The review identifies tradeoffs between the accuracy and political relevance of results based on a study's scale of analysis and provides context for the policy and system dynamics that engender distributional inequities at each scale. The discussion narrows from global to local perspectives, centering the experiences of historically marginalized populations in the U.S. context, and farmworker communities in California's Central Valley. The Central Valley focused qualitative studies included in this chapter are used to develop the conceptual model that guides the study's analyses.

Chapter 3 transitions the paper from an overview of existing literature, to describe the data and methods used for the study's analyses, and Chapter 4 discusses results and policy implications. These analyses aim to estimate food insecurity impacts specific to farmworker communities in the Central Valley. This sample population was chosen due to their historic underrepresentation in data and policy, already heightened rates of food insecurity, and

likelihood to withstand the worst of future changes to agricultural production and employment loss. The regression analyses estimate statistical relationships between agricultural land use, employment, and food insecurity outcomes; each of these links are established in existing studies, overviewed in Chapter 2. To contextualize the regression findings, this study applies the coefficient estimates to a water restriction simulation exercise, which projects agricultural job loss and food insecurity outcomes pursuant to a range of potential land loss scenarios feasible under future policy and climate conditions.

This paper runs a series of fixed effects regressions and employs a two-stage least squares approach, instrumenting the agricultural employment term to address heteroskedasticity, non-normality, and non-linearity concerns. Results from the regression models find a statistically significant and positive relationship between the area of productive cropland and employment in the agriculture sector, along with a statistically significant and negative relationship between agricultural employment and food insecurity. Applying these estimates to the land fallow estimates provided by Hanak et al. (2019), scaled up to include the Sacramento Valley using data from the most recent 2021 drought captured in Medellin-Azuara et al. (2022), this study estimates an increase in food insecurity anywhere from 3.31% to 9.27%. However, data coverage issues within foundational datasets inhibit result specificity, producing downwardly biased food insecurity estimates.

The goals of this analysis were complicated by limitations to the input data. As discussed throughout the literature review, common data collection and management methods, along with gaps in data coverage among DACs and DUCs, mask effects among the farmworker communities targeted by this analysis. Two key variables, the agricultural employment and acreage parameters, successfully isolate effects on field laborers employed by California's

agriculture sector. However, data on food insecurity, meal cost, income, and WIC participation are representative of the general population and only available at the county level. These four variables underestimate and/or miss effects felt by marginalized groups, and these issues, in turn, limit the specificity of this paper's results.

Despite these data limitations, the analyses in this study still find significant food insecurity impacts under future water restriction scenarios, which will affect tens of thousands of vulnerable households throughout the Central Valley. The study results suggest that policies with the potential to alter agricultural productivity, such as SGMA, will impact household-level food insecurity. SGMA does not recognize these food insecurity outcomes; the bill does not acknowledge the impacts that could arise from the substantial job loss triggered by the retirement of productive agricultural lands. What's more, SGMA does not establish any monitoring framework to measure outcomes among impacted households. This study's regression and simulation analyses reveal the expansive scope of policy outcomes, drawing attention to the household-level impacts, which are largely overlooked by existing quantitative studies and SGMA implementation plans. Quantifying these potential outcomes provides some baseline from which policymakers could begin planning for future outcomes. Ultimately, this study aims to call attention to these household-level impacts and facilitate discussions surrounding inclusivity in data and policy.

The gaps in data coverage among foundational datasets limit the ability of food and water insecurity research to accurately represent the lived experiences of minority populations. This issue is pervasive among national-, state-, and even county-level data, as common data collection and aggregation methods obscure severe food and water insecurity effects among small outlier populations. Future research in these spaces should strive to incorporate bottom-up data

collection processes in order to capture the nuance inherent to these household- and individual-scale issues. As discussed in the literature review, the FIES, HWISE, and IWISE datasets have successfully bridged the gap between policy relevance and accuracy, disseminating individual- and household-level surveys at representative scales using Gallup Inc.'s World Poll. While these datasets face their own shortcomings, innovative approaches to knowledge generation and data collection such as this can help to enhance data quality and inform inclusive and effective policy solutions moving forward.

REFERENCES

"1. Understanding the ACS: The Basics," Accessed November 23, 2022. https://www.census.gov/programs-surveys/acs/library/handbooks/general.html

"60 Million People Turned to Food Banks in 2020 | Feeding America." Accessed January 11, 2023. https://www.feedingamerica.org/about-us/press-room/60-million-turned-to-charitable-food-2020.

"Agricultural Impacts of Sustainable Water Use in the United States - ProQuest." Accessed December 23, 2021. https://www.proquest.com/docview/2570657398?parentSessionId=52TgPHZI9mZVSzwglZyPAcB1EDBkeMnMnQdqHoG%2B3X4%3D&pq-origsite=summon&accountid=12725.

"Agricultural Policy Monitoring and Evaluation 2021: Addressing the Challenges Facing Food Systems by OECD - Issue," June 22, 2021. https://issuu.com/oecd.publishing/docs/agricultural_policy_monitoring_and_evaluation_2021.

"Agricultural Trade - OECD." Accessed January 16, 2023. https://www.oecd.org/agriculture/topics/agricultural-trade/.

Alabi, Michael Omotayo, and Ojelanki Ngwenyama. "Food Security and Disruptions of the Global Food Supply Chains during COVID-19: Building Smarter Food Supply Chains for Post COVID-19 Era." *British Food Journal* 125, no. 1 (January 1, 2022): 167–85. https://doi.org/10.1108/BFJ-03-2021-0333.

Alexander, Shani Harmon, and Lauren Esteli. "Rationing Water, Changing the Landscape California's Sustainable Groundwater Management Act." *Natural Resources & Environment* 35, no. 3 (Winter 2021): 4–8.

Alkon, Alison Hope, Nancy Peluso, Julian Agyeman, Kari Marie Norgaard, Ron ReedSr., Carolina Van Horn, John J. Green, Eleanor M. Green, Anna M. Kleiner, and Laura-Anne Minkoff-Zern. *Cultivating Food Justice: Race, Class, and Sustainability*. Cambridge, UNITED STATES: MIT Press, 2011. http://ebookcentral.proquest.com/lib/ncsu/detail.action?docID=3339335.

