Title

Agricultural Implications of Implementing California's Sustainable Groundwater Management Act in the Greater Kings River Basin

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Agricultural Implications of Implementing California's Sustainable Groundwater Management Act in the Greater Kings River Basin

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in

Environmental Systems

by

Spencer Allan Cole

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2023

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Abstract

The Sustainable Groundwater Management Act (SGMA), enacted in 2014, serves as California's first foray into establishing a comprehensive groundwater management program. Under this legislation, basins are required to mitigate groundwater overdraft to reach sustainable conditions by 2040 or 2042. Reductions in groundwater pumping are anticipated to drive substantial shifts in the San Joaquin Valley's agricultural sector, which has historically depended on groundwater to provide water for irrigation. This research examines a case study of SGMA implementation in the Kings and Tulare Lake groundwater basins, focusing on potential impacts for agricultural land cover and economics. Publicly available information on spatial cropping patterns, irrigation requirements, and crop production economics as well as overdraft information and historical water availability from Groundwater Sustainability Plans (GSPs) are used to calibrate a hydroeconomic agricultural production optimization model representing the agriculture in the study area. Scenarios integrating overdraft responsibilities with options for surface water trading and groundwater supply augmentation through recharge are modeled to explore potential outcomes for future agriculture under SGMA. Results suggest ranges and distributions for land fallowing and losses of agricultural revenue under a variety of possible scenarios. Findings also highlight the importance of water trading and groundwater recharge programs in meeting sustainability in the basins and barriers to implementing these programs are discussed.

Introduction

History and background

In September 2014, California Governor Jerry Brown successfully enacted the Sustainable Groundwater Management Act (SGMA) which represents the first attempt to institutionalize a statewide system for groundwater management. Despite the importance of groundwater as the source for about 40% of total beneficial human water use in the state (Chapelle et al., 2017) and supporting a growing $50 billion agricultural sector (CDFA, 2020), management of this resource at the state level had been yet to materialize. Before the enactment of SGMA, groundwater rights in California were linked to land ownership and groundwater extraction was largely unregulated apart from circumstances requiring legal intervention (e.g. adjudication). In the years leading to the genesis of SGMA California faced periods of dry conditions, including 1976-1977, 1987-1992, 2007-2009, and 2012-2016, which spurred formal analysis in many groundwater basins and legislative interest in groundwater management reform (Leahy, 2016). Foundational legislation for the future SGMA package arose during these periods, including SB 1505, initially intended to serve as a comprehensive groundwater management plan; AB 3030, which established the process for the voluntary formation of groundwater management plans (GMP); SB 1938, which required implementation of a GMP to request state funds for groundwater projects; and SB 6 X7, which established the CASGEM groundwater monitoring system.

SGMA consists of a three-bill package of AB 1739, SB 1319, and SB 1168. Collectively, these bills establish the framework and timeline defining groundwater management reform in California. Under the provisions of SGMA and with technical guidance from the California Department of Water Resources (DWR), groundwater sustainability agencies (GSAs) in high-priority groundwater basins must develop plans for reaching groundwater sustainability by 2020 and implement these plans by 2040, meanwhile medium-priority basins must do so by 2022 and 2042, respectively. Each groundwater basin is to be conjunctively managed by one or more GSAs, which in turn may be composed of several local agencies. If basin areas are not managed by a local GSA or under adjudication, the overlying county government is assumed to take groundwater management responsibility unless it opts out, in which case the State Water Resources Control Board (SWRCB) may intervene. SGMA seeks to address what it deems the “six undesirable results” of unsustainable groundwater management, namely: lowering groundwater levels, reduction in storage, seawater intrusion, degraded quality, land subsidence, and surface water depletion.

Groundwater sustainability plans (GSPs) for high- and medium-priority groundwater basins throughout the state are currently under review by the DWR and may require revisions to address groundwater overdraft, which is seen as the primary driver of the undesirable results under SGMA. Mitigating overdraft can be achieved through supply augmentation, demand reduction, or a combination of these strategies. Groundwater overdraft in the San Joaquin Valley (SJV), where most basins are designated “critical”, is estimated to be about 1.8 million acre-feet (Arnold et al., 2017; Escriva-Bou & Hanak, 2018; Hanak et al., 2020). Research on eliminating overdraft in the SGMA horizon suggests that the bulk of the water budget shift will consist of reduced agricultural water demand, however, some studies suggest that about 380-460 thousand acre-feet of supplies may be developed annually using groundwater recharge (Hanak et al., 2019; Alam et al., 2020). As a water supply augmentation tool, groundwater recharge is considered vastly more affordable (Bachand et al., 2016) and often faces fewer regulatory, economic, or environmental barriers as compared to surface storage expansion or desalination. Despite the potential of groundwater recharge, knowledge gaps limit the implementation and scalability of this approach. During the early stages of SGMA planning, studies exploring the benefits and costs of groundwater recharge can serve as a crucial resource for GSAs and other agencies as they navigate California's water future.

In the following sections, first the research questions and motivations for focusing on the chosen study area are introduced. Next, the study area is introduced in more detail. Afterwards the methods used in the study are described, including how the agricultural baseline is created, calibration of the agricultural production model, and how water supply and trading scenarios are developed. Then, results for different spatial scales are described and changes in cropping patterns and water use behavior are highlighted. Discussion is brought surrounding what investments may be needed to achieve the study's results. Lastly, limitations of this research and suggestions for future work are outlined before concluding.

Motivations and research questions

This research explores a case study of SGMA implementation in the Kings and Tulare Lake groundwater basins (referred to in this study as the "Greater Kings River Basin") and examines the potential role of groundwater recharge and surface water trading in mitigating agricultural losses under this policy. The research questions motivating this work are outlined below.

(1) How might SGMA implementation impact agricultural production and management practices in the Greater Kings River basin?
(2) What role can intentional groundwater recharge and surface water trading play in offsetting agricultural losses driven by mitigating groundwater overdraft under SGMA?

These questions are examined through the use of agricultural production modeling by implementing scenarios that couple overdraft mitigation requirements with water trading options and new supplies from groundwater recharge.

The Greater Kings River Basin (henceforth "GKRB") is a well-suited region for piloting this study for several reasons. Firstly, basins contained in the study area have historically experienced significant groundwater overdrafts. According to the values adopted by the GSAs in the study area, the annual overdraft is estimated at 198 and 87 thousand acre-feet for the Kings and Tulare Lake groundwater basins, respectively, representing about 16% of the total SJV overdraft and 9% of agricultural water use in the GKRB. These water management challenges are coupled with opportunities; historically, excess Kings River flow during flooding years has been diverted out of the basin and into the San Joaquin River, representing potential water for recharge capture. This opportunity is reflected in the GSPs relevant to the Kings and Tulare Lake basins, all of which highlight groundwater recharge as a promising tool in their planned actions for meeting sustainability goals. The Kings basin also exhibits strong landscape characteristics for groundwater recharge, with much of the area classified as “excellent” in the Soil Agricultural Groundwater Banking Index framework (SAGBI; O’Geen et al., 2015) and geologic features identified that are suitable for deep percolation (Knight et al., 2022). Agricultural production in the Greater Kings River Basin is sizeable, totaling nearly $5 billion (CNRAa, 2022; USDA, 2022; author calculations) and dominated by permanent trees and vineyards, many of which are in areas that are vulnerable to groundwater sustainability challenges such as the highly groundwater reliant McMullin Area GSA. Lastly, most agricultural water supplies in the GKRB are obtained through diversions of the Kings River which has no significant users outside of the study area—this is contrasted by other basins in the SJV with high overdraft, such as Kern, which has a substantial portion of imported supplies. These imported supplies may become more constrained as management practices shift, lending uncertainty to assumptions regarding surface water availability in future years.

Greater Kings River Basin study area

The GKRB (Figure 1) is in the southern portion of the San Joaquin Valley of California and encompasses portions of Fresno, Kings, and Tulare counties. Headwaters of the Kings River initiate in the foothills of the Sierra Nevada Mountains and the main channel of the river propagates southwest from the impoundment at Pine Flat Reservoir through Fresno and Kings Counties. To the northwest, the GKRB is bordered by the San Joaquin River which interfaces with the Kings River through the Friant-Kern Canal, which runs across the northern border of Fresno Irrigation District and intersects the river upstream of Fresno Weir. In the south, the Kings River splits into two central forks near the border of Kings County, resulting in the North Fork and South Fork. The North Fork proceeds northwest and transitions into the man-made James Bypass which diverts water from entering Fresno Slough and meets the San Joaquin River at Mendota Pool. The South Fork continues southwards through Kings County and eventually terminates in the now-dry Tulare lakebed along with the Tule River. In the east, the Kaweah River runs inside Tulare County and the main channel terminates near Visalia, with tributaries sprawling throughout the surrounding region.

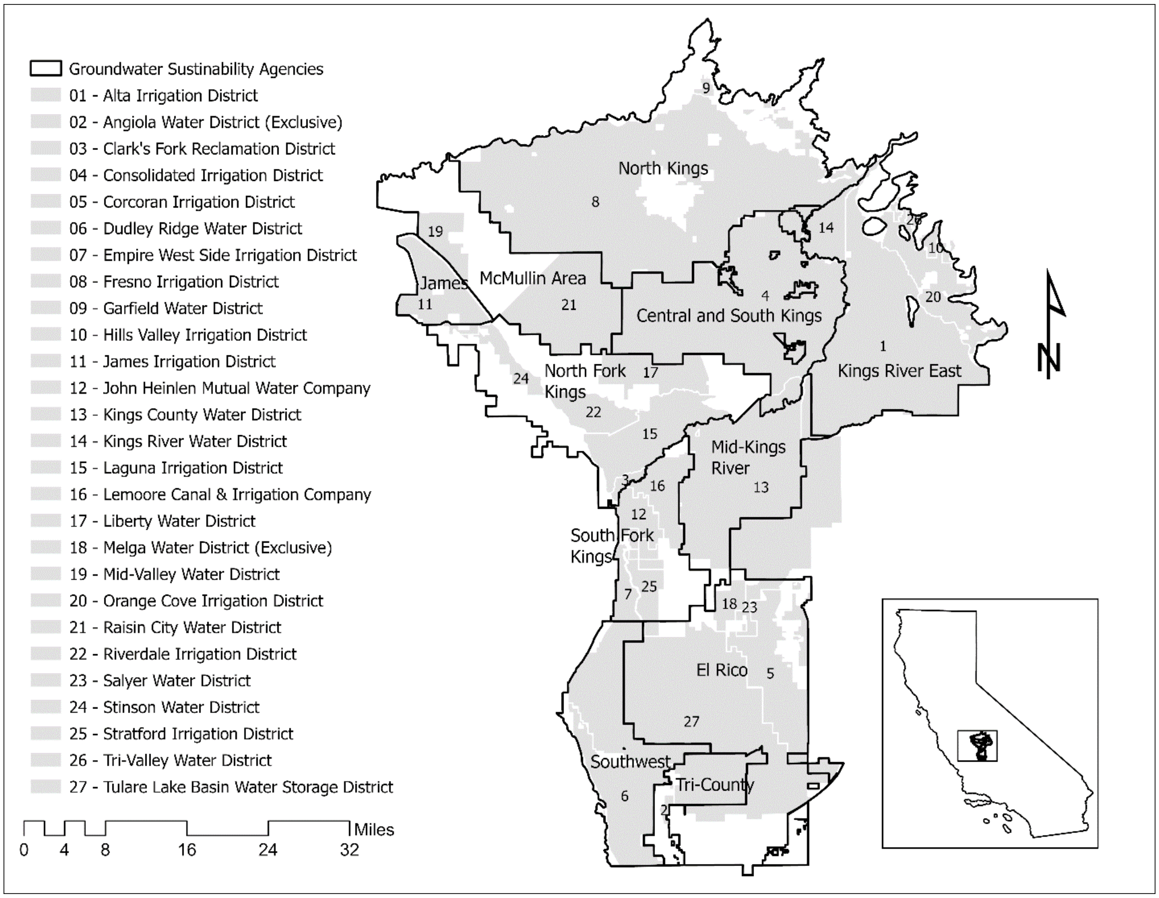

__Figure 1__: Greater Kings River Basin study area and boundary definitions. The study area encompasses 2 groundwater basins (Kings and Tulare Lake) and 12 GSAs (7 in Kings and 5 in Tulare Lake) as well as 27 water districts. Additionally, some GSAs have "white area" regions which encompass irrigated agriculture not overlaying any water district and it is assumed that these areas are completely dependent on groundwater for water supply unless otherwise noted.

Organizational entities

Two major groundwater basins overlap the study area. The Kings basin encompasses a large portion of Fresno County and small portions of Tulare County, containing Fresno ID, Alta ID, and Consolidated ID among other smaller water utilities. To the south, the Tulare Lake basin primarily covers areas within Kings County and includes the service areas of Kings County WD and Tulare Lake Basin WSD as well as a collection of other utilities. Each of the groundwater basins is divided into several Groundwater Sustainability Agencies (GSAs). These agencies serve as the local organizational units under the Sustainable Groundwater Management Act and are charged with balancing inflows and outflows in their respective groundwater aquifers as we approach SGMA's 2040 horizon.

The Kings River is conjunctively managed by several organizations, namely the Kings River Water Association and the US Army Corps of Engineers. Kings River Water Association (KRWA) is made up of 27 member units (Figure 1) consisting of the water districts allocated water from the river and the Kings River Conservation District (KRCD). Pine Flat Dam, the only major impoundment on the river, was constructed by and continues to be operated by the US Army Corps of

Engineers (USACE). Members of KRWA hold entitlement to all storage in Pine Flat Reservoir that is not set aside for flood control purposes, totaling approximately 1.0 million acre-feet (KRCD, 2009).

Contained within the study area are 27 agricultural-serving water districts as well as several private water companies that serve shareholders. Service areas of water districts can encompass shareholders of mutual water companies and districts oftentimes act as the majority shareholders of water companies, allowing entitlement to the water rights of the company. For example, Kings County WD is a partial or sole shareholder in several ditch companies within their service area, including Lakeside Ditch Company, Riverside Ditch Company, Peoples Ditch Company, and Last Chance Ditch Company (KRCD, 2009). Whereas the water source for many of the districts is the Kings River, contractors of state and federal projects also reside within the region. State Water Project contractors include Tulare Lake Basin WSD, Dudley Ridge WD, and Empire West Side ID. Central Valley Project contractors include Orange Cove ID, James ID, Fresno ID, Hills Valley ID, Tri-Valley WD, and Garfield WD. Some districts in the study area have no reliable surface water supply; for example, Raisin City WD, despite its moderate size, depends entirely on private groundwater as of 2016 and does not provide water service to its constituents (Raisin City Water District, 2016). Other districts utilize unique water management strategies, such as landowners importing water rights associated with properties outside the service area, which is a core strategy of Dudley Ridge WD (Dudley Ridge Water District, 2021).

Hydrology and water supplies

Water sources in the study area include local supplies (Kings River, Kaweah River, Tule River, miscellaneous minor waterways), imported surface supplies (Central Valley Project and State Water Project), and groundwater pumping. Canals serve an important purpose in distributing water from the Kings River and other sources to the farms in the GKRB (Figure 2). Tulare Lake Basin WSD operates the Lateral A and Lateral B canals which extend from the State Water Project's California Aqueduct and deliver water to the service area of the district. To the north, the Central Valley Project's Friant-Kern Canal stretches from Millerton Reservoir on the San Joaquin River southeast through Fresno County until terminating at the Kern River. The Kings River and groundwater pumping each provide roughly 46% of agricultural water demands, while imports and other local supplies compose 5% and 3%, respectively.

Hydrologic records of the total annual flow along the Kings River are available dating from 1954 to the present (68 years)[1]. During this period, the average annual flow of the river below Pine Flat Dam is 1.54 million acre-feet. However, during the 1997-2011 period which serves as the baseline period for the analysis in this study to retain consistency with timeframes used in GSP analyses, the average annual flow is 1.65 million acre-feet, slightly higher than the historical record. The Kings River's flow is punctuated by immensely wet periods occurring once every 3 or 4 years which serve to recharge the region's aquifers and offset dry years. The highest and lowest annual flows during the instrumental record from 1954 to the present were 4.48 million

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[1] Data described in this paragraph are in reference to monthly flow (sensor #66) for station KGF obtained from the California Data Exchange Center (CDEC), available at https://cdec.water.ca.gov.

acre-feet in 1983 (264% of average) and 360 thousand acre-feet in 2015 (21% of average), respectively.

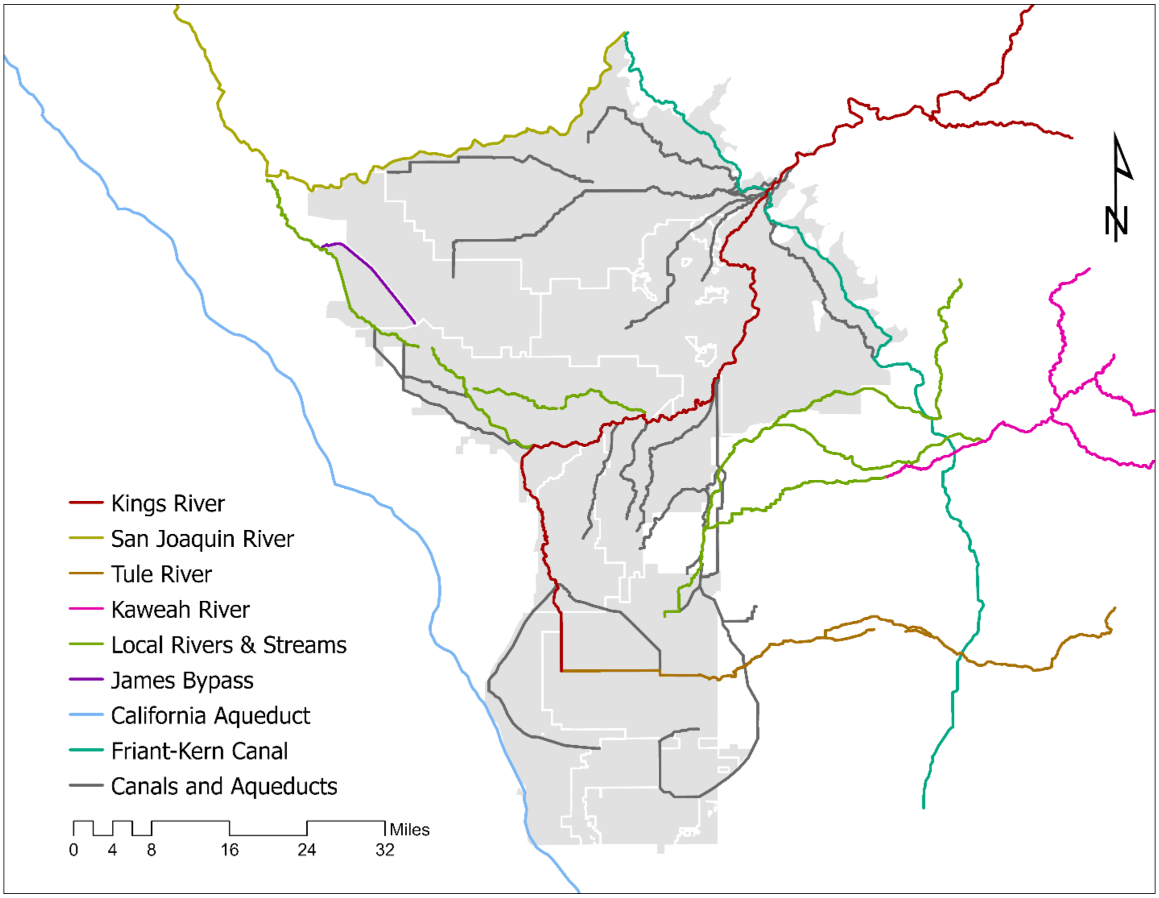

***Figure 2**: Geography of major waterways and conveyance infrastructure in the study area. Many smaller canals are not shown.*

Agricultural production and trends

About 890,000 acres of agriculture are located within the study area as of 2018 (CNRA, 2022a; author calculations). Agricultural production in the study area consists primarily of tree and vine crops and field and grain crops, which compose 63% and 26% of agricultural lands, respectively (Figure 3). Feed crops and non-tree fruit and vegetable crops compose the remaining 11% of the land within the study area. Approximately two-thirds of the total agricultural land (613,000 acres) is within the Kings basin, and the remaining one-third (278,000 acres) is within the Tulare Lake basin. Permanent crops compose 79% of agriculture in the Kings basin as compared to only 28% in the Tulare Lake basin. Annual agricultural revenues in the GKRB total about $4.85 billion with perennial trees and vines representing about 85% ($4.13 billion). Field and grain crops, non-tree fruits and vegetables, and feed crops are valued at about $337 million, $293 million, and $85 million, respectively. Revenues in the Kings basin total $3.97 billion of which 91% are permanent and 9% are annual crops. Meanwhile, revenues in Tulare Lake basin total $876 million of which 59% are permanent and 41% are annual crops.

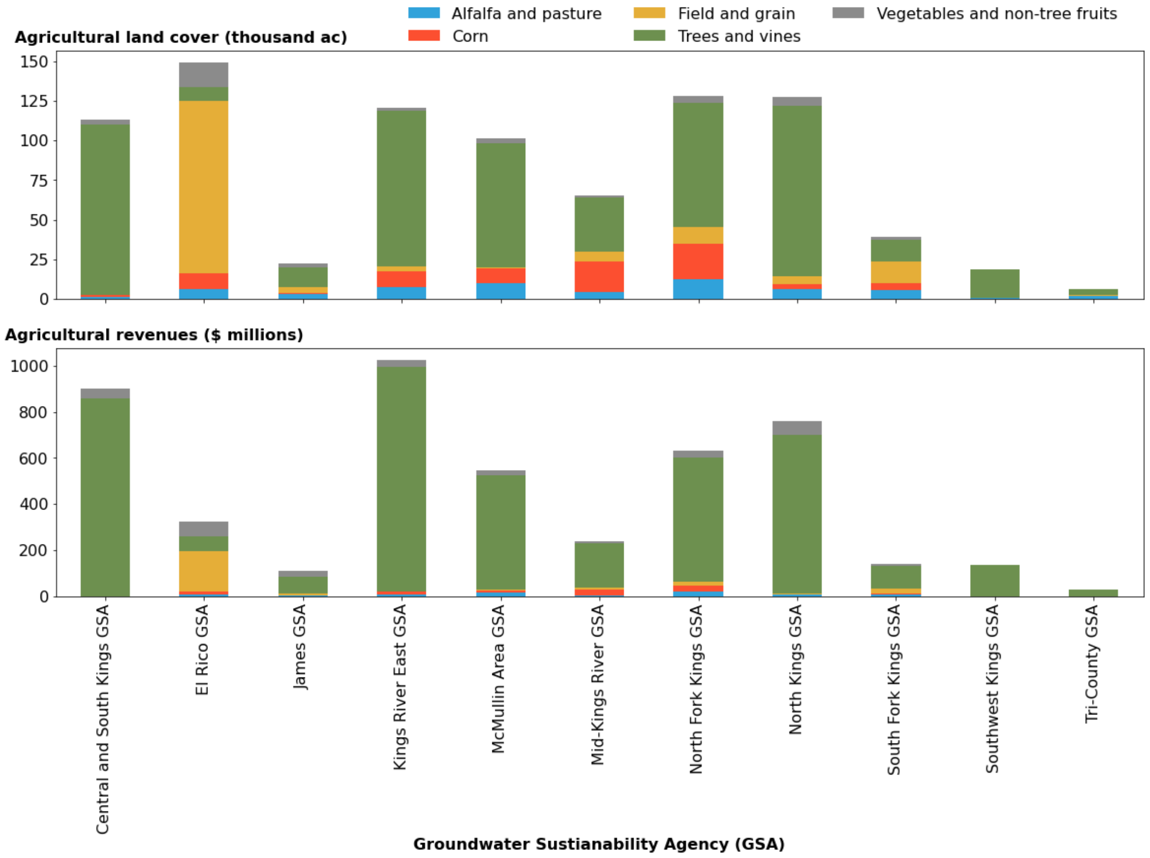

***Figure 3**: Distributions of agricultural lands by major crop classification and GSA within the study area. Source: Author calculations from the 2018 LandIQ spatial crop mapping dataset (CNRA, 2022a) and 2018 USDA NASS crop prices and yields for Fresno and Kings counties (USDA, 2022).*

Fresno and Kings, the main counties overlapping the study area, have experienced significant shifts in agricultural land use over the past several decades as documented in harvested acreage data from USDA. Figure 4 shows changes in harvested acreage of permanent crops, annual crops, and total crops between 1980 and 2018. Kings County has experienced a net reduction in total harvested acreage of 250,000 acres during this period. The major shifts consist of a reduction in annual plantings of about 325,000 acres and an increase of 75,000 acres in permanent crops. Similarly, Fresno County net reduction in total harvested acreage was approximately 215,000 acres, with 545,000 acres fewer annual crops and 330,000 acres more permanent crops over the same time period. Note that these shifts are representative of Fresno and Kings counties, respectively, rather than the study area boundary itself, but should lend some suggestions on trends for the GKRB. In addition to having implications on the agricultural revenues generated in the region, these trends suggest a "hardening" of agricultural water demands, as permanent crops cannot be temporarily fallowed during dry periods to allow flexibility in managing limited water resources (Lund et al., 2018). Inflexibility in annual irrigation demands may lend itself to more costly future droughts as regulations on water uses become more commonplace (Mall & Herman, 2019).

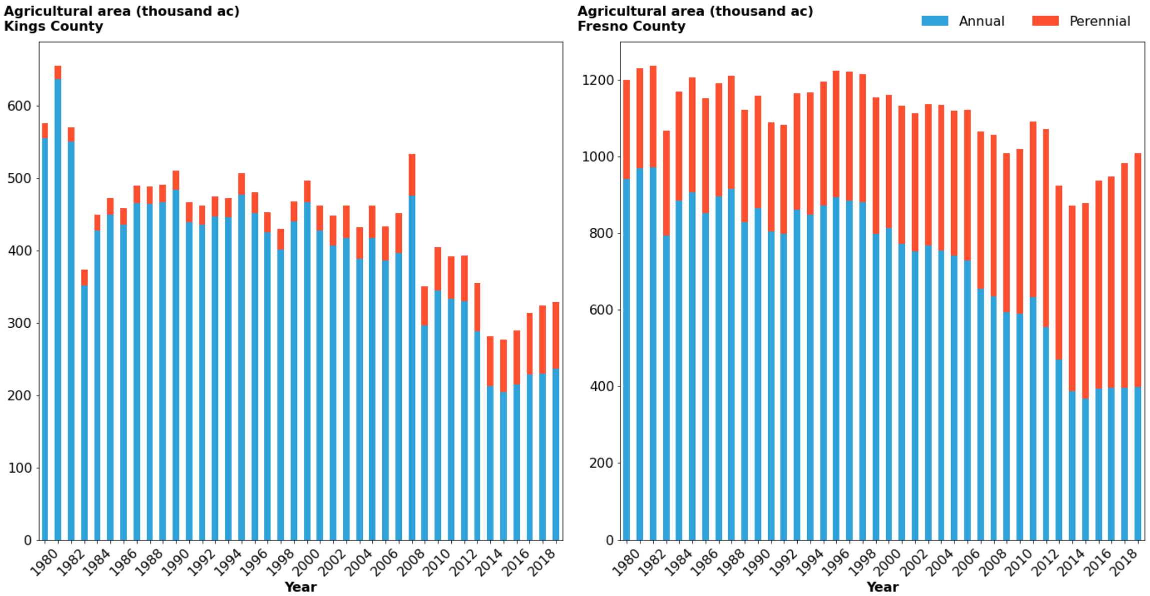

Figure 4*: Shifts in the acreage of major agricultural classes in Kings (left) and Fresno (right) counties relative to 1980 conditions. Note that these estimations cover irrigated acreages in Fresno and Kings counties rather than areas specifically encompassed by the study area boundary. Source: Author calculations from USDA NASS harvested acreage. (USDA, 2022).*

In the GKRB there are spatial concentrations of permanent and annual agricultural land cover. This paradigm largely reflects trends in physical water supply availability and water rights seniority in the study area. Districts such as Fresno ID, Alta ID, and Consolidated ID have firm water rights and priority in making diversions from the Kings River over many other downstream users, providing the water security needed to support permanent crops in larger amounts. Many of the major water districts located in the Kings groundwater basin have permanent acreage exceeding 65%. Conversely, water districts in the Tulare Lake basin have significantly lower permanent crop production; in particular, Tulare Lake Basin WSD and several small districts along the western strip of the South Fork Kings GSA have a majority of annual crops. Districts in the Tulare Lake basin often have less secure Kings River supplies and rely on imported water supplies from the State Water Project or other local supplies.

Methods

Methodological framework

The impacts of SGMA implementation in this study are examined through the lens of hydroeconomic modeling, which estimates shifts in agricultural and water management practices following profit-maximizing farmer behavior. Figure 5 highlights the major steps in the methodological approach to this research. Historical data from groundwater sustainability plans are used to capture trends in groundwater overdraft, surface water availability, and intentional groundwater recharge. This information along with more recent agricultural land use and water demand data is used to generate an expected average water balance projecting into the SGMA implementation timeframe. Agricultural production models are calibrated based on a variety of input data, including cropping distributions representative of the current period, irrigation water demands, and crop economics and production cost information. Lastly, the developed scenarios explore reductions in groundwater use under SGMA regulations and incorporate a variety of adaptation practices. These practices include flexible water trading spanning from local to regional scales as well as examining strategies for mitigating groundwater overdraft through the capture of floodwater discharge for intentional recharge. Scenarios are passed through the agricultural production model to estimate potential cropping pattern response, crop revenue losses, and amounts of water traded between parties.