Amuedo-Dorantes, Catalina, and Esther Arenas-Arroyo. "Immigrant Fertility in the Midst of Intensified Enforcement." *Centre on Migration, Policy and Society*, January 2017.

"Analyse the Data | Voices of the Hungry | Food and Agriculture Organization of the United Nations." Accessed January 31, 2023. https://www.fao.org/in-action/voices-of-the-hungry/analyse-data/en/.

Baker, J. S., Van Houtven, G., Cai, Y., Moreda, F. (2021). A Hydro-Economic Methodology for the Food-Energy-Water Nexus: Valuation and Optimization of Water Resources. RTI

Press Publication No. MR-00442105. Research Triangle Park, NC: RTI Press. https://doi.org/10.3768/rtipress.2021.mr.0044.2105

Baylis, Kathy, Thomas Heckelei, and Thomas W. Hertel. "Agricultural Trade and Environmental Sustainability." *Annual Review of Resource Economics* 13, no. 1 (2021): 379–401. https://doi.org/10.1146/annurev-resource-101420-090453.

Bethancourt, Hilary, Edward Frongillo, Sara Viviani, Carlo Cafiero, and Sera Young. "Household Water Insecurity Is Positively Associated With Household Food Insecurity in Low- and Middle-Income Countries." *Current Developments in Nutrition* 6, no. Supplement_1 (June 1, 2022): 549. https://doi.org/10.1093/cdn/nzac060.007.

Birchfield, Lauren, and Jessica Corsi. "Between Starvation and Globalization: Realizing the Right to Food in India." *Michigan Journal of International Law* 31, no. 4 (January 1, 2010): 691–764.

Bowen, Sarah, Sinikka Elliott, and Annie Hardison-Moody. "The Structural Roots of Food Insecurity: How Racism Is a Fundamental Cause of Food Insecurity." *Sociology Compass* 15, no. 7 (2021): e12846. https://doi.org/10.1111/soc4.12846.

Brewis, Alexandra, Cassandra Workman, Amber Wutich, Wendy Jepson, Sera Young, and Household Water Insecurity Experiences-Research Coordination Network (HWISE-RCN). "Household Water Insecurity Is Strongly Associated with Food Insecurity: Evidence from 27 Sites in Low- and Middle-Income Countries." *American Journal of Human Biology* 32, no. 1 (2020): e23309. https://doi.org/10.1002/ajhb.23309.

Bryant, Benjamin P., T. Rodd Kelsey, Adrian L. Vogl, Stacie A. Wolny, Duncan MacEwan, Paul C. Selmants, Tanushree Biswas, and H. Scott Butterfield. "Shaping Land Use Change and Ecosystem Restoration in a Water-Stressed Agricultural Landscape to Achieve Multiple Benefits." *Frontiers in Sustainable Food Systems* 4 (2020). https://www.frontiersin.org/articles/10.3389/fsufs.2020.00138.

Burke, Michael P., Sonya J. Jones, Edward A. Frongillo, Maryah S. Fram, Christine E. Blake, and Darcy A. Freedman. "Severity of Household Food Insecurity and Lifetime Racial Discrimination among African-American Households in South Carolina." *Ethnicity & Health* 23, no. 3 (April 2018): 276–92. https://doi.org/10.1080/13557858.2016.1263286.

Cafiero, Carlo, Gheri Filippo, Anne W. Kepple, Jose Moncayo, and Sara Viviani. *Access to Food in 2021: Filling Data Gaps: Results of Twenty National Surveys Using the Food Insecurity Experience Scale (FIES)*. Food & Agriculture Org., 2022.

"California Women, Infants and Children Program Redemption by County - Full Description - California Health and Human Services Open Data Portal." Accessed January 31, 2023. https://data.chhs.ca.gov/dataset/california-women-infants-and-children-program-redemption-by-county/resource/4416f76b-634d-49b1-abae-00cab27c4b06?inner_span%3DTrue.

Carney, Megan. “Compounding Crises of Economic Recession and Food Insecurity: A Comparative Study of Three Low-Income Communities in Santa Barbara County.” *Agriculture and Human Values* 29, no. 2 (June 1, 2012): 185–201. https://doi.org/10.1007/s10460-011-9333-y.

Center for Farmworker Families. “Get Informed.” Accessed January 12, 2023. https://farmworkerfamily.org/information.

Cha, Paulette, and Joy Collins. “Health Care Access among California’s Farmworkers.” Public Policy Institute of California, April 2022. https://www.ppic.org/publication/health-care-access-among-californias-farmworkers/.

Chapagain, A. K., A. Y. Hoekstra, and H. H. G. Savenije. “Water Saving through International Trade of Agricultural Products.” *Hydrology and Earth System Sciences* 10, no. 3 (June 30, 2006): 455–68. https://doi.org/10.5194/hess-10-455-2006.

Chaparro, M Pia, Brent Langellier, Kerry Birnbach, Matthew Sharp, and Gail Harrison. “Nearly Four Million Californians Are Food Insecure,” July 9, 2012, 9.

Chatterjee, Bipul and Sophia Murphy. Trade and Food Security. E15Initiative. Geneva: International Centre for Trade and Sustainable Development (ICTSD) and World Economic Forum, 2014. www.e15initiative.org/

Chen, Ruxia, Huimin Yan, Fang Liu, Wenpeng Du, and Yanzhao Yang. “Multiple Global Population Datasets: Differences and Spatial Distribution Characteristics.” *ISPRS International Journal of Geo-Information* 9, no. 11 (November 2020): 637. https://doi.org/10.3390/ijgi9110637.

Chenarides, Lauren, Mark Manfredo, and Timothy J. Richards. “COVID-19 and Food Supply Chains.” *Applied Economic Perspectives and Policy* 43, no. 1 (2021): 270–79. https://doi.org/10.1002/aepp.13085.