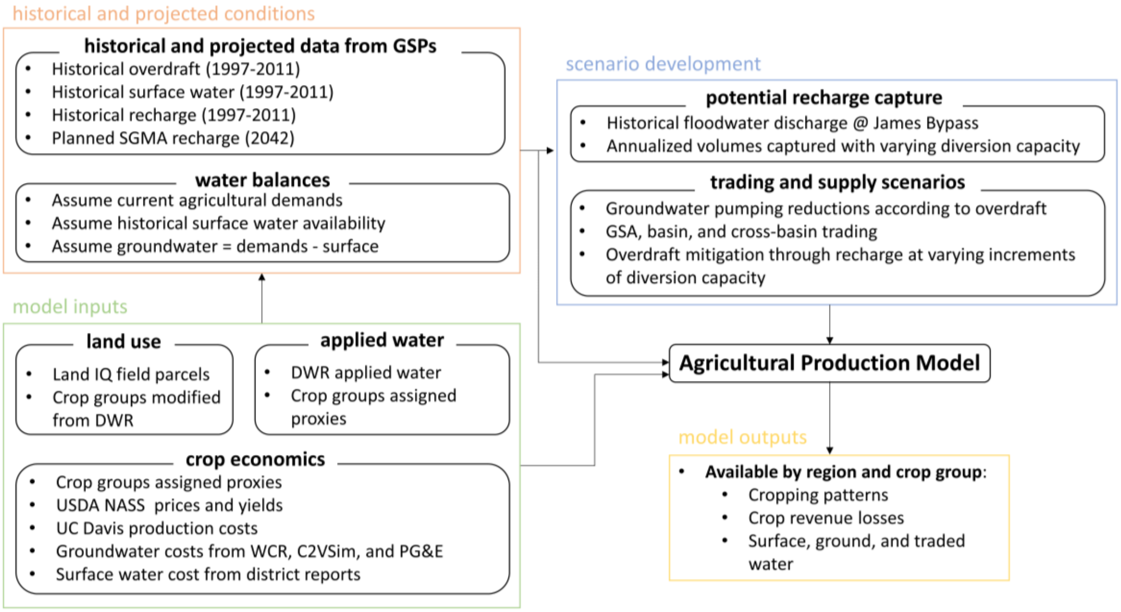

***Figure 5**: Flowchart describing the methodological approach.*

Model input datasets

Land use

Baseline agricultural land use in this study is represented by the 2018 LandIQ spatial crop mapping dataset made available by the California Department of Water Resources (CNRA, 2022a). The LandIQ dataset was chosen as the land use reference for this study for several reasons. Firstly, LandIQ includes spatial resolution of cropping types at the field scale which is paramount for locating and classifying agriculture within individual water districts or white areas. Secondly, this data source is widely considered to be the most accurate spatial crop mapping available for a variety of locations across the Central Valley, boasting accuracy exceeding 95% and covering approximately 14 million acres (CNRA, 2022a).

Land use was intersected with study area boundaries as in Figure 1 and further defined in Supplementary Information Table SI2 using ArcGIS Pro to identify overlaps and parcel areas were re-calculated to prevent double counting of parcels across district boundaries. Parcels were assigned to district service areas and additional lands were assigned to "white areas" of overlying GSAs. Processed parcels were exported and non-agricultural land uses (e.g. urban, riparian, etc.) were filtered from the dataset. The land use employed in the model considers only single-cropping; multi-cropping constitutes about 50,000 acres within the study area based on LandIQ classifications. Agricultural commodities in the LandIQ dataset were classified into 21 crop groups which are used in the modeling process. The crop groups represented in this study were developed following standard DWR groupings with modifications arising from the assessment of economically important commodities to improve the resolution of categories. The major crop groups included in this study are: alfalfa, almonds, berries, corn, cotton, cucurbits, dry beans, field and grain, wine grapes, table grapes, lettuce, onions and garlic, other orchards, other truck, pasture, pistachios, safflower, subtropical, fresh tomatoes, processing tomatoes, and walnuts. Crop groups and commodities are summarized in the Supplementary Information Table SI1. Agricultural acreages by crop group were modified by disaggregating selected crop groups, namely young perennials, vineyards, and tomatoes, which have subclasses with unique economic and production characteristics. Vineyards are distributed into wine grapes and table grapes considering harvested acreages of the respective grape types in USDA NASS for Fresno and Kings counties in 2018 (USDA, 2022). Tomatoes are distributed into processing tomatoes and fresh tomatoes using a similar approach. Young perennial acreage is distributed within each modeling region according to the standing acreage of mature perennials, as in Equation 1.

$$x_{land,i,g} = \frac{\tilde{x}_{land,i,g}}{\sum_i \tilde{x}_{land,i,g}} \tag{1}$$

$\forall\ i \in \{\text{Almonds, Pistachios, Subtropical, Orchards, Walnuts}\}$

$\forall\ g \in \{\text{regions}\}$

Where $x_{land,i,g}$ is the distributed acreage, $\tilde{x}_{land,i,g}$ is the mature acreage, and indices i and g represent crop groups and regions, respectively. The set of regions includes both water districts and white areas. To improve the stability of the model calibration, combinations of crop groups and regions with total acreage below 50 acres were removed. It is estimated that such discarded fields totaled 1,375 acres. Spatial distributions of crops by major crop group (alfalfa and pasture, corn, field and grain, trees and vines, and vegetables and non-tree fruits) are shown in Figure 6.

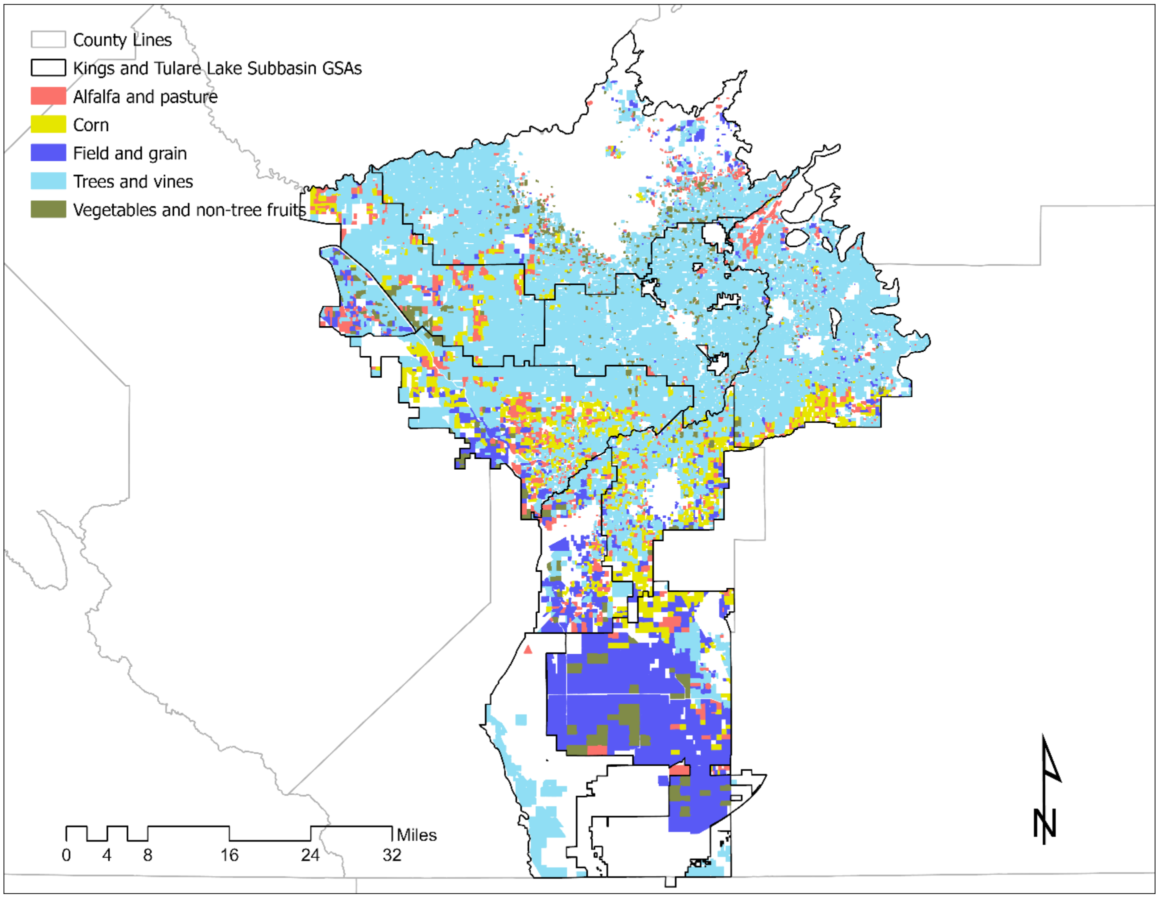

***Figure 6**: Locations of crops by major crop class (alfalfa & pasture, corn, field & grain, trees & vines, and vegetables & non-tree fruits). Source: LandIQ 2018 land use mapping dataset and author-defined classes.*

Applied water demands

Crop applied annual water demands per acre (in acre-feet/acre-yr) were estimated from DWR estimates at the Detailed Analysis Unit (DAU) scale. Relevant DAUs for the study area was located by intersecting all DAUs with the GSA boundaries for the Kings and Tulare Lake basins. Annual applied water for 2011-2013 was extracted from the DWR Water Plan dataset (CADWR, 2018) for all regional offices, and statistical summaries of mean, minimum, and maximum values were obtained for each DAU. 2011-2013 was chosen as a representative period for applied water because the 2014 and 2015 dry years may not be representative of longer-term demand trends and more recent years are not yet available to match the current land use dataset. Mean 2011-2013 applied water values were averaged for all relevant DAUs and assigned to crop groups in the model. Correction factors were applied to reduce the water demands for alfalfa and irrigated pasture to place them more in line with unit demands from Agricultural Water Management Plans (AWMPs) for major districts in the study area.

Crop prices and yields

To estimate agricultural net and gross revenues, each of the 21 crop groups used in this study was assigned a commodity to serve as a production proxy. Modeling of crop groups using proxies as opposed to individual commodities is necessary to overcome economic and other data availability bottlenecks and land use classification resolution limitations. Proxies were chosen based on assessments of acreages of individual commodities within each group in both the LandIQ dataset and harvested acreage estimates from USDA NASS for Fresno and Kings Counties. Additionally, decisions in proxies considered the suitability of commodities in representing the overall economic profile (e.g. average returns per acre) of the commodities included in crop groups. Commodities used as proxies for each crop group are given in Supplementary Information Table SI1. USDA NASS crop price, yield, and harvested acreage data (USDA, 2022) for commodities used as proxies in the model were filtered for Fresno and Kings Counties in 2018 and area-weighted average prices and yields were calculated. All prices were inflated to represent 2019 dollars. An assessment of prices for major commodities in the nearby counties between 2010 and 2019 showed no significant peaks or troughs, and 2018 prices were taken to be representative of recent trends. Safflower and dry beans prices and yields were not represented in USDA NASS for the counties overlapping the study area and thus values were taken from Tulare County. Irrigated pasture is not included in USDA NASS and economics data were instead estimated from UC Davis Cost and Return Studies for irrigated pasture production.

Crop supply elasticities

Crop price elasticities are values representing the relationship of response between total crop production and price. Higher elasticity values suggest more sensitivity and indicate that the production of the crop may respond strongly to price shifts, meanwhile a low elasticity value indicates a rather weak influence of price on crop production. These values are required for model calibration to define the curvature of the non-linear cost function. Crop-specific values can be obtained at regional scales using econometric approaches, however, literature detailing these values as relevant to California agriculture is scarce. Elasticity values were estimated for counties in the San Joaquin Valley using ordinary least squares (OLS) regressions predicting planted acreage as a function of price and were refined with values from the literature[2].

Crop production costs

Production input costs for the selection of crops in the study were estimated using selected UC Davis Cost and Return Studies (UCDC&R). UCDC&R studies survey individual producers of commodities and detail crop production information including establishment costs, equipment costs, land capital costs, labor expenses, input costs, and anticipated returns. Nearly all available cost studies relevant to the selected proxy commodities in this study were considered, totaling 54 entries distributed across the 21 crop groups. Costs in the model database are distributed across 4 categories: land, supplies, labor, and water. Following these categories, line items in the cost portfolio within each study were categorized into land, supplies, and labor costs. Water costs in the model are calculated using a separate approach and are not derived from the UCDC&R studies. Land capital and rental costs were excluded when determining costs for the final model database under the assumption that these costs are fixed regardless of land cover and are thus not relevant to the decision-making process driving crop shifts. Land costs include

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[2] Crop supply elasticities were estimated using price, yield, and harvested acreage data for San Joaquin Valley counties from USDA NASS reports. See Rodríguez-Flores et al., 2022 for more information.

other fixed costs associated with the farm production including insurance, taxes, annualized perennial establishment costs, and annualized equipment costs. Supplies costs include pesticides, fertilizer, fuel, and other miscellaneous material costs. Labor costs include hand and machine labor as well as custom costs for externally hired services, such as packing and hauling products. Importantly, the commodities used to develop cost structures for the model should ideally be the same as the economic proxies assigned for prices and yields, and at the least should have comparable revenues to avoid distorting the profits of the crop group.

Whereas UCDC&R studies include estimated crop returns and suggest an anticipated profit margin from price and yield ranges, the provided returns oftentimes show poor agreement with USDA price and yield information. To combat these discrepancies, the costs and returns from the UCDC&R studies are used to develop portfolios of costs by type relative to the suggested returns and these cost shares are applied to crop price and yield information from USDA NASS to determine final costs used in the model. For each of the three cost types taken from UCDC&R studies, cost shares are calculated as in Equation 2 and are applied to calculate the final costs as in Equation 3.

$$f\omega_k = \frac{\omega_{s,k}}{p_s y_s} \tag{2}$$

$$\omega_{m,k} = f\omega_k p_m y_m \tag{3}$$

$\forall\ k \in \{\text{land, labor, supplies}\}$

Where $f\omega_k$ is the cost fraction relative to returns, $\omega_{s,k}$ is the UCDC&R study cost, p_s and y_s are the average crop prices and yields estimated in the study, respectively, and p_m and y_m are the crop prices and yields from USDA NASS used in the model, respectively, and k gives the index for input type.

Surface and groundwater costs

Water sources in the model include surface and groundwater, of which each has a distinctive cost associated with its use. Surface water sources in the study area are imported State Water Project (SWP) water, imported Central Valley Project (CVP) water, and local diversions. Whereas the wholesale cost to districts in obtaining water supplies from these sources may differ, retail rates for deliveries to individual agricultural users are often consistent within districts except under special circumstances (e.g. severe drought conditions, locations requiring specialty infrastructure, or volumetric allocation exceedance). Agricultural water rates and structures can vary greatly between districts and often change from year to year as water availability influences voting approval to change water rates and structures. In the GKRB many irrigation districts with senior water rights (e.g. Consolidated ID, Fresno ID) have implemented a rate schedule consisting of fixed charges on a per-acre basis subject to allocations depending on water availability or hybrid schedule with fixed and volumetric components. Other districts with less secure water supplies (e.g. Orange Cove ID) generally opt for a volumetric schedule and obtain most of their revenue from water sales rather than assessments. Considering the range of rate scheduling strategies used by districts in the study area, the average equivalent volumetric rate was estimated to be about $35/acre-foot.