Chilton M, Rose D. A rights-based approach to food insecurity in the United States. Am J Public Health. 2009 Jul;99(7):1203-11. doi: 10.2105/AJPH.2007.130229. Epub 2009 May 14. PMID: 19443834; PMCID: PMC2696644.

Coates J., Swindale A. & Bilinsky P. 2007. *Household Food Insecurity Access Scale (HFIAS) for Measurement of Food Access: Indicator Guide*. Food and Nutrition Technical Assistance III Project (FANTA) (ed.), FHI 360/FANTA, Washington, DC.

Coleman-Jensen, Alisha, Matthew P. Rabbitt, Christian A. Gregory, and Anita Singh. “Household Food Security in the United States in 2020.” Accessed July 13, 2022. http://www.ers.usda.gov/publications/pub-details/?pubid=102075.

Dabrowski, J. M., E. Masekoameng, and P. J. Ashton. “Analysis of Virtual Water Flows Associated with the Trade of Maize in the SADC Region: Importance of Scale.” *Hydrology and Earth System Sciences* 13, no. 10 (2009): 1967.

De Fraiture, C., X. Cai, U. Amarasinghe, M. Rosegrant, and D. Molden. 2004. Does international cereal trade save water? The impact of virtual water trade on global water use. Comprehensive Assessment Research Report 4, IWMI, Colombo, Sri Lanka.

Deitz, Shiloh, and Katie Meehan. “Plumbing Poverty: Mapping Hot Spots of Racial and Geographic Inequality in U.S. Household Water Insecurity.” *Annals of the American Association of Geographers* 109 (March 8, 2019): 1–18. https://doi.org/10.1080/24694452.2018.1530587.

DKA. “Global Food Security Q2 2022.” Accessed January 31, 2023. https://www.dka.global/global-food-security-q2-2022.

Dobbin, Kristin. “Research Brief: Small Disadvantaged Community Participation in Groundwater Sustainability Agencies.” *UC Davis Center for Environmental Policy and Behavior*, June 2018.

Eldridge, Honor May. “Building Resilience into Our Food Systems.” Resilience, April 9, 2020. https://www.resilience.org/stories/2020-04-09/building-resilience-into-our-food-systems/.

Elliott, V. Food deserts threaten health of poor and old.Times1997,5, 5.

Energy Information Administration - EIA- Independent Statistics and Analysis. “California’s Hydroelectric Generation Affected by Historic Drought,” July 7, 2021. https://www.eia.gov/todayinenergy/detail.php?id=48616.

Ercin, A. Ertug, and Arjen Y. Hoekstra. “Water Footprint Scenarios for 2050: A Global Analysis.” *Environment International* 64 (March 1, 2014): 71–82. https://doi.org/10.1016/j.envint.2013.11.019.

“Farm Subsidies in California: | Environmental Working Group.” Accessed May 8, 2022. https://www.ewg.org/research/farm-subsidies-california.

Fedinick, Kristi Pullen, Steve Taylor, Michele Roberts, Richard Moore, and Erik Olson. “Watered Down Justice.” *Natural Resources Defense Council*, March 27, 2020.

Feinstein, Laura, Rapichan Phurisamban, Amanda Ford, Christine Tyler, and Ayanna Crawford. “Drought and Equity in California.” Accessed May 20, 2022. https://www.adaptationclearinghouse.org/resources/drought-and-equity-in-california.html.

Fernandez-Bou, Angel Santiago, Jose Rodriguez-Flores, A Guzman, Jose Pablo Ortiz Partida, Leticia Classen Rodriguez, P Sánchez-Pérez, Jorge Valero-Fandiño, et al. *Water*,

Environment, and Socioeconomic Justice in California: A Multi-Benefit Framework, 2022. https://doi.org/10.13140/RG.2.2.25328.79361.

Flegal, Chione, Solana Rice, Jake Mann, and Jennifer Tran. "California Unincorporated: Mapping Disadvantaged Communities in the San Joaquin Valley," Accessed May 5, 2022. https://www.policylink.org/resources-tools/california-unincorporated-mapping-disadvantaged-communities-in-the-san-joaquin-valley.

Flores-Landeros, Humberto. "Community Perspectives and Environmental Justice in California's San Joaquin Valley | Environmental Justice." Accessed February 27, 2023. https://www.liebertpub.com/doi/10.1089/env.2021.0005.

Food and Agriculture Organization of the United Nations. "Hunger and Food Insecurity," 2021. http://www.fao.org/hunger/en/.

Food and Agriculture Organization of the United Nations. "The State of Food Insecurity in the World", 2015. www.fao.org/3/a-i4646e.

"Food Insecurity Experience Scale (FIES) | INDDEX Project." Accessed January 31, 2023. https://inddex.nutrition.tufts.edu/data4diets/indicator/food-insecurity-experience-scale-fies.

"Food Insecurity Report Briefs | Feeding America." Accessed August 9, 2022. https://www.feedinggamerica.org/research/map-the-meal-gap/overall-executive-summary.

Fulton, Julian, Heather Cooley, and Peter H. Gleick. "Water Footprint Outcomes and Policy Relevance Change with Scale Considered: Evidence from California." *Water Resources Management* 28, no. 11 (September 1, 2014): 3637–49. https://doi.org/10.1007/s11269-014-0692-1.

Gelman, Andrew, and Jennifer Hill. *Data Analysis Using Regression and Multilevel/Hierarchical Models*. Analytical Methods for Social Research. Cambridge: Cambridge University Press, 2006. doi:10.1017/CBO9780511790942.

Gosliner, Wendi, Daniel M. Brown, Betty C. Sun, Gail Woodward-Lopez, and Patricia B. Crawford. "Availability, Quality and Price of Produce in Low-Income Neighbourhood Food Stores in California Raise Equity Issues." *Public Health Nutrition* 21, no. 9 (June 2018): 1639–48. https://doi.org/10.1017/S1368980018000058.

Graham, Neal T., Iyer Gokul, Mohamad I. Hejazi, Son H. Kim, Patel Pralit, and Matthew Binsted. "Agricultural Impacts of Sustainable Water Use in the United States." *Scientific Reports (Nature Publisher Group)* 11, no. 1 (2021). http://dx.doi.org/10.1038/s41598-021-96243-5.