Costs for groundwater are attributed to the energy cost associated with lifting water out of the aquifer. Unit pumping costs are estimated using the approach outlined in Equation 4 as a function of electricity price, potentiometric depth, and pump system efficiency.

$$\omega_{ground,g} = \frac{p_e h_p\left(9.81\frac{m}{s^2}\right)\left(1233.48\frac{m^3}{af}\right)\left(998\frac{kg}{m^3}\right)}{\eta_s\left(3.6*10^6\frac{J}{kWh}\right)} \tag{4}$$

$\forall\ g \in \{\text{regions}\}$

Where ω_{ground} (\$/af) is the unit electricity cost for groundwater pumping, h_p (m) is the potentiometric head, p_e (\$/kWh) is the average electricity price, and η_s (%) is pump system efficiency. Unit electricity cost is assumed to be 22¢/kWh based on PG&E 2015-2019 average rates for large agriculture (Pacific Gas & Electric Company, 2022), and pump system efficiency is assumed to be 75%. These values are intended to capture representative energy costs for pump lift and as such do not consider drawdown, friction losses, and capital well costs.

Potentiometric heads for each region were estimated using C2VSim-FG Version 1.01 (Brush et al., 2013) input data and Well Completion Reports (WCR) records (CNRA, 2022b). Monthly head values by layer and ground surface elevations for each node in the C2VSim-FG mesh were used to calculate time series node depths by layer from 1973 to 2015. Node depths were averaged across each water year and layer to simulate the approximate annual conditions considering seasonal fluxes in groundwater levels at each node. Average depths by model region were calculated after mapping individual node locations to districts and white areas. To determine which aquifer layers were most relevant for groundwater pumping in each model region, WCR records for agricultural production wells with spatial information and descriptions of well screen locations were isolated. The C2VSim-FG node nearest to each well in the WCR subset was found using spatial analysis techniques and the bottom of well screen locations were compared to aquifer stratigraphy information for the relevant node to determine which aquifer layer the well was likely extracting water from. Aquifer layers most relevant to calculating pumping costs for each model region were determined assuming that the layer with the highest number of wells terminating in it would best replicate potentiometric heads for pumping. Mean depths by model region in the layers identified were taken for the 2015 water year and assigned as the potentiometric head for use in Equation 4. The total counts of nodes and wells utilized in this analysis were n=2,765 and n=12,399, respectively. After assessing the most suitable aquifer layer to represent pumping in each region, the average potentiometric head and unit pumping cost across the study area were estimated to be about 152 ft and \$45/acre-foot, respectively.

Water availability by source

Historical surface water deliveries were provided in GSPs and were extensively reviewed to construct district-scale portfolios of water by source. In the Kings basin GSPs, diversions from the Kings River (1966-2017) and water from the Central Valley Project (1997-2011) to individual water districts and companies were provided annually. Surface water for the Tulare Lake basin was provided for individual diversion points (e.g. canal turnouts and weirs) on an annual basis (1997-2011) and includes local diversions and water from the State Water Project. Kings River diversion amounts in the GSPs are aggregated from Kings watermaster records. To retain consistency with the period of analysis for overdraft in the GKRB GSPs, 1997-2011 was chosen as a representative period for assessing average annual surface water availability. This period includes a variety of water year types considering Kings River flows, with the period containing 4 "wet" years, 3 "dry" years, and 8 "normal" years. This analysis excluded about 50 thousand acre-feet per year of non-agricultural CVP supplies in the North Kings GSA which are allocated for the City of Fresno. Although Fresno ID also has flexible contracts with the City of Fresno to provide additional supplies when needed, these contracts are not firm and this water was assumed to be openly available to Fresno ID. Locations of deliveries in the Kings and Tulare Lake basins were reclassified to reflect the attribution of surface water availability to districts in this study. Supplementary Information Table SI3 gives a full explanation of how surface water deliveries were attributed. Figure 7 summarizes annual surface water deliveries for GSAs in the study area from 1997-2011 including Kings River diversions, CVP supplies, SWP supplies, and other local supplies from the Tule and Kaweah Rivers and other minor streams. On average, Kings River and groundwater each supply about 46% of water use in the study area, while other local sources provide 3% and imports from CVP and SWP account for 2% and 3% of use, respectively. The total applied water for irrigation is about 3.3 million acre-feet per year across the GKRB.

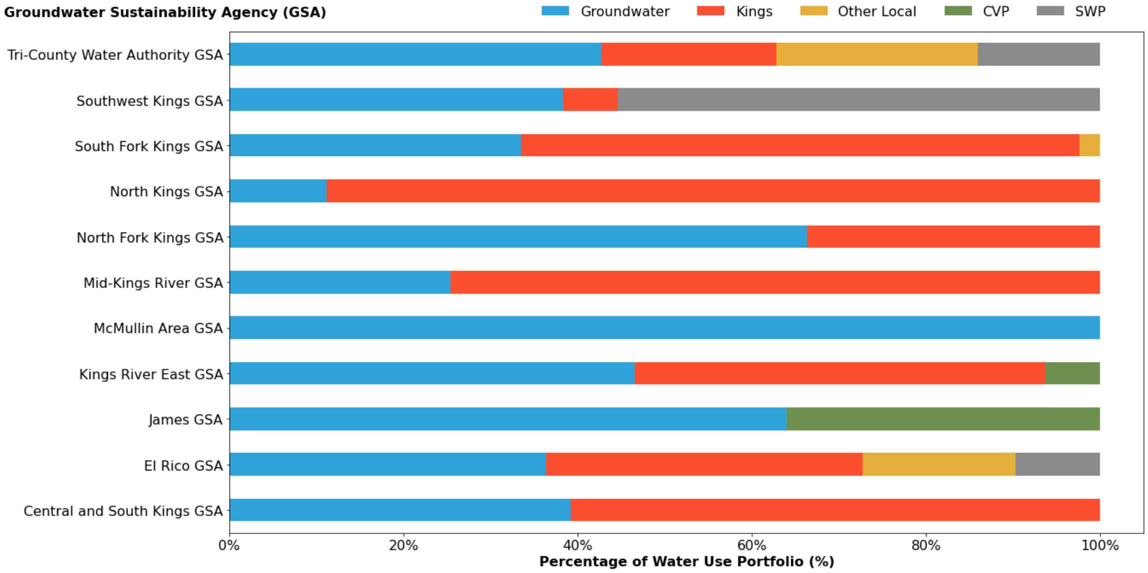


***Figure 7**: Average water use by source portfolio by GSA considering average 1997-2011 surface water deliveries and 2018 agricultural demands. Other local supplies include the Tule River, Kaweah River, Deer Creek, and other minor local supplies. Source: Author calculations from Kings and Tulare Lake basin GSPs, LandIQ 2018 land use mapping dataset, and DWR applied water use by crop type.*

Scenario development

Water balances under SGMA

Agricultural demands for each model region were estimated from data on land use and applied water described in the above sections. Surface water deliveries for agriculture were estimated following the previously described approach using an average of 1997-2011 data from the GSPs. Groundwater use for each region were calculated assuming pumping closed balances between surface water availability and agricultural water demands. Total demands in the GKRB were estimated to be about 3.3 million acre-feet and surface water and groundwater uses were estimated at 1.8 and 1.5 million acre-feet, respectively. Table 1 summarizes base agricultural demands, surface water uses, and groundwater pumping for each GSA area in the study area.

This study assumes future agricultural water demands before considering SGMA implementation will remain similar to those of the 2018 cropping baseline outlined above. Meanwhile, the average availability and distribution of surface water resources to individual KRWA units in the SGMA timeline are assumed to be consistent with the historical period of 1997-2011 presented in the GSP water budgets. Likewise, groundwater overdraft follows the estimates outlined in the GSPs based on the historical period. It is assumed that overdraft shares will be distributed among each GSA according to the current coordination agreements outlined in each groundwater basin or other GSP estimates of which GSAs are driving groundwater overdraft. The total overdraft is estimated at 285 thousand acre-feet, with 198 thousand acre-feet and 87 thousand acre-feet in the Kings and Tulare Lake basins, respectively. Table 1 below outlines the estimated overdraft in each basin and the distribution of mitigation shares to each GSA. Irrigation efficiency is needed to estimate the net impacts of overdraft mitigation to account for the deep percolation of applied water which recharges the aquifer.

***Table 1**: Overdraft mitigation shares, irrigation demands, surface water use, groundwater use, and average irrigation efficiency by groundwater sustainability agency. Asterisks indicate GSAs that have zero or negative responsibility according to coordination agreements and other GSP estimates. Source: Kings and Tulare Lake basin GSPs.*

Basin	**Groundwater Sustainability Agency**	**Agricultural demand (af/yr)**	**Surface water use (af/yr)**	**Groundwater use (af/yr)**	**Overdraft share (af/yr)**	**Irrigation efficiency (%)**
Kings	Central and South Kings GSA	453,194	275,366	177,828	8,828	84
	James GSA*	90,149	32,465	57,684	0	80
	Kings River East GSA	458,691	245,184	213,506	13,678	82
	McMullin Area GSA	407,813	0	407,813	113,151	79
	North Fork Kings GSA	486,186	163,671	322,515	62,544	80
	North Kings GSA*	501,919	445,752	56,168	0	82
	Kings basin subtotal	**2,397,952**	**1,162,438**	**1,235,515**	**198,200**	**81**
Tulare Lake	El Rico GSA	452,015	287,848	164,167	20,810	85
	Mid-Kings River GSA	235,810	176,018	59,793	28,490	85
	South Fork Kings GSA	135,875	90,381	45,494	37,840	85
	Southwest Kings GSA*	81,573	50,332	31,241	0	85
	Tri-County WA GSA*	24,503	14,033	10,470	0	85
	Tulare Lake basin subtotal	**929,777**	**618,612**	**311,165**	**87,140**	**85**

	Study area total	**3,327,729**	**1,781,050**	**1,546,679**	**285,340**	**83**

Water trading

Water trading can serve as an important tool for mitigating costs for agriculture during times of water scarcity by allowing water to be traded towards areas with higher economic demand and reducing aggregate economic impacts. The benefits of agricultural-to-urban water transfers have been well studied in various literature, while trading within agricultural systems has been increasingly examined in recent research (Chong & Sunding, 2006). For example, amid drought in 1991, the state developed an emergency water bank—the 1991 California Drought Water Bank (CDWB)—which was used to facilitate water transfers. These transfers consisted primarily of water sales from farmers of field and grain crops and were sold within the market to support urban uses and high-value permanent crops (McBean & Bautista, 1995). Additionally, Hanak et al. (2019) place agricultural water trading among the most promising strategies for reducing the costs of transitioning to a sustainable groundwater future under SGMA. However, achieving flexible water trading can be complicated by institutional dimensions, including infrastructure constraints, whether relevant parties have established trading agreements, determining transaction costs, logistics in the coordination of trades, and other challenges.

As a baseline, this study assumes that surface water trading occurs among parties within each GSA to reduce aggregate economic impacts of water shortages on agriculture. Under the within-GSA trading assumption, water will be distributed to crops in a way that attempts to retain higher-value crops first if scarcity is present. Whereas field and grain crops and other lower value commodities are not assumed to forfeit water to more profitable crops, the model formulation will likely embrace this exchange until reaching a dynamic economic equilibrium point considering the portfolio of existing crops in each GSA area. In this study, an explicit transaction cost for facilitating water transfers is not administered and it is assumed that trades may occur if a net economic benefit can be realized. Scenarios in this study explore more flexible trading options by incrementally expanding the trading pool to include first all users within their respective groundwater basin and then users across basin boundaries.

Water trading in this study encompasses all sources of surface water but excludes explicit groundwater trading. Sources of surface water within the GKRB include the Kings River, Tule River, Kaweah River, CVP imports, SWP imports, and other minor local supplies. Kings River water is diverted by nearly all water districts outlined in this study and composes about 86% of the total average surface water use in the study area. Other local supplies, including the Tule and Kaweah Rivers, are only significant in the Tulare Lake groundwater basin and can be seasonally ephemeral. Imported CVP water is provided to some districts in the Kings River East GSA via the Friant-Kern Canal and SWP water is brought to districts in the Southwest Kings, Tri-County WA, and El Rico GSAs through lateral canals from the California Aqueduct. It is assumed that the bulk of surface water transfers would be facilitated through the forfeiture of diverting rights for Kings River supply to other parties either upstream or downstream of the trader. Additionally, it is assumed that the necessary infrastructure for facilitating water trades either currently exists or will likely be constructed within the SGMA timeframe. Minor flexibility in groundwater pumping distributions compared with the baseline water balance is allowed and explained further in future sections but direct groundwater transfers are not considered in this study.

Recharge capture

Most natural waterways within the GKRB have historically terminated in the now-dry Tulare lakebed, with flows from the Kings River, Kaweah River, and Tule River being diverted for agricultural purposes before reaching this location or seasonally pooling during particularly wet periods. The Kings River splits into two forks near the border between the Kings and Tulare Lake groundwater basin boundaries. The South Fork continues and terminates in the Tulare lakebed while the North Fork travels northwest through the Murphy Slough towards the Fresno Slough. Water from the North Fork is diverted away from entering the Fresno Slough through the man-made James Bypass which was constructed in 1912 to prevent flooding damages in the vulnerable slough. Flows through the bypass represent the historical water leaving the basin that was not diverted for irrigation, urban uses, or recharge capture. Figure 8 below shows daily discharge through the bypass for the available record of 1947 to 2009 from USGS gage number 11253500. Gage data is unavailable from the beginning of the 1954 water year through 1973. Maximum discharges have reached just above the 4,750cfs design capacity of the bypass whereas typical flows during normal and dry years are 0cfs.

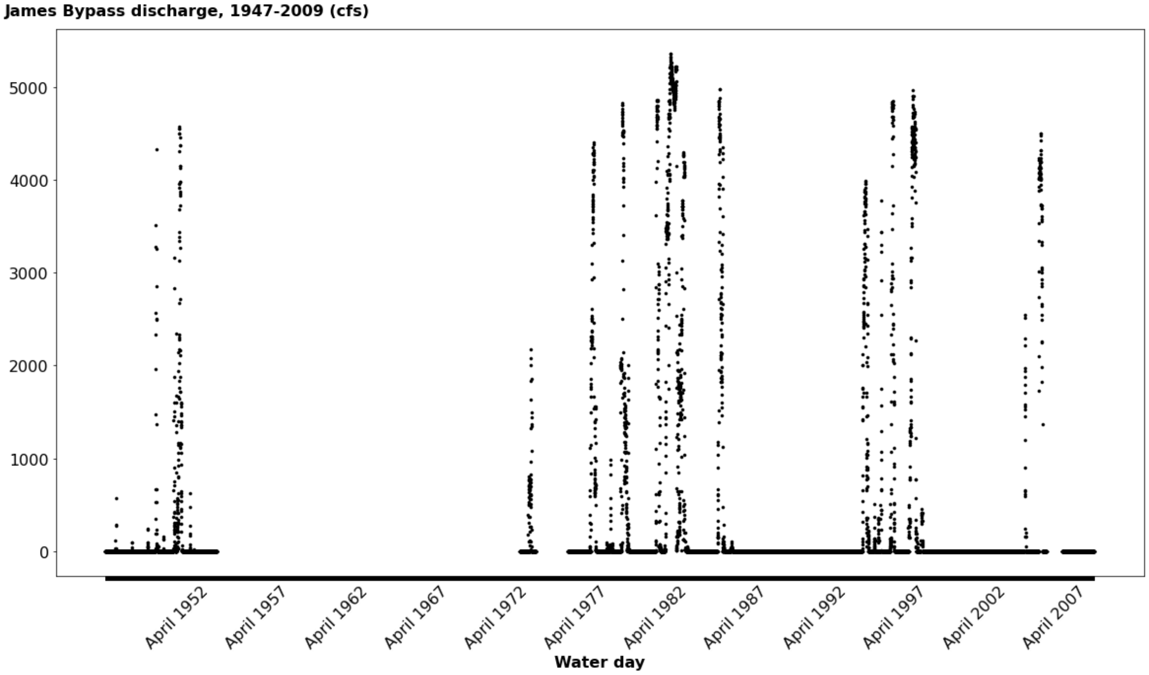


***Figure 8**: Daily discharge from the James Bypass, 1947-2009. Source: USGS data for James Bypass station (gage number 11253500).*

To estimate uncaptured floodwater leaving the basin that could be developed in future years to offset groundwater storage depletion, historic James Bypass discharge was examined. Records for the 1997-2009 period were selected to examine annual discharge through the bypass to maintain relative consistency with the 1997-2011 period used in the development of the GSP water balances. Using the 1997-2009 subset of daily discharge, potential recharge capture from the James Bypass was estimated under diversion capacity constraints ranging from 0cfs to 4,500cfs at 100cfs intervals. If the daily average discharge exceeded the capacity constraint at each time step, it was assumed that only the flow below the threshold was captured. Total capture volumes from this method were annualized at each diversion capacity by dividing by the number of years contained in the period assessed. This analysis was carried out using Python 3.8 and annualized floodwater capture volumes as a function of diversion capacity were estimated as presented in Figure 9. At a maximum assumed diversion capacity of 4,500cfs, it would be possible to capture up to an average of 140 thousand acre-feet per year after assessing daily flows under this threshold. Although it may be possible to capture additional flow if diversion capacity were expanded to the maximum observed discharge amount of 5,360cfs, these flows exceed the design capacity of the bypass itself and logistical challenges would likely provide barriers for capturing these flows. Assessing a longer term period which includes the 1970s and early 1980s—during which time the Kings River experienced a number of particularly wet years—may suggest slightly higher volumes of water with the potential for supporting recharge. Whereas historical James Bypass discharge data is used to estimate the potential for recharge capture, diversions of this flow could be achieved upstream of where the Kings River splits into the North Fork and South Fork to the north of Lemoore and before the water enters the James Bypass. Recharge may be facilitated through a variety of approaches including uses of constructed basins or on-farm recharge projects which use existing agricultural areas as makeshift infiltration basins.

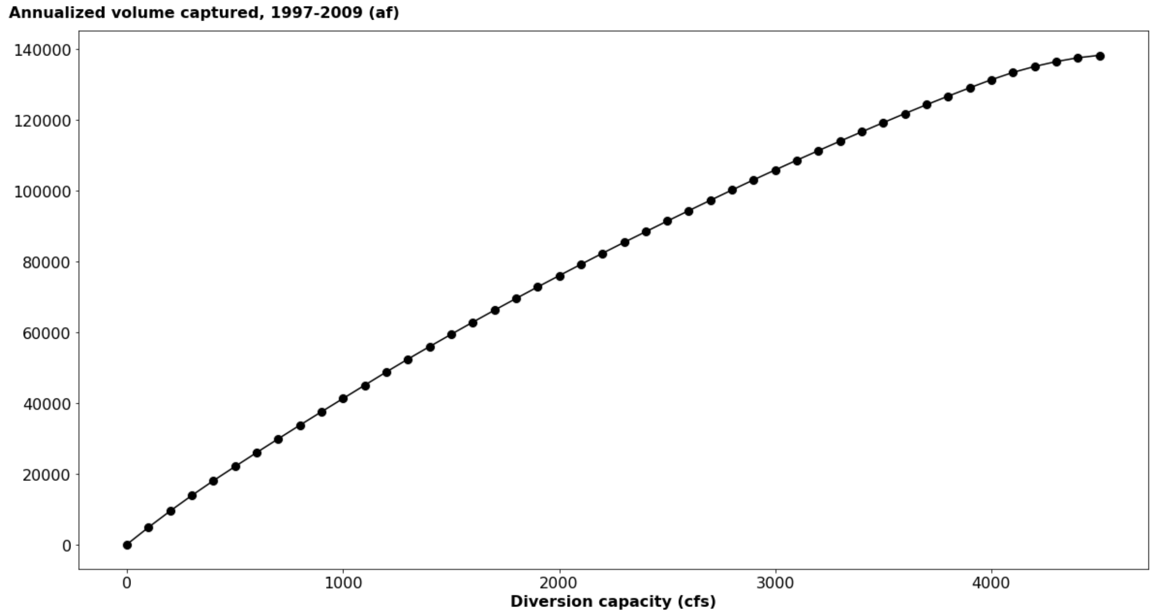


Figure 9: *Potential floodwater capture for recharge as a function of James Bypass diversion capacity. Calculated from 1997-2009 subset of daily discharge. Source: USGS.*

Summary of modeling scenarios

Twelve scenarios are examined in this study (**Table 2**). Each scenario assumes that groundwater overdraft responsibilities must be mitigated through demand reduction but can be offset by the development of new groundwater supplies from recharge efforts. Scenarios combine assumptions about trading flexibility and the levels of potential recharge capture attainable within the SGMA sustainability timeframe of 2040. Four levels of recharge capture (0cfs, 1500cfs, 3000cfs, and 4500cfs) were chosen to represent the range of possible outcomes associated with the investments made to improve floodwater capture. Under the no recharge capture (0cfs) scenarios (A, E, and I), it is assumed that future intentional groundwater recharge remains consistent with historical trends in terms of amounts and locations of recharge. Additional scenarios (which exclude A, E, and I) explore the potential for greater floodwater capture relative to the historical period according to the equivalent diversion capacity required to divert water away from the James Bypass. It is assumed that new supplies in the Kings Basin are distributed relative to each GSA's share of overdraft responsibility—except for GSAs with no overdraft responsibility according to the coordination agreements (see Table 1)—resulting in a distribution of 57% to McMullin Area GSA, 32% to North Fork Kings GSA, 7% to Kings River East GSA, and 4% to Central and South Kings GSA. No additional supplies are assumed to be developed in Tulare Lake GSAs. It is assumed that these new supplies can only be used within the GSAs they are assumed to be developed within and that these supplies cannot be traded or exchanged with other areas. More information on how scenarios are implemented in the modeling framework is provided in future sections.

***Table 2**: Summary of trading and recharge capture scenarios examined in modeling.*

Scenario code	**Trading flexibility**	**Equivalent diversion capacity (cfs)**	**Annualized recharge capture (af/yr)**	**Scenario description**
A	GSA	0	0	GSA trading and 0cfs additional recharge capture.
B	GSA	1,500	59,312	GSA trading and 1500cfs additional recharge capture.
C	GSA	3,000	105,763	GSA trading and 3000cfs additional recharge capture.
D	GSA	4,500	138,130	GSA trading and 4500cfs additional recharge capture.
E	Basin	0	0	Basin trading and 0cfs additional recharge capture.
F	Basin	1,500	59,312	Basin trading and 1500cfs additional recharge capture.
G	Basin	3,000	105,763	Basin trading and 3000cfs additional recharge capture.
H	Basin	4,500	138,130	Basin trading and 4500cfs additional recharge capture.
I	Cross-basin	0	0	Cross-basin trading and 0cfs additional recharge capture.
J	Cross-basin	1,500	59,312	Cross-basin trading and 1500cfs additional recharge capture.

K	Cross-basin	3,000	105,763	Cross-basin trading and 3000cfs additional recharge capture.
L	Cross-basin	4,500	138,130	Cross-basin trading and 4500cfs additional recharge capture.

Hydroeconomic agricultural production model

Positive Mathematical Programming

Scenarios are examined in this research with a calibrated hydroeconomic agricultural production model (henceforth “model”) built upon the concept of Positive Mathematical Programming (PMP; Howitt, 1995). Agricultural PMP approaches use a minimal set of data on input uses, land allocations, and economic production data to calibrate an optimization model which exactly replicates observed conditions when no when no resource use limitations or crop production economics depart from baseline conditions. PMP operates on the assumption individual farmers or agricultural management entities aim to maximize profits when making decisions about crop plantings. Thus, marginal costs of production are equal marginal revenues at the *observed* baseline conditions. PMP implicitly captures non-linearities in crop production conditions which may cause overspecialization under alternative methods (e.g. linear programming), preventing an over-abundance of high-profitability crops which may not reflect baseline production conditions. Such non-linearities include soil quality, risk tolerance, water supply reliability, and availability of investment capital, among others. Once calibrated, a PMP model can be used as a tool to test diverse sets of scenarios by introducing appropriate resource constraints or penalties to the profit-maximizing objective function.

Thus, calibration employs available data for crop production economics, water availability by source, and contemporary agricultural land uses to represent a “baseline” condition that serves as the reference to assess various water management or policy scenarios. In this study, baseline 2040 crop production is drawn using 2018 land, and assumes that economic and surface water availability conditions follow historical trends. Scenarios build on top of this baseline to incorporate groundwater overdraft requirements under SGMA and approaches for mitigating these impacts (e.g. recharge and surface water trading). Region delineations in the model follow a tiered approach ranging from the scale of individual water districts to groundwater sustainability planning areas (GSAs), and finally to the groundwater basin scale. The use of multiple spatial designations allows for greater flexibility in implementing scenarios within the model framework. Regional definitions used in the model can be found in Supplementary Information Table SI2. The PMP model is coded in Python 3.8 and uses the GLPK and IPOPT solvers for linear and non-linear optimization, respectively.

Model calibration

The agricultural production model in this study builds upon the OpenAg model developed by Medellin-Azuara et al. (2023), which has been applied in several case studies throughout California and the Pacific Northwest. Calibration of the agricultural model was undertaken following the methodology outlined in Howitt et al. (2012) with modifications to incorporate a split of surface and groundwater supplies as described in Rodríguez-Flores et al. (2022).

Calibration follows a four-step process consisting of (1) testing for positive marginal crop profitability, (2) solve a linear optimization program to observed values, (3) parameterize a non-linear cost function and a constant elasticity of substitution (CES) production function (Howitt et al. 2012), and (4) validate production input use by comparing with baseline conditions. After all calibration procedures and quality checks have been completed the calibrated model is modified to simulate scenarios. Units of all terms are in \$2019 USD, tons, acres, and acre-feet.

Non-positive net margins in crops (checking point in step 1) often disrupts resource allocation in the linear program (step 2 above) leading to an inability to derive Lagrange values on the observed land constraint (Howitt et al. 2012). Non-positive net returns occur for a variety of reasons, including accounting of a wide range of costs in the cost and return studies that are sometimes not applicable, and mismatch of gross returns information that is obtained from a different database. To remedy such data caveats, Equations 5 and 6 are employed to readjust average revenues and costs to have a nominal profit.

$$f_{\pi,i,g} = \frac{p_{i,g}\, y_{i,g}}{(1+t_{\pi})\sum_k \omega_k} \tag{5}$$

$$\widehat{\omega}_{k,i,g} = f_{\pi,i,g}\omega_{k,i,g} \tag{6}$$

$\forall\ k \in \{\text{land, labor, supplies, water}\}$

$\forall\ g \in \{\text{regions}\}$

$\forall\ i \in \{\text{crops}\}$

Where f_{π} is the profitability correction factor, p is crop price, y is crop yield, ω_k is initial cost by input type, t_{π} is a user-defined minimum profitability threshold, and $\widehat{\omega}_k$ gives the corrected cost by input type. In this way, costs are downscaled slightly to achieve minimum crop profitability without magnifying gross revenues. Corrections are only applied in cases when the minimum profitability threshold is not met and is not applied to crops at or above this threshold. The minimum profitability threshold for this study is chosen to be 2.5% net returns over gross returns. Future instances of the term ω_k indicate corrected cost values.

In stage two of the calibration process, optimization of crop profits aggregated by region and constrained by observed conditions in land allocation by crop type is performed. Through the optimization, Lagrange values on land are obtained and used in parametrizing the nonlinear cost function for the calibrated model. Equations 7 through 9 specify the linear optimization program (step 2).

$$Max\ \{x_{land,i,g}\}\ \Pi_g = \sum_i x_{land,i,g}\left(p_{i,g}y_{i,g} - \sum_k \omega_{k,i,g}\right) \tag{7}$$

Subject to:

$$\sum_i x_{land,i,g} \leq \sum_i \tilde{x}_{land,i,g} \tag{8}$$

$$x_{land,i,g} \leq \tilde{x}_{land,i,g} + \varepsilon \tag{9}$$

$\forall\ k \in \{\text{land, labor, supplies, water}\}$

$\forall\ g \in \{\text{regions}\}$

$\forall\ i \in \{\text{crops}\}$

Where x_{land} is the decision variable for land allocation by crop, p is crop price, y is crop yield, ω_k is cost by input type, $\tilde{x}_{land}$ is the baseline observed land allocated by crop, and ε is a perturbation parameter to ensure that Lagrange values can be obtained. During the calibration phase of model development, the water unit cost, ω_{water} is a weighted average of costs for surface and groundwater sources considering available supplies by region. When the optimization is solved, a Lagrange value on the general land constraint, λ_{land}, is calculated from Equation 8 and crop-specific Lagrange values, λ_{crop}, are similarly calculated from Equation 9. In Equation 7, the g index indicates that the optimization is performed individually for each model region and thus unique Lagrange values may be obtained for crops in each region.