Greene, Christina. "Broadening Understandings of Drought – The Climate Vulnerability of Farmworkers and Rural Communities in California (USA)." *Environmental Science & Policy* 89 (November 1, 2018): 283–91. https://doi.org/10.1016/j.envsci.2018.08.002.

Greenwald, Howard P., and Vanessa Zajfen. “Food Insecurity and Food Resource Utilization in an Urban Immigrant Community.” *Journal of Immigrant and Minority Health* 19, no. 1 (February 2017): 179–86. https://doi.org/10.1007/s10903-015-0331-9

Gregory, Christian A., and Alisha Coleman-Jensen. “Do High Food Prices Increase Food Insecurity in the United States?” *Applied Economic Perspectives and Policy* 35, no. 4 (2013): 679–707.

Grimaccia, Elena, and Alessia Naccarato. “Food Insecurity Individual Experience: A Comparison of Economic and Social Characteristics of the Most Vulnerable Groups in the World.” *Social Indicators Research* 143, no. 1 (May 1, 2019): 391–410. https://doi.org/10.1007/s11205-018-1975-3.

Gundersen, Craig, and James P Ziliak. “Food Insecurity Research in the United States: Where We Have Been and Where We Need to Go.” *Applied Economic Perspectives and Policy* 40, no. 1 (2018): 119–35. https://doi.org/10.1093/aepp/ppx058.

Hagerty, Nick. “Adaptation to Surface Water Scarcity in Irrigated Agriculture,” December 3, 2021, 86.

Hamerschlag, Kari. “Farm Subsidies in California: Skewed Priorities and Gross Inequities,” May 1, 2010, 7.

Hanak, Ellen, Alvar Escriva-Bou, Brian Gray, Sarge Green, Thomas Harter, Jelena Jezdimirovic, Jay Lund, Josué Azuara, Peter Moyle, and Nathaniel Seavy. *Water and the Future of the San Joaquin Valley*, 2019. https://doi.org/10.13140/RG.2.2.24360.83208.

Harrison, Gail G, Matthew Sharp, and George Manolo-LeClair. “Food Security Among California’s Low-Income Adults Improves, But Most Severely Affected Do Not Share in Improvement,” June 1, 2007, 12.

Hassen, Ben Tarek, and Hamid El Bilali. “Impacts of the Russia-Ukraine War on Global Food Security: Towards More Sustainable and Resilient Food Systems?” *Foods* 11, no. 15 (January 2022): 2301. https://doi.org/10.3390/foods11152301.

Hatchett, Benjamin J., Arielle L. Koshkin, Kristen Guirguis, Karl Rittger, Anne W. Nolin, Anne Heggli, Alan M. Rhoades, et al. “Midwinter Dry Spells Amplify Post-Fire Snowpack Decline.” *Geophysical Research Letters* 50, no. 3 (2023): e2022GL101235. https://doi.org/10.1029/2022GL101235.

Howitt, Richard, Josué Medellín-Azuara, Duncan MacEwan, Jay Lund, and Daniel Sumner. “Economic Analysis of the 2014 Drought for California Agriculture.” *UC Davis Center for Watershed Sciences*, July 23, 2014, 28.

Huang, Xingying, and Daniel L. Swain. “Climate Change Is Increasing the Risk of a California Megaflood.” *Science Advances* 8, no. 32 (August 12, 2022): eabq0995. https://doi.org/10.1126/sciadv.abq0995.

James, D. (2015), “World says yes to food security in South, WTO says no”, available at: www.twn.my/title2/susagri/2015/sa392.htm

Janssens, Charlotte, Petr Havlík, Tamás Krisztin, Justin Baker, Stefan Frank, Tomoko Hasegawa, David Leclère, et al. “Global Hunger and Climate Change Adaptation through International Trade.” *Nature Climate Change* 10, no. 9 (September 2020): 829–35. https://doi.org/10.1038/s41558-020-0847-4.

Jensen, Helen H., Brent Kreider, and Oleksandr Zhylyevskyy. “Investigating Treatment Effects of Participating Jointly in SNAP and WIC When the Treatment Is Validated Only for SNAP.” *Southern Economic Journal* 86, no. 1 (2019): 124–55. https://doi.org/10.1002/soej.12365.

Jepson, Wendy E., Amber Wutich, Shalean M. Colllins, Godfred O. Boateng, and Sera L. Young. “Progress in Household Water Insecurity Metrics: A Cross-Disciplinary Approach.” *WIREs Water* 4, no. 3 (2017): e1214. https://doi.org/10.1002/wat2.1214.

Jepson, Wendy, and Emily Vandewalle. “Household Water Insecurity in the Global North: A Study of Rural and Periurban Settlements on the Texas–Mexico Border.” *The Professional Geographer* 68, no. 1 (January 2, 2016): 66–81. https://doi.org/10.1080/00330124.2015.1028324.

Kaiser, Lucia. “Why Do Low-Income Women Not Use Food Stamps? Findings from the California Women’s Health Survey.” *Public Health Nutrition* 11, no. 12 (December 2008): 1288–95. https://doi.org/10.1017/S1368980008002528.

Kaiser, Lucia, Nikki Baumrind, and Sheila Dumbauld. “Who Is Food-Insecure in California? Findings from the California Women’s Health Survey, 2004.” *Public Health Nutrition* 10, no. 6 (June 2007): 574–81. https://doi.org/10.1017/S1368980007382542.

Kalil, A., & Chen, J.-H. (2008). Mothers' Citizenship Status and Household Food Insecurity Among Low-Income Children of Immigrants: New Directions for Child and Adolescent Development, 2008 (121), 43–62.

Laborde, David, Will Martin, Johan Swinnen, and Rob Vos. “COVID-19 Risks to Global Food Security.” *Science* 369, no. 6503 (July 31, 2020): 500–502. https://doi.org/10.1126/science.abc4765.