In the third stage of calibration, the Lagrange values obtained from the linear optimization program are employed to parametrize a Constant Elasticity of Supply (CES) production function with constant returns to scale as in Equation 10 (Howitt et al. 2012).

$$\varphi_{i.g} = \tau_{i,g} \left(\textstyle\sum_k \beta_{i,g,k}\, x_{i,g,k}^{\rho}\right)^{\frac{\upsilon}{\rho}} \tag{10}$$

$$\tau_{i,g} = \frac{y_{i,g} x_{land,i,g}}{\left(\sum_i \beta_{i,g,k} x_{i,g,k}^{\rho}\right)^{\frac{\upsilon}{\rho}}} \tag{11}$$

$\forall\ k \in \{\text{land, labor, supplies, water}\}$

$\forall\ g \in \{\text{regions}\}$

$\forall\ i \in \{\text{crops}\}$

Where φ is the production output, τ is a “scale parameter” (Equation 11), β_k is the share parameter by input type, y is crop yield, x_k is the production use factor by input type, ρ is a parameter calculated as $\rho = \frac{\sigma-1}{\sigma}$ where σ is the elasticity of substitution (assumed to equal 0.17 following Howitt et al. 2012), and k, g, and i are the subindexes for input type, model region, and crop, respectively. Constant returns to scale require that $\upsilon = 1$ and $\sum_k \beta_k = 1$. CES function cost share parameters for the four inputs (land, labor, supplies, and water) are calculated as in Equations 12 and 13.

$$\beta_{land,i,g} = \left[\frac{1}{1+\left(\frac{x_{land,i,g}^{-\frac{1}{\sigma}}}{\omega_{land,i,g}+\lambda_{land,g}+\lambda_{crop,i,g}}\right)\left(\sum_k \frac{\omega_{k,i,g}}{x_{k,i,g}^{\left(-\frac{1}{\sigma}\right)}}\right)}\right] \tag{12}$$

$$\beta_{k,i,g} = \beta_{land,i,g}\left[\frac{x_{land,i,g}^{\left(-\frac{1}{\sigma}\right)}\left(\frac{\omega_{k,i,g}}{\alpha_{k,i,g}}\right)}{\left(\alpha_{k,i,g} x_{land,i,g}\right)^{\left(-\frac{1}{\sigma}\right)}\left(\omega_{land,i,g}+\lambda_{crop,i,g}+\lambda_{land,g}\right)}\right] \tag{13}$$

$\forall\ k \in \{\text{labor, supplies, water}\}$

$\forall\ g \in \{\text{regions}\}$

$\forall\ i \in \{\text{crops}\}$

Where x_k is the production use factor by input type, ω_k is cost by input type, λ_{land} and λ_{crop} are the general and crop-specific Lagrange values, respectively, σ is the elasticity of substitution, and α_k is the Leontief coefficient by input type. The Leontief coefficients are equal to 1 for all inputs excluding water where the value is the crop unit applied water requirement. Notice the exclusion of land from the input set indexed to k as the share parameter of land is calculated in Equation 12 and used as a term in calculating the remaining share parameters. Also, as part of step 3 is the specification of an exponential (PMP) cost function, requiring the parametrization of the elasticity parameter and exponential intercept of the land area response function as in Equations 14 and 15.

$$\gamma_{i,g} = \frac{1}{\theta_i \tilde{x}_{land,i,g}} \tag{14}$$

$$\delta_{i,g} = \frac{\omega_{land,i,g} + \lambda_{crop,i,g}}{\gamma_{i,g} \exp(-\gamma_{i,g} \tilde{x}_{land,i,g})} \tag{15}$$

$\forall\ g \in \{\text{regions}\}$

$\forall\ i \in \{\text{crops}\}$

Where θ is the supply elasticity, $\tilde{x}_{land}$ is the observed land use, ω_{land} is the land cost, λ_{crop} is the crop-specific Lagrange value, and exp() is the natural exponential. All subindexes are as defined in previous paragraphs.

Finally, in the fourth stage, the calibrated model is checked to assess for model performance in matching baseline conditions for production input use in all crops and regions. The objective of the calibrated model is to maximize net returns by regional unit of analysis, by allocating input resources to the production of different crops. When checking the calibration, a weighted average cost of water is used to account for baseline surface and groundwater supplies. The model is subject to constraints on total land and water availability in addition to a constraint limiting deficit irrigation. Equation 16 below gives the model objective function and Equations 17-19 give additional constraints acting on the model.

$$Max.\{x_{k,i,g}\}\ \Pi_g = \sum_i \left[(p_{i,g} \varphi_{i,g}) - \left(\delta_{i,g} \exp(\gamma_{i,g} x_{land,i,g}) \right) - \sum_{k \neq land} (\omega_{k,i,g} x_{k,i,g}) \right] \tag{16}$$

Subject to:

$$\sum_i x_{land,i,g} \leq \sum_i \tilde{x}_{land,i,g} \tag{17}$$

$$\sum_i x_{water,i,g} \leq \sum_i \tilde{x}_{water,i,g} \tag{18}$$

$$\frac{x_{water,i,g}}{x_{land,i,g}} \geq 0.999 \alpha_{water,i,g} \tag{19}$$

$\forall\ k \in \{\text{land, labor, supplies, water}\}$

$\forall\ g \in \{\text{regions}\}$

$\forall\ i \in \{\text{crops}\}$

Where x_k is the decision variable for input allocation by crop and input type, p is crop price, φ is the CES production function, δ is the intercept of the cost function, γ is the elasticity parameter of the cost function, ω_k is cost by input type, $\tilde{x}_k$ is the observed production use factor by input type, α_k is the Leontief coefficient by input type, and $\exp()$ is the natural exponential. Equation 16 gives the maximization of the objective function performed for each region (subindex g). The first term in the objective is crop gross revenues calculated from the average price and the CES production function. The second term represents the crop specific nonlinear PMP costs attributed to land which are calculated from the parameters from the previous steps. The third term gives the sum of average costs for other inputs apart from land. Equations 17 and 18 define the general resource constraints for land and water, respectively, which restrict allocatable resources to the observed amounts. Equation 19 defines a deficit irrigation constraint that prevents the program from allocating more land to the production of individual crops than what can be supported by the associated water allocations. After solving the optimization for each region, allocated land and water resources are checked against the observed amounts and cases of crop and region combinations where allocated land or water deviate beyond a 1% threshold from the input database are treated as calibration failure, suggesting a need for revisions in the calibration process.

Calibrated model

The fully calibrated model follows Equations 16-19 above with adjustments to support scenario implementation using constraints. Whereas the calibration procedure uses a blended water cost and does not distinguish water by source, the calibrated model separates the two. A constraint is also introduced to limit the retirement of silage corn in the study area; although silage corn does not have high economic value as compared to many alternative crops, it is needed as an input to feed operations for dairies in the surrounding area and may be prioritized over other low-value crops when adapting to water scarcity. Lastly, a constraint on total allocable acreage for combinations of crops and regions is added to improve model performance and behavior when expanding the optimization to various scales.

Optimization in the fully calibrated model is undertaken by aggregating model regions at the spatial scale pertaining to the scenario and enforcing constraints arising from potential management actions. Unless otherwise constrained, it is assumed that benefits (e.g. development of additional surface supplies) and costs (e.g. land fallowing due to groundwater curtailments) are shared by the districts or other entities within each GSA. Equations 20-27 define the fully calibrated model.

$$Max\ \{x_{k,i,g}\}\ \Pi_j = \sum_i \Big[\left(p_{i,g}\varphi_{i,g}\right) - \left(\delta_{i,g}\exp\left(\gamma_{i,g}x_{land,i,g}\right)\right) - \sum_{k=labor,supplies}\left(\omega_{k,i,g}x_{k,i,g}\right) - \omega_{surface,i,g}x_{surface,i,g} - \omega_{ground,i,g}x_{ground,i,g}\Big] \tag{20}$$

Subject to:

$$\sum_i x_{land,i,g} \leq \sum_i \tilde{x}_{land,i,g} \tag{21}$$

$$\sum_i \left(x_{surface,i,g} + x_{ground,i,g}\right) \leq \sum_i \tilde{x}_{water,i,g} \tag{22}$$

$$\sum_i x_{surface,i,j} \leq \left(\sum_i \tilde{x}_{surface,i,j}\right) + f_{surface,j} \tag{23}$$

$$\sum_i x_{ground,i,j} \leq \left(\sum_i \tilde{x}_{ground,i,j}\right) + f_{ground,j} \tag{24}$$

$$\frac{x_{water,i,g}}{x_{land,i,g}} \geq 0.975\alpha_{water,i,g} \tag{25}$$

$$x_{land,corn,g} \geq 0.75\tilde{x}_{land,corn,g} \tag{26}$$

$$x_{land,i,g} \leq 1.05\tilde{x}_{land,i,g} \tag{27}$$

$\forall\ k \in \{\text{land, labor, supplies, surface water, groundwater}\}$

$\forall\ g \in \{\text{regions}\}$

$\forall\ j \in \{\text{GSA, basin, cross-basin}\}$

$\forall\ i \in \{\text{crops}\}$

Where all parameters are as defined previously with the addition of decision variables for surface ($x_{surface}$) and groundwater (x_{ground}) and associated modifications to the resource list (subindex k). Subindex j refers to the trading flexibility allowed in the model scenario (GSA, basin, or cross-basin) and determines the aggregation at which the optimization is performed and how constraints are administered. Equation 22 limits allocations of surface and groundwater to observed irrigation requirements. Equations 23 and 24 constrain the allocation of surface and groundwater supplies, respectively, to the observed water balance with terms ($f_{surface}$ and f_{ground}) to represent potential shifts in resource availability (e.g. groundwater pumping restrictions imposed by scenarios). Equation 25 limits deficit irrigation in crops to 2.5% of observed unit applied water requirements. Lastly, Equation 26 requires the model to allocate at least 75% of the observed land use for corn in each model region following the explanation given above. Equation 27 constrains the model to allocate only up to 105% of the observed land use for any individual crop and region combination because the calibration process occurs for individual regions and can create discrepancies that are capitalized on by the optimization by expanding valuable crops when grouping multiple regions. In lieu of this constraint, the model behavior may prioritize expanding permanent crops to offset economic losses from reducing acreage for low-value crops.

Modeling scenarios

Scenarios are implemented using the model outlined in Equations 20-27 and associated sets for inputs, regions, and crops with modifications to reflect water availability and trading flexibility. Firstly, depending on the trading preference for the selected scenario the model optimization will be performed at that scale (GSA, basin, cross-basin). If modeling is performed at basin scale for example, then selected constraints are applied to finer spatial scales (GSA) but resource allocation considers the optimal pattern across the entire basin. Secondly, Equation 24, which gives the total regional groundwater use constraint is modified to reflect the SGMA restrictions and additional sustainable pumping allowed under scenarios with recharge augmentation. The supply modifying term f_{ground} is calculated as in Equation 28 below.

$$f_{ground,g} = \frac{(OD_g + R_g)}{\eta_{irr,g}} \tag{28}$$

$\forall\ g \in \{\text{GSAs}\}$

Where OD is the overdraft share of the region, R is the annualized recharge augmentation volume associated with the scenario, η_{irr} is average irrigation efficiency in the region, and subindex g is as defined previously but refers to GSAs. Values for all parameters are given in Tables 1 and 2 with accompanying explanations of how annualized recharge is distributed to individual GSAs.

Lastly, constraints are added to help bound shifts in resource uses when the optimization scale is expanded. In Equation 29 groundwater use for model regions (water districts, white areas) is constrained to be at least one-quarter of the pumping in the base water balance. Equation 30 limits the upper bound on pumping in model regions to be 105% of base pumping plus any recharge augmentation in the associated GSA area. These constraints are added to ensure that groundwater uses in model regions do not shift too far from base amounts when flexibility is allowed which can occur due to differences in pumping depths and cost. Finally, Equation 31 explicitly constrains the maximum groundwater use within each GSA area to the base amount plus recharge augmentation. Note that Equations 29 and 30 use model regions (water districts, white areas) as their spatial subindex while Equation 31 uses GSA for its subindex.

$$\sum_i x_{ground,i,g} \geq 0.25 \sum_i \tilde{x}_{ground,i,g} \tag{29}$$

$$\sum_i x_{ground,i,g} \leq 1.05 \sum_i \left(\tilde{x}_{ground,i,g}\right) + f_{ground,g} \tag{30}$$

$\forall\ g \in \{\text{regions}\}$

$\forall\ i \in \{\text{crops}\}$

$$\sum_i x_{ground,i,j} \leq \left(\sum_i \tilde{x}_{ground,i,j} \pm f_{ground,j}\right) \tag{31}$$

$\forall\ j \in \{\text{GSAs}\}$

$\forall\ i \in \{\text{crops}\}$

Where all terms are as defined in previous sections and f_{ground} is calculated as in Equation 28 above.

Results

This section summarizes modeling findings broadly for scenarios and regions. **Table SI4** through **Table SI27** in the Supplementary Information section provide detailed modeling results for individual regions and scenarios.

Study area land fallowing, revenue losses, and net groundwater pumping reductions

For this study, results are presented relative to baseline scenario A which represents an implementation of SGMA by 2040 with local trading and no additional water supplies from floodwater capture (Figure 10). Under the baseline scenario, the total annual reduction in applied water for irrigation from groundwater pumping across the study area is 351 thousand acre-feet (10.6%) after accounting for percolation from irrigation. Reductions in available water under scenario A result in the fallowing of roughly 71,000 acres (8.0%) of current agricultural land and entail crop revenue losses of about $208 million (4.3%).

Keeping assumptions about local flexibility in water trading, scenarios B, C, and D explore the benefits of capturing additional supplies in the form of groundwater recharge. Scenario B assumes an annual average of about 59,000 acre-feet in expanded floodwater capture for recharge, reducing total water shortages, land fallowing, and crop revenue losses to 278 thousand acre-feet (8.4%), 53,000 acres (6.0%), and $139 million (2.9%), respectively. In scenario C another 47 thousand acre-feet per year are assumed to be recharged, reducing water shortages to 221 thousand acre-feet (6.6%). These water availability changes further improve economic outcomes, with crop revenue losses of $103 million (2.1%) and 41,000 acres (4.6%) of fallowed land. Lastly, scenario D assumes a generous 138 thousand acre-feet of annual capture over baseline conditions reducing water shortage to just 181 thousand acre-feet (5.4%), with economic losses and land retirement of $81 million (1.7%) and 32,000 acres (3.6%), respectively.

In the next set of simulations—scenarios E through H—surface water may be traded among parties within each of the two groundwater basins in the study area (Figure 10). Scenario E replicates SGMA conditions under this trading assumption and assumes that no new supplies are developed from management actions or projects (water shortage 10.6%), resulting in 73,000 acres (8.1%) of fallow land and $156 million (3.2%) in crop revenue losses. Fallow land increases slightly when flexibility in water trading is added because cropland taken out of production (primarily field and grain) tend to have lower unit water demands as compared to crops retired in the previous scenarios (forage crops, trees and vines). In scenario F surface water trading is allowed between parties within each basin in addition to capturing an estimated annual 59,000 acre-feet in recharge to offset groundwater pumping—resulting in a net water shortage of 278 thousand acre-feet (8.4%), crop revenue losses totaling $107 million (5.8%), and land fallowing of 52,000 acres (2.2%). Scenarios F and G continue trends in improving floodwater capture and have net groundwater use reductions of 221,000 and 181,000 acre-feet per year, respectively (6.6% and 5.4%). Associated land fallowing and crop revenue losses total 37,000 (4.2%) and 27,000 acres (3.0%) and $78 million (1.6%) and $56 million (1.1%), respectively. Economic outcomes in scenarios with basin-level trading are consistent with equivalent scenarios with limited trading options and one less increment of supply augmentation (e.g. paired scenarios E and B, F and C, and G and D perform similarly).