Lawler, Joshua J., David J. Lewis, Erik Nelson, Andrew J. Plantinga, Stephen Polasky, John C. Withey, David P. Helmers, Sebastián Martinuzzi, Derric Pennington, and Volker C. Radeloff. “Projected Land-Use Change Impacts on Ecosystem Services in the United

States." *Proceedings of the National Academy of Sciences* 111, no. 20 (May 20, 2014): 7492–97. https://doi.org/10.1073/pnas.1405557111.

Leach, William D., Brian Y. An, and Shui-Yan Tang. "Evaluating California's Sustainable Groundwater Management Act: The First Five Years of Governance and Planning." *JAWRA Journal of the American Water Resources Association* 57, no. 6 (2021): 972–89. https://doi.org/10.1111/1752-1688.12967.

Lewis, Josette, and Jessica Rudnick. "The Policy Enabling Environment for Climate Smart Agriculture: A Case Study of California." *Frontiers in Sustainable Food Systems* 3 (2019). https://www.frontiersin.org/article/10.3389/fsufs.2019.00031.

Liu, Yibin, and Heather A. Eicher-Miller. "Food Insecurity and Cardiovascular Disease Risk." *Current Atherosclerosis Reports* 23, no. 6 (March 27, 2021): 24. https://doi.org/10.1007/s11883-021-00923-6.

Liu, Wenfeng, Marta Antonelli, Matti Kummu, Xu Zhao, Pute Wu, Junguo Liu, La Zhuo, and Hong Yang. "Savings and Losses of Global Water Resources in Food-Related Virtual Water Trade." *WIREs Water* 6, no. 1 (2019): e1320. https://doi.org/10.1002/wat2.1320.

Long, Michael A., Lara Gonçalves, Paul B. Stretesky, and Margaret Anne Defeyter. "Food Insecurity in Advanced Capitalist Nations: A Review." *Sustainability* 12, no. 9 (January 2020): 3654. https://doi.org/10.3390/su12093654.

MacLeod, Clara, and Linda Estelí Méndez-Barrientos. "Groundwater Management in California's Central Valley: A Focus on Disadvantaged Communities." *Case Studies in the Environment* 3, no. 1 (December 31, 2019): 1–13. https://doi.org/10.1525/cse.2018.001883.

Mall, Natalie K., and Jonathan D. Herman. "Water Shortage Risks from Perennial Crop Expansion in California's Central Valley." *Environmental Research Letters* 14, no. 10 (October 2019): 104014. https://doi.org/10.1088/1748-9326/ab4035.

Manalo-LeClair, George. "The 2014 Drought: Implications for Food Security," October 3, 2014. https://nourishca.org/publications/report/the-2014-drought-implications-for-food-security/.

"Map the Meal Gap." Feeding America, 2014.

Matias, Susana, Maria Marois, and Marc Schenker. "Prevalence and Correlates of Food Insecurity in Latino Farm Worker Households in California's Central Valley." *Current Developments in Nutrition* 4, no. Suppl 2 (May 29, 2020): 237. https://doi.org/10.1093/cdn/nzaa043_088.

Medellín-Azuara, J., Escriva-Bou, A., Abatzoglou, J.A., Viers, J.H, Cole, S.A., RodríguezFlores, J.M., and Sumner, D.A. (2022). Economic Impacts of the 2021 Drought on California Agriculture. Preliminary Report. University of California, Merced. Available at http://drought.ucmerced.edu.

Medellín-Azuara, J., MacEwan, D., Howitt, R. E., Koruakos, G., Dogrul, E. C., Brush, C. F., Kadir, T. N., Harter, T., Melton, F., & Lund, J. R. (2015). Hydroeconomic analysis of groundwater pumping for irrigated agriculture in California's Central Valley, USA. Hydrogeology Journal, 23(6), 1205–1216. https://doi.org/10.1007/s10040-015-1283-9

Meehan, Katie, Wendy Jepson, Leila M. Harris, Amber Wutich, Melissa Beresford, Amanda Fencl, Jonathan London, et al. "Exposing the Myths of Household Water Insecurity in the Global North: A Critical Review." *WIREs Water* 7, no. 6 (2020): e1486. https://doi.org/10.1002/wat2.1486.

Mekonnen, Mesfin M., and Arjen Y. Hoekstra. "Blue Water Footprint Linked to National Consumption and International Trade Is Unsustainable." *Nature Food* 1, no. 12 (December 2020): 792–800. https://doi.org/10.1038/s43016-020-00198-1.

Mekonnen, Mesfin M., and Winnie Gerbens-Leenes. "The Water Footprint of Global Food Production." *Water* 12, no. 10 (October 2020): 2696. https://doi.org/10.3390/w12102696.

Meyer, B. D. and N. Mittag. 2018. Misreporting of government transfers: How important are survey design and geography? Working paper, CERGE-EI. http://home.cergeei.cz/mittag/papers/FoodAPS.pdf (last accessed on October 1, 2022).

Minkoff-Zern, Laura-Anne. "Hunger amidst Plenty: Farmworker Food Insecurity and Coping Strategies in California." *Local Environment* 19, no. 2 (February 2014): 204–19. https://doi.org/10.1080/13549839.2012.729568.

Morris, Patricia McGrath, Linda Neuhauser, and Cathy Campbell. "Food Security in Rural America: A Study of the Availability and Costs of Food." *Journal of Nutrition Education* 24, no. 1 (1992): 52S.

Mubako, Stanley T., and Christopher L. Lant. "Agricultural Virtual Water Trade and Water Footprint of U.S. States." *Annals of the Association of American Geographers* 103, no. 2 (2013): 385–96.

Mueller, J. Tom, and Stephen Gasteyer. "The Widespread and Unjust Drinking Water and Clean Water Crisis in the United States." *Nature Communications* 12, no. 1 (June 22, 2021): 3544. https://doi.org/10.1038/s41467-021-23898-z.

Nam, Yunju, Jin Huang, Colleen Heflin, and Michael Sherraden. "Racial and Ethnic Disparities in Food Insufficiency: Evidence from a Statewide Probability Sample," June 2015. https://doi.org/10.1086/681574.

Napoli, Marion, Pasquale De Muro, and Matteo Mazziotta. "Towards a Food Insecurity Multidimensional Index (FIMI)," n.d.

Neff, Roni A., Anne M. Palmer, Shawn E. McKenzie, and Robert S. Lawrence. "Food Systems and Public Health Disparities." *Journal of Hunger & Environmental Nutrition* 4, no. 3–4 (November 30, 2009): 282–314. https://doi.org/10.1080/19320240903337041.

New American Economy Research Fund. "Immigration and Agriculture." Accessed January 6, 2023. https://research.newamericaneconomy.org/report/immigration-and-agriculture/.

Nord, Mark, and Mark Prell, eds. *Food Security Improved Following the 2009 ARRA Increase in SNAP Benefits*. Economic Research Report Number 116, 2011. https://doi.org/10.22004/ag.econ.262242.

Oki, T., and S. Kanae. "Virtual Water Trade and World Water Resources." *Water Science and Technology* 49, no. 7 (April 2004): 203–9.

Oki, Taikan, Shinjiro Yano, and Naota Hanasaki. "Economic Aspects of Virtual Water Trade." *Environmental Research Letters* 12, no. 4 (March 2017): 044002. https://doi.org/10.1088/1748-9326/aa625f.

Ornelas, Izaac, Wenson Fung, Susan Gabbard, and Daniel Carroll. "California Findings from the National Agricultural Workers Survey (NAWS) 2015–2019." *JBS International*, January 2022.

Pannu, Camille. "Bridging the Safe Drinking Water Gap for California's Rural Poor" 24, no. 2 (2018): 19.

Park S, Onufrak S, Patel A, Sharkey JR, Blanck HM. Perceptionsof drinking water safety and their associations with plain waterintake among US Hispanic adults. J Water Health 2019;17(4):587–96.

Pauloo, R. A., A. Escriva-Bou, H. Dahlke, A. Fencl, H. Guillon, and G. E. Fogg. "Domestic Well Vulnerability to Drought Duration and Unsustainable Groundwater Management in California's Central Valley." *Environmental Research Letters* 15, no. 4 (March 2020): 044010. https://doi.org/10.1088/1748-9326/ab6f10.

Peeples, Lynn. "Across the US, Millions of People Are Drinking Unsafe Water. How Can We Fix That?" *Ensia* (blog). Accessed January 19, 2023. https://ensia.com/features/thirsting-for-solutions/.

Pelto, Debra J., Alex Ocampo, Olga Garduño-Ortega, Claudia Teresa Barraza López, Francesca Macaluso, Julia Ramirez, Javier González, and Francesca Gany. "The Nutrition Benefits Participation Gap: Barriers to Uptake of SNAP and WIC Among Latinx American Immigrant Families." *Journal of Community Health* 45, no. 3 (June 2020): 488–91. https://doi.org/10.1007/s10900-019-00765-z.

Pfister, Stephan, and Peter Bayer. "Monthly Water Stress: Spatially and Temporally Explicit Consumptive Water Footprint of Global Crop Production." *Journal of Cleaner Production*,

Towards eco-efficient agriculture and food systems: Selected papers from the Life Cycle Assessment (LCA) Food Conference, 2012, in Saint Malo, France, 73 (June 15, 2014): 52–62. https://doi.org/10.1016/j.jclepro.2013.11.031.

Phojanakong, Pam, Emily Brown Weida, Gabriella Grimaldi, Félice Lê-Scherban, and Mariana Chilton. "Experiences of Racial and Ethnic Discrimination Are Associated with Food Insecurity and Poor Health." *International Journal of Environmental Research and Public Health* 16, no. 22 (January 2019): 4369. https://doi.org/10.3390/ijerph16224369.

Poblacion, Ana, John Cook, Stephanie Ettinger de Cuba, Allison Bovell, Richard Sheward, Justin Pasquariello, and Diana Cutts. "Can Food Insecurity Be Reduced in the United States by Improving SNAP, WIC, and the Community Eligibility Provision?" *World Medical & Health Policy* 9, no. 4 (2017): 435–55. https://doi.org/10.1002/wmh3.248.

Pope, Nolan G. 2016. "The Effects of DACAmentation: The Impact of Deferred Action for Childhood Arrivals on Unauthorized Immigrants." Journal of Public Economics 143. Elsevier B.V.: 98–114.

Poppendieck, J. Sweet Charity? Emergency Food and the End of Entitlement; Penguin: New York, NY, USA, 1998.

Potochnick, Stephanie, Jen-Hao Chen, and Krista Perreira. "Local-Level Immigration Enforcement and Food Insecurity Risk among Hispanic Immigrant Families with Children: National-Level Evidence." *Journal of Immigrant and Minority Health* 19, no. 5 (October 1, 2017): 1042–49. https://doi.org/10.1007/s10903-016-0464-5.

Public Policy Institute of California. "Income Inequality in California." Accessed August 10, 2022. https://www.ppic.org/publication/income-inequality-in-california/.

Public Policy Institute of California. "The WIC Program in California." Accessed January 31, 2023. https://www.ppic.org/publication/the-wic-program-in-california/.

Public Policy Institute of California. "Undocumented Immigrants in California." Accessed January 31, 2023. https://www.ppic.org/publication/undocumented-immigrants-in-california/.

Radeloff, V. C., E Nelson, A. J. Plantinga, D. J. Lewis, D Helmers, J. J. Lawler, J. C. Withey, et al. "Economic-Based Projections of Future Land Use in the Conterminous United States under Alternative Policy Scenarios." *Ecological Applications* 22, no. 3 (2012): 1036–49. https://doi.org/10.1890/11-0306.1.

Rodriguez, Carmen, Sylvia L. Crowder, Mary Rodriguez, Laura Redwine, and Marilyn Stern. "Food Insecurity and the Hispanic Population during the COVID-19 Pandemic." *Ecology of Food and Nutrition* 60, no. 5 (September 3, 2021): 548–63. https://doi.org/10.1080/03670244.2021.1974014.

Rodriguez, Lizette, Marcel Horowitz, Dorina Espinoza, and Alberto Aguilera. “The Impact of the California Drought on Food Security among Rural Families of Mexican Origin,” 2015.