Scenarios I, J, K, and L examine optimistic cases where all parties in the study area can engage in surface water trading regardless of location (Figure 10). In Scenario I, no additional supplies are developed, resulting in the same total groundwater shortage as in scenarios A and E (10.6%) but surface trading opportunities shift trends in fallowing. Total fallow land increases relative to scenario E to 76,000 acres (8.6%) and crop revenue losses decrease to $131 million (2.7%) and more fallowing occurs in the Tulare Lakebed where an abundance of field and grain crops are produced. Scenario J reduces water shortages to 278 thousand acre-feet (8.4%) by capturing 59 thousand acre-feet of new supplies, resulting in 54,000 acres (6.1%) and $105 million (2.2%) in land fallowing and crop revenue losses, respectively. Water use reductions in scenario K decrease to 221 thousand acre-feet (6.6%), accompanied by reductions in impacts on land fallow and revenue losses to 38,000 acres (4.2%) and $79 million (1.6%). Finally, in scenario L an estimated 138 thousand acre-feet could be captured to offset overdraft (water shortage 181 thousand acre-feet, 5.4%). Under these conditions and assuming the most flexible surface water trading practices, land fallowing totals about 26,000 acres (2.9%) and revenue losses from crops are $57 million (1.2%). More flexible trading provides about $25 million in benefits over within-basin options in scenario I but provides negligible economic benefits when more supplies are available (scenarios J, K and L).

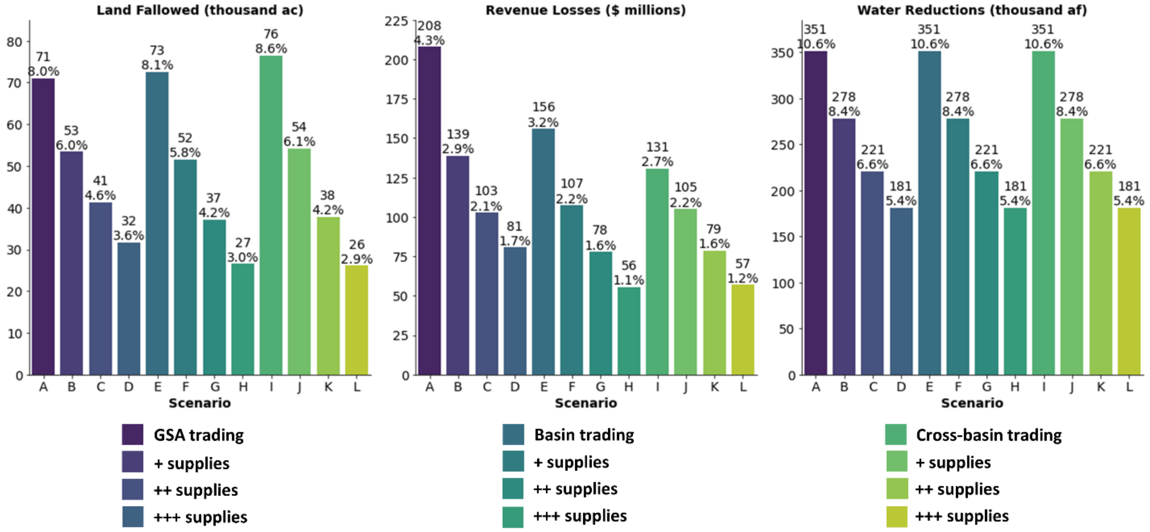


***Figure 10**: Summarized land fallowing, revenue losses, and net water use reductions for the study area in all scenarios.*

Outcomes for management areas

Modeling results highlight disparities in impacts across GSAs, individual water districts, and white areas, which are a product of differences in overdraft shares, water supply portfolios and characteristic cropping patterns. The GSA with the highest overdraft share is McMullin Area GSA with net pumping reductions of 113 thousand acre-feet per year required before accounting for recharge from percolating applied water—representing 57% of the total overdraft in the Kings basin and 28% of the GSA's annual demand. North Fork Kings GSA follows in overdraft with just under half of the McMullin share or about 63 thousand acre-feet per year. On the other hand, several GSAs have no responsibility for reducing groundwater pumping: Southwest Kings GSA, Tri-County WA GSA, James GSA, and North Kings GSA are not required to adjust their groundwater use.

These conditions are reflected especially in the results of scenarios A through D, where land fallowing and revenue losses from crops are concentrated in areas with high overdraft responsibility and the ability to import surface water is limited. In scenario A when no supplies are developed the most impacted areas are McMullin Area GSA and South Fork Kings GSA, which have percentage-wise land fallowing of 30.0% and 26.8% and revenue losses of 20.6% and 21.4%, respectively. About half of the 30,000 acres of land fallowed in McMullin Area GSA is attributed to removals of tree and vine crops such as almonds, grapes, and pistachios, and another 10,000 acres—nearly all base acreage—of alfalfa and pasture are expected to come out of production. Perennial removals in McMullin account for about three-quarters of revenue losses totaling $112 million when supplies and trading are restricted. South Fork Kings GSA experiences severe losses as well, with about 10,000 acres fallowed consisting of 4,000 acres of field and grain crops, 2,300 acres of perennials, and 2,600 acres of alfalfa and pasture among other minor crop losses. Revenue losses total $30 million with about half attributed to tree and vine removals. North Fork Kings GSA also experiences significant fallowing of 18,000 acres and revenue losses of $37 million under scenario A but these impacts are less pronounced as a percentage of production. When surface water trading is restricted but groundwater is replenished with 138,000 acre-feet of annual supplies (scenario D) impacts in South Fork Kings GSA remain nearly the same as in scenario A, however, McMullin Area GSA significantly benefits from new supplies—resulting in land fallowing and revenue losses to 8.3% and 3.7%, respectively. Fallowing in McMullin drops from about 30,000 acres to only 8,400 acres and halving economic pressures on tree and vine crops.

As trading flexibility increases in the scenarios, crop fallowing patterns shift to reflect opportunities for trading that preserve valuable agriculture at the expense of less economically productive lands. Figure 11 gives insight into these trends by summarizing impacts at the GSA level. McMullin Area GSA stands out as the most economically impacted area in scenario A when trading with outside GSAs is restricted. Impacts across all three variables (land fallowing, revenue losses, and net water use reductions) drop substantially in scenario E when trading within the basin is allowed, facilitating reductions in land fallowing from 30,000 acres to 10,000 acres and revenue losses from $112 million to $23 million through purchasing surface water in the amount of 84 thousand acre-feet from other parties. El Rico GSA, which sprawls the Tulare Lake bed, exhibits an opposite response as trading becomes more accessible. While initial overdraft responsibility in this area and hence impacts in scenario A are minor compared with other areas, El Rico exports water when opportunities are presented due to the prominence of lower-value commodities that could be retired (see **Figure 3**) as demonstrated in scenarios E and I where El Rico experiences substantial increases in land fallowing and net water use reductions.

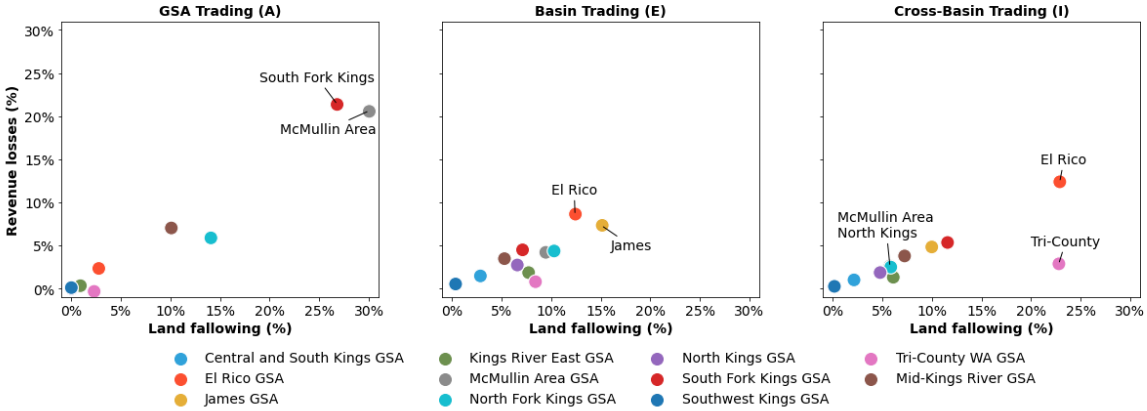


***Figure 11**: Land fallowing, revenue losses, and net water use reductions summarized by GSA for all scenarios. GSAs in the results panel of the figure (left) are organized from north to south as displayed in the map panel (right).*

Model results also predict shifts in cropping and water use behaviors for water districts, as presented for scenarios A, E, and I in Figure 12. When trading is allowed only within GSAs (scenario A), districts with the highest percentage-wise impact in land fallowing and revenues include Mid-Valley WD, Raisin City WD, John Heinlen MWC, Stratford ID, Empire West Side ID, and Lemoore Canal & Irrigation Company. Additionally, white areas in McMullin Area GSA and South Fork Kings GSA are anticipated to have significant losses (see **Table SI4**). In scenario E when trading is expanded to other parties within each basin the land use and economic losses for individual districts become more balanced; whereas in scenario A several users have reductions in irrigated land and/or revenues above 20%, impacts for all districts are below 20% in scenario E except for Kings River WD which has high fallowing of irrigated pasture. Lastly, when cross-basin trading is permitted (scenario I) many districts experience impacts similar to those in scenario E, however, total land fallowing in Tulare Lake Basin WSD doubles from 15% to 30%.

Mid-Valley WD benefits the most from water trading, reducing revenue losses by 33 percentage points under cross-basin trading, followed by Raisin City WD which can reduce economic impacts by 19 percentage points. John Heinlen MWC, Empire West Side ID, Stratford ID, and Lemoore Canal & Irrigation Company can each reduce their revenue losses by between 15 and 17 percentage points through trading. Meanwhile, economic losses from trading are much less pronounced for individual regions, with Tulare Lake Basin WSD, Melga WD, and Salyer WD being the only parties experiencing greater than 10 percentage points in revenue losses attributed to water transfers. Most benefits from trading can be achieved with transfers between parties in each basin (scenario E) with cross-basin trading only benefiting a limited number of districts and posing significant administrative challenges.

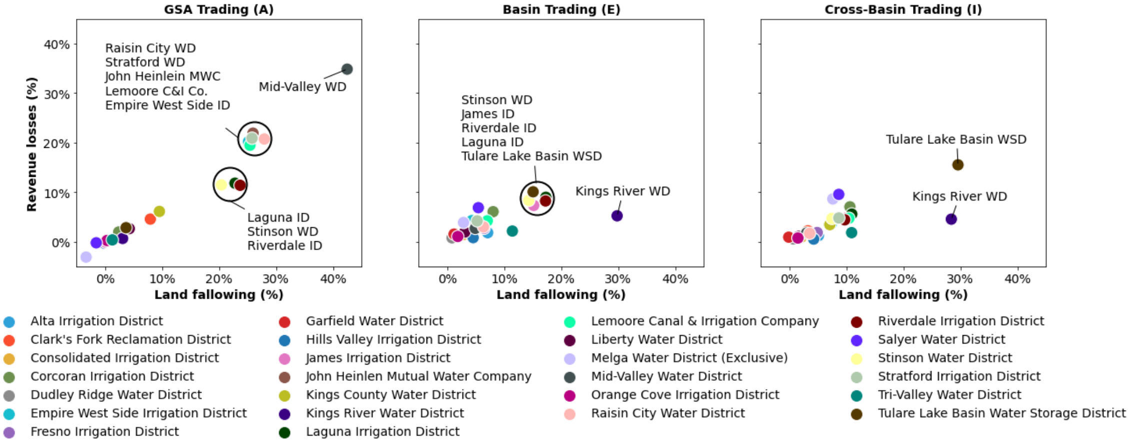


***Figure 12**: Land fallowing and agricultural revenue losses by model region relative to base land and revenue amounts. Values presented are for scenarios without supply augmentation (scenarios A, E, and I). Values for white areas are excluded to prevent clutter.*

Cropping pattern shifts

Aggregate land fallowing impacts across the study area for each scenario are summarized in **Figure 13**: Land fallowing summarized by major crop class and scenario.Figure 13 for five major crop classes: alfalfa and pasture, corn, field and grain, trees and vines, and vegetables and non-tree fruits. As scenarios progress through increments of supplies within each trading sequence (e.g. scenarios A to D) the need to reduce applied water from pumping becomes less constraining and total land fallowing tends to decrease. Trends in fallowing by crop class reflect profitability and trading constraints and result in similar land retirement for some classes even as supplies become available. For example, in scenarios A through D, fallowing of field and grain crops remains similar whereas fallowing in trees and vines and alfalfa and pasture are reduced by over two-thirds and one-half, respectively. Scenarios E through H with basin trading exhibit similar trends, as do scenarios I through L with cross-basin trading yet fallowing of field and grains composes a more significant portion of fallow land and thus decreases more substantially as supplies become available. Total land fallowing in scenarios with comparable water supplies remains similar, however, portfolios of which crops are taken out of production can vary substantially depending on trading flexibility. Scenarios A, E, and I each have slightly above 70,000 acres of land fallowed, although the portions of this land composed of alfalfa and pasture, field and grain, and trees and vines change substantially from 35%, 14%, and 32% in scenario A to 45%, 23%, and 15% in scenario E, and finally 39%, 41%, and 11% in scenario I.