Rosengrant, Mark W., Claudia Ringler, and Tingju Zhu. “Water for Agriculture: Maintaining Food Security under Growing Scarcity.” Accessed July 25, 2022. https://doi.org/10.1146/annurev.environ.030308.090351.

Rosinger, Asher Y. “Using Water Intake Dietary Recall Data to Provide a Window into US Water Insecurity.” *The Journal of Nutrition* 152, no. 5 (May 1, 2022): 1263–73. https://doi.org/10.1093/jn/nxac017.

Rosinger, Asher Y., Hilary J. Bethancourt, and Sera L. Young. “Tap Water Avoidance Is Associated with Lower Food Security in the US: Evidence from NHANES 2005-2018.” *Journal of the Academy of Nutrition and Dietetics*, July 21, 2022. https://doi.org/10.1016/j.jand.2022.07.011.

Rudnick, J., A. DeVincentis, and L. Méndez-Barrientos. “The Sustainable Groundwater Management Act Challenges the Diversity of California Farms.” *California Agriculture* 70, no. 4 (November 16, 2016): 169–73.

Rushforth, Richard R., and Benjamin L. Ruddell. “A Spatially Detailed Blue Water Footprint of the United States Economy.” *Hydrology and Earth System Sciences* 22, no. 5 (May 22, 2018): 3007–32. https://doi.org/10.5194/hess-22-3007-2018.

Safford, Hugh D., Alison K. Paulson, Zachary L. Steel, Derek J. N. Young, and Rebecca B. Wayman. “The 2020 California Fire Season: A Year like No Other, a Return to the Past or a Harbinger of the Future?” *Global Ecology and Biogeography* 31, no. 10 (2022): 2005–25. https://doi.org/10.1111/geb.13498.

Saraiva, Carina (CDPH-MCAH-EAPD-SPE). “MIHA Data Snapshots of Prenatal WIC Participants.” *California Department of Public Health*, April 2017.

Savary, Serge, Sonia Akter, Conny Almekinders, Jody Harris, Lise Korsten, Reimund Rötter, Stephen Waddington, and Derrill Watson. “Mapping Disruption and Resilience Mechanisms in Food Systems.” *Food Security* 12, no. 4 (2020): 695–717. https://doi.org/10.1007/s12571-020-01093-0.

“SGMA Groundwater Management (SGMA) Portal - Department of Water Resources.” Accessed January 31, 2023. https://sgma.water.ca.gov/portal/gsp/status.

Smith, Michael D., Matthew P. Rabbitt, and Alisha Coleman- Jensen. “Who Are the World’s Food Insecure? New Evidence from the Food and Agriculture Organization’s Food Insecurity Experience Scale.” *World Development* 93 (May 1, 2017): 402–12. https://doi.org/10.1016/j.worlddev.2017.01.006.

State of California - Department of Justice - Office of the Attorney General. “Central Valley,” March 21, 2012. https://oag.ca.gov/gambling/game/central_valley.

Stoler, Justin, Joshua D. Miller, Ellis A. Adams, Farooq Ahmed, Mallika Alexander, Gershim Asiki, Mobolanle Balogun, et al. “The Household Water Insecurity Experiences (HWISE) Scale: Comparison Scores from 27 Sites in 22 Countries.” *Journal of Water, Sanitation and Hygiene for Development* 11, no. 6 (September 28, 2021): 1102–10. https://doi.org/10.2166/washdev.2021.108.

Sumner, Daniel A, Carlyn Marsh, Quaid Moore, Scott Somerville, and Josué Medellín-Azuara. “California Farms Adjust to Drought.” *University of California Giannini Foundation of Agricultural Economics*, October 2021, 4.

“Sustainable Groundwater Management Act” (PDF). Retrieved 25 February, 2022.

Tester, June M., Lisa G. Rosas, and Cindy W. Leung. “Food Insecurity and Pediatric Obesity: A Double Whammy in the Era of COVID-19 | SpringerLink,” October 16, 2020. https://link.springer.com/article/10.1007/s13679-020-00413-x.

The State of Food Security and Nutrition in the World 2021. FAO, IFAD, UNICEF, WFP and WHO, 2021. https://doi.org/10.4060/cb4474en.

Tom, Michelle S., Paul S. Fischbeck, and Chris T. Hendrickson. “Energy Use, Blue Water Footprint, and Greenhouse Gas Emissions for Current Food Consumption Patterns and Dietary Recommendations in the US.” *Environment Systems and Decisions* 36, no. 1 (March 1, 2016): 92–103. https://doi.org/10.1007/s10669-015-9577-y.

UNCCD. “The Global Food Security Index.” Accessed January 31, 2023. https://www.unccd.int/resources/knowledge-sharing-system/global-food-security-index.

Upton, John. “Three Ways The West Can Adapt To Drought.” Accessed November 28, 2021. https://www.climatecentral.org/news/three-ways-the-west-can-adapt-to-drought-18878.

US Census Bureau. “Understanding and Using American Community Survey Data: What All Data Users Need to Know.” Census.gov. Accessed January 6, 2023. https://www.census.gov/programs-surveys/acs/library/handbooks/general.html.

“USDA ERS - Global Food Insecurity Grows in 2022 Amid Backdrop of Higher Prices, Black Sea Conflict.” Accessed January 31, 2023. https://www.ers.usda.gov/amber-waves/2022/november/global-food-insecurity-grows-in-2022-amid-backdrop-of-higher-prices-black-sea-conflict/.

USDA.gov. “Immigration and the Competitiveness of California Agriculture - UNIVERSITY OF CALIFORNIA, DAVIS,” September 30, 2014. https://portal.nifa.usda.gov/web/crisprojectpages/0183894-immigration-and-the-competitiveness-of-california-agriculture.html.

Vanham, D., Mesfin Mekonnen, and Arjen Ysbert Hoekstra. “The water footprint of the EU for different diets.” *Ecological indicators* 32 (2013): 1–8. https://doi.org/10.1016/j.ecolind.2013.02.020.