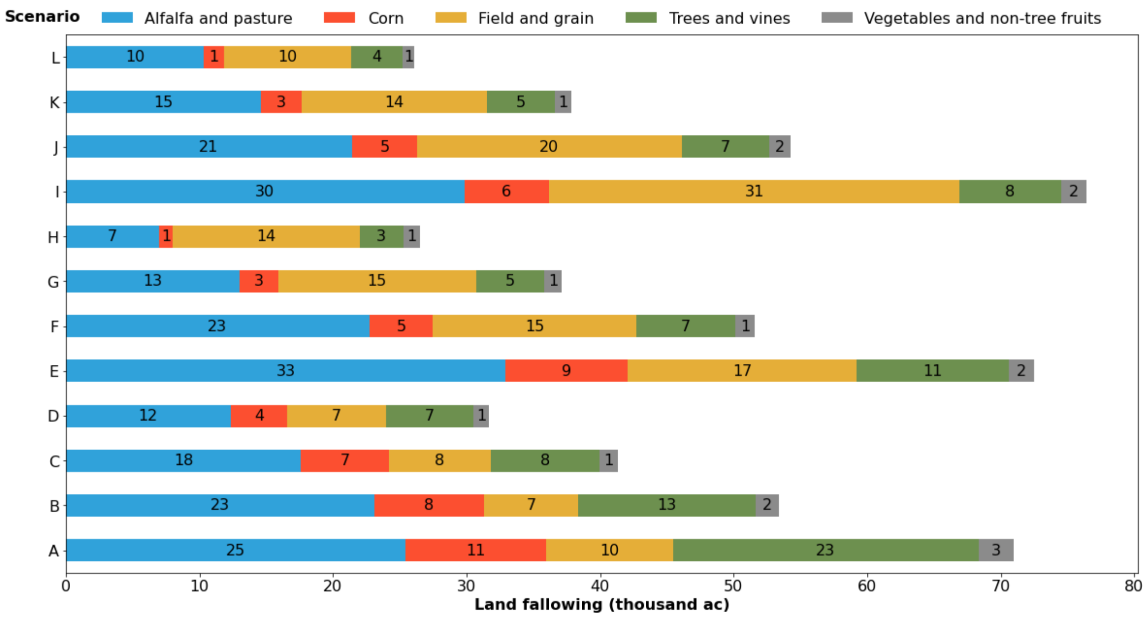


***Figure 13**: Land fallowing summarized by major crop class and scenario.*

Whereas modeling results forecast potential shifts in cropping behaviors at the scale of model regions and crop categories, insights about finer spatial trends can be drawn through mapping these impacts to parcel scale crop mapping (Figure 14). In Figure 14 fallow risk is calculated as a percentage of land fallowed relative to the base land in each combination of crop and region, thus representing the approximate probability that a given parcel is fallowed according to the modeling results. Under scenario A, risks for parcel fallowing are concentrated in areas with the highest overdraft shares, namely the McMullin Area, North Fork Kings, and South Fork Kings GSAs. Of the 59,000 acres fallowed in these areas, about one-third is in trees and vines, another third is in alfalfa and pasture, and the remaining land is distributed between corn, field and grain, and other crops. Another 12,000 acres are fallowed across Mid-Kings River GSA (6,500 acres), El Rico GSA (4,000 acres), and Kings River East GSA (1,100 acres), consisting primarily of alfalfa, corn, cotton, and safflower. In the aggregate, 20% of perennial crops in McMullin Area GSA are expected to be fallowed due to groundwater pumping reductions. In South Fork Kings GSA, nearly all perennials have fallowing risks between 10% to 22%. The Central and South Kings, James, North Kings, and Southwest Kings GSAs experience no fallowing.

In scenario E when trading can be used as a tool to retain high-value crops, aggregate fallowing in McMullin Area GSA is reduced by two-thirds (20,000 acres), and 14,000 acres of perennial removals are avoided in this area. Likewise, fallowing in North Fork Kings and South Fork Kings GSAs are reduced by 5,000 acres and 7,000 acres, respectively, including in combination 2,500 acres of trees and vines that are retained in these two areas. An additional 3,200 acres, 8,200 acres, and 8,400 acres are taken out of production in the Central and South Kings, Kings River East, and North Kings GSAs, respectively. About 4,700 acres of perennials are fallowed between the North Kings and Central and South Kings GSAs and scattered pastureland near the junction of the Kings River and Friant-Kern Canal is taken out of production. Most lands in the Kings River

East GSA continue to have low fallow risk although about 3,500 acres of alfalfa and corn along the southern border may be fallowed. The risk of fallowing for many acres in the Mid-Kings and South Fork Kings GSAs are reduced significantly (about 10,000 acres fewer fallowed), meanwhile field and grain crops, alfalfa and pasture, and some lower value vegetables in El Rico GSA shift into higher risk classes (14,000 acres of additional fallowing).

Trends reflected in the transition from scenario A to E largely continue in scenario I when cross-basin trading is possible. Spatial distributions of fallow risk in the Kings basin remain similar, although overall risk continues to decrease from 47,000 acres to 31,000 acres as signified by the lower intensity in coloration on these parcels in Figure 14. Fallowing in the Tulare Lake basin and particularly in El Rico GSA increases substantially from 25,000 acres to nearly 45,000 acres. Reductions in fallowing from scenario E in the Kings basin are well-distributed between crop classes while increased fallow in the Tulare Lake basin is almost entirely in field and grain crops with lesser reductions in alfalfa and pasture. Intermediate scenarios between A, E, and I show similar trends, however, overall fallowing risk is reduced substantially due to the advent of new supplies to support agriculture.

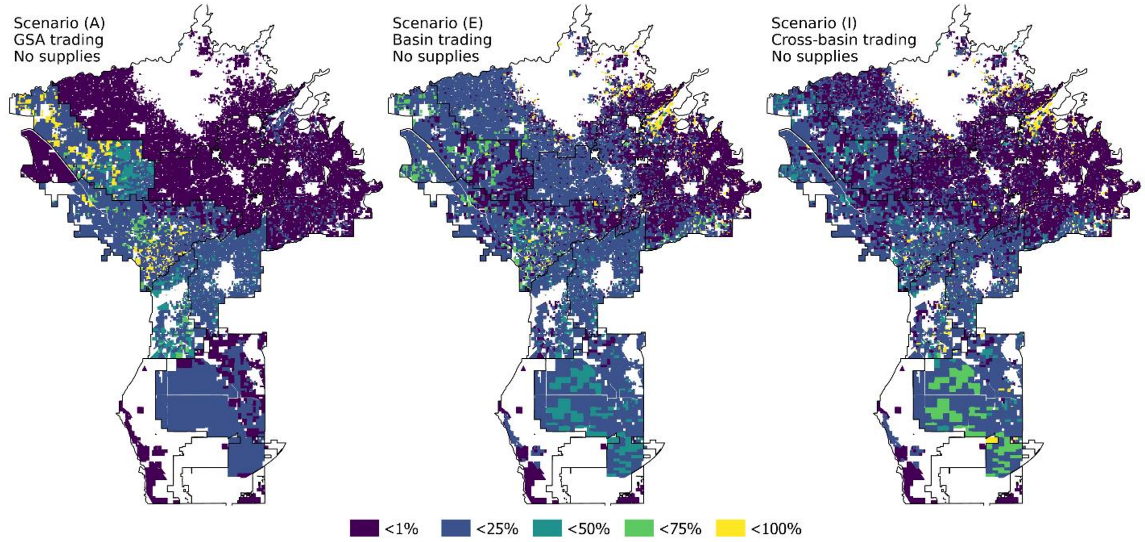


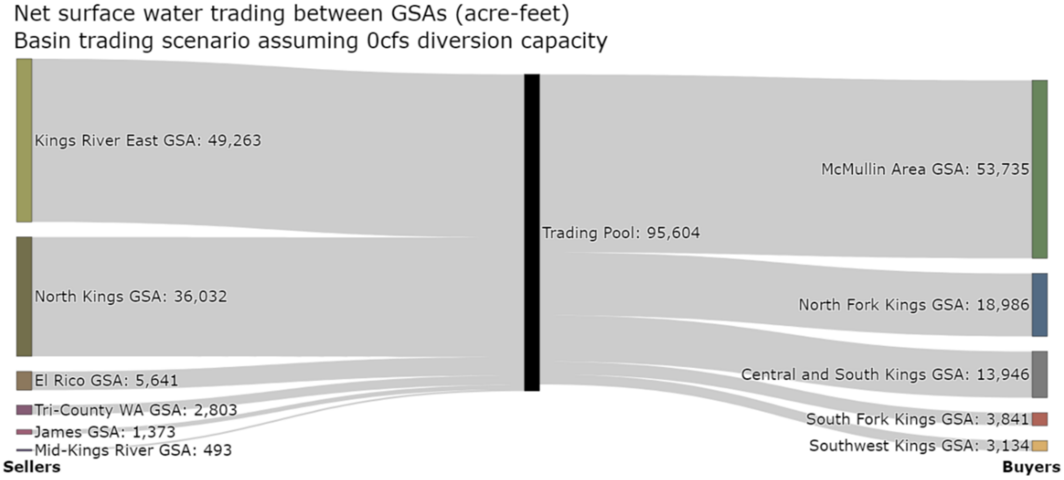
***Figure 14**: Parcel risk for fallowing in scenarios A (0cfs, GSA trading), E (0cfs, basin trading), and I (0cfs, cross-basin trading). Risks are calculated by aggregating land fallowing by major crop classes in modeling results and mapping back to the original LandIQ field mapping dataset. Purple fields have slight expansion or very little fallow risk, and yellow fields have nearly complete fallow risk. All percentages are relative to base cropping amounts by category and region.*

Water use reductions and trading

Capturing water supplies from groundwater recharge using floodwater that has historically left the basin can significantly reduce economic impacts related to groundwater restrictions under SGMA. In the most generous future scenario, an average of 138 thousand acre-feet per year of new supplies could be made available with the proper infrastructural investments for recharge and management practices. Benefits associated with groundwater recharge are most clear in scenarios A through D before considering changes in trading flexibility. It is significant to note that these benefits are considered before the costs with capturing these supplies are assessed, which limits the net benefit to be obtained from these approaches; these considerations are further addressed in the discussion section. In scenario A when no additional supplies are available the aggregate agricultural revenue losses in the study area are about $208 million with the bulk of losses ($112 million) in McMullin Area GSA. With the first increment of diversion capacity in scenario B, about 50 thousand acre-feet per year of new supplies are available, providing nearly $70 million yearly in economic relief through reduced fallowing. These improvements are mirrored to a lesser degree in scenarios C and D which provide incremental yearly economic benefits of $36 million and $22 million, respectively; as more supplies are captured the marginal benefit of each acre-foot is less impactful because crop portfolios taper off in value. Recharge provides the greatest economic relief in McMullin Area GSA—reducing losses by $40 million (36%) in the initial increment—followed by North Fork Kings GSA ($13 million, 37%).

Benefits associated with surface water trades between parties can be identified by comparing scenarios with similar water supplies as barriers to water transfers are eliminated. Across the study area, the incremental benefits of allowing within-basin trading are highest when no supplies are developed (scenario A, $208 million to E, $156 million) at $52 million. However, after 52 thousand acre-feet of supplies are developed in the first increment of supplies the benefit of within-basin trading is diminished to only $32 million (scenario B, $139 million to scenario F, $107 million). Benefits from basin trading are further diminished to $25 million in scenarios under the second and third increments of supplies from groundwater recharge (comparing scenarios C to G and D to H, respectively). Results from scenarios E through H and scenarios I through L provide insight into the benefits of allowing cross-basin trading. An additional $25 million in revenues are retained when no supplies are developed (scenario E, $156 million to scenario I, $131 million), however, as more supplies are developed more flexible trading yields negligible benefits over scenarios allowing within-basin trading. These results suggest that within-basin trading options are likely the most realistic for reducing aggregate economic impacts while reducing administrative barriers and transaction costs that may limit net trading benefits.

Figure 15 details net imports and exports of surface water summarized by GSA when no new supplies from recharge are captured under the basin and cross-basin trading scenarios (E and I). When basin trading is permitted, about 95 thousand acre-feet per year of surface water are traded, with Kings River East GSA (49 thousand acre-feet) and North Kings GSA (36 thousand acre-feet) serving as the primary exporters of water and McMullin Area GSA (53 thousand acre-feet), North Fork Kings GSA (19 thousand acre-feet), and Central and South Kings GSA (14 thousand acre-feet) the main recipients of this purchased water. Nearly all trading occurs in the Kings basin where overdraft share is higher and more perennial crops are at risk of fallowing, although about 7 thousand acre-feet are traded in the Tulare Lake basin. Once cross-basin trading options are available the total trading pool increases to 145 thousand acre-feet and El Rico GSA becomes the most substantial net exporter at 57 thousand acre-feet. Net trades out from Kings River East GSA and North Kings GSA remain similar to the basin trading scenario at 43 thousand acre-feet and 29 thousand acre-feet, respectively. McMullin Area GSA continues to purchase the most water (68 thousand acre-feet) followed by North Fork Kings GSA (39 thousand acre-feet), however, Mid-Kings River GSA becomes a significant purchaser as well (33 thousand acre-feet).



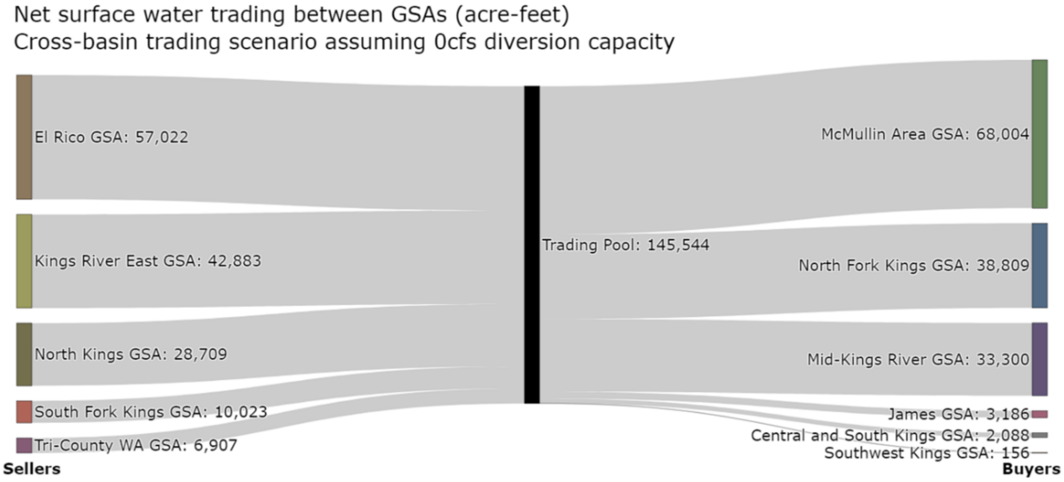


***Figure 15**: Net water trades between GSAs assuming no supplies captured under basin and cross-basin trading (scenarios E and I). Left and right GSAs represent sellers and buyers of water, respectively.*

Discussion

Achieving sustainability under SGMA will challenge the agricultural footprint of the Greater Kings River Basin and will likely catalyze shifts in water and crop management practices. In the scenario considered the baseline for this study (scenario A), SGMA implementation would require a 10% reduction in total applied water, causing the retirement of about 9% of irrigated cropland and incurring a 4% reduction in agricultural revenues. These impacts consider only regulations imposed by SGMA and may be compounded by future droughts, climatic conditions, and policies.

Water conveyance and trading

This study follows a basic assumption that any sources of surface water that have historically served as part of a district's portfolio can be traded without restriction or significant transaction costs. Whereas the primary source of surface water in the study area is the Kings River—which has a diverse set of established diverters and provides a natural waterway for conveying supplies—other sources may be more physically challenging to transfer. For example, other local supplies and imported SWP water comprise about one-quarter of the average portfolio of the largest cross-basin water exporter El Rico GSA (see Figure 7 and Figure 15), and infrastructure to physically trade this water with other areas is lacking. On the other hand, surface water trades under the scenario with the highest trading potential remain below any individual GSA's allocation of Kings River supplies even in the driest of years and it is assumed that Kings River allocations would make up most of the trading pool in this study.

Nonetheless, the conveyance of supplies to buyers could prove challenging. While most parties in the Kings basin have established canal systems for diverting Kings River water the McMullin Area GSA, which has the highest incentive to purchase water, has historically lacked such a system. Throughout the latter half of the 20th century, multiple attempts were made to develop the Mid-Valley Canal (Raisin City Water District, 2016) which would connect the areas under the McMullin Area GSA to the greater CVP system but plans never materialized. There are canal construction and expansion projects underway