Veettil, Anoop Valiya, and Ashok K. Mishra. “Water Security Assessment Using Blue and Green Water Footprint Concepts.” *Journal of Hydrology* 542 (November 1, 2016): 589–602. https://doi.org/10.1016/j.jhydrol.2016.09.032.

Vos, Rob & Glauber, Joseph & Laborde, David & Hernandez, Manuel. (2022). COVID-19 and rising global food prices: What's really happening?. 10.13140/RG.2.2.31433.62563.

Vos, J., R. Boelens, and P. Mena. “From Local to Virtual Water Control: The Globalization of Water Insecurity and Water Access Conflicts.” *Global Water Forum* (blog), May 13, 2014. https://globalwaterforum.org/2014/05/13/from-local-to-virtual-water-control-the-globalization-of-water-insecurity-and-water-access-conflicts/.

Wadsworth, Gail, Thea Rittenhouse, and Sarah Cain. “Assessing and Addressing Farm Worker Food Security,” March 2016, 66.

Walker, Renee E., Christopher R. Keane, and Jessica G. Burke. “Disparities and Access to Healthy Food in the United States: A Review of Food Deserts Literature.” *Health & Place* 16, no. 5 (September 2010): 876–84. https://doi.org/10.1016/j.healthplace.2010.04.013.

Walsemann, Katrina M., Annie Ro, and Gilbert C. Gee. “Trends in Food Insecurity among California Residents from 2001 to 2011: Inequities at the Intersection of Immigration Status and Ethnicity.” *Preventive Medicine* 105 (December 2017): 142–48. https://doi.org/10.1016/j.ypmed.2017.09.007.

Wang, Dan, Klaus Hubacek, Yuli Shan, Winnie Gerbens-Leenes, and Junguo Liu. “A Review of Water Stress and Water Footprint Accounting.” *Water* 13, no. 2 (January 2021): 201. https://doi.org/10.3390/w13020201.

Winham, Donna M., and Traci L. Armstrong Florian. “Nativity, Not Acculturation, Predicts SNAP Usage Among Low-Income Hispanics With Food Insecurity.” *Journal of Hunger & Environmental Nutrition* 10, no. 2 (April 3, 2015): 202–13. https://doi.org/10.1080/19320248.2014.962779.

“WIC Program Participant Info.” Accessed January 31, 2023. https://www.cdph.ca.gov/Programs/CFH/DWICSN/Pages/ResearchandData/WICProgramParticipantInfo.aspx.

Wirth, Cathy, Ron Strochlic, and Christy Getz. “Hunger in the Fields: Food Insecurity among Farmworkers in Fresno County,” January 2007. https://www.researchgate.net/publication/255532448_Hunger_in_the_fields_Food_insecurity_among_farmworkers_in_Fresno_county.

Wolfson, Julia A., and Cindy W. Leung. “Food Insecurity and COVID-19: Disparities in Early Effects for US Adults.” *Nutrients* 12, no. 6 (June 2020): 1648. https://doi.org/10.3390/nu12061648.

Workie, Endashaw, Joby Mackolil, Joan Nyika, and Sendhil Ramadas. “Deciphering the Impact of COVID-19 Pandemic on Food Security, Agriculture, and Livelihoods: A Review of the Evidence from Developing Countries | Elsevier Enhanced Reader.” Accessed January 15, 2023. https://doi.org/10.1016/j.crsust.2020.100014.

Wutich, Amber, Jessica Budds, Laura Eichelberger, Jo Geere, Leila Harris, Jennifer Horney, Wendy Jepson, et al. “Advancing Methods for Research on Household Water Insecurity: Studying Entitlements and Capabilities, Socio-Cultural Dynamics, and Political Processes, Institutions and Governance.” *Water Security* 2 (November 2017): 1–10. https://doi.org/10.1016/j.wasec.2017.09.001.

Wutich, Amber, Wendy E. Jepson, Justin Stoler, Patrick Thomson, Michelle Kooy, Alexandra Brewis, Chad Staddon, and Katie Meehan. “A Global Agenda for Household Water Security: Measurement, Monitoring, and Management.” *JAWRA Journal of the American Water Resources Association* 57, no. 4 (August 1, 2021): 530–38. https://doi.org/10.1111/1752-1688.12926.

Yang, Hong, Stephan Pfister, and Anik Bhaduri. “Accounting for a Scarce Resource: Virtual Water and Water Footprint in the Global Water System.” *Current Opinion in Environmental Sustainability*, Aquatic and marine systems, 5, no. 6 (December 1, 2013): 599–606. https://doi.org/10.1016/j.cosust.2013.10.003.

Young, Sera L, and Joshua D Miller. “Water Insecurity in the United States: Quantifying an Invisible Crisis.” *The Journal of Nutrition* 152, no. 5 (May 5, 2022): 1183–84. https://doi.org/10.1093/jn/nxac048.

Young, Sera L. “Viewpoint: The Measurement of Water Access and Use Is Key for More Effective Food and Nutrition Policy.” *Food Policy* 104 (October 1, 2021): 102138. https://doi.org/10.1016/j.foodpol.2021.102138.

Young, Sera L., Hilary J. Bethancourt, Zacchary R. Ritter, and Edward A. Frongillo. “The Individual Water Insecurity Experiences (IWISE) Scale: Reliability, Equivalence and Validity of an Individual-Level Measure of Water Security.” BMJ Global Health 6, no. 10 (October 1, 2021): e006460. https://doi.org/10.1136/bmjgh-2021-006460.

Zamora-Reyes, Diana, Ellie Broadman, Erica Bigio, Bryan Black, David Meko, Connie A. Woodhouse, and Valerie Trouet. “The Unprecedented Character of California’s 20th Century Enhanced Hydroclimatic Variability in a 600-Year Context.” *Geophysical Research Letters* 49, no. 19 (2022): e2022GL099582. https://doi.org/10.1029/2022GL099582.

Zhu, Yu. “International Trade and Food Security: Conceptual Discussion, WTO and the Case of China.” *China Agricultural Economic Review* 8, no. 3 (January 1, 2016): 399–411. https://doi.org/10.1108/CAER-09-2015-0127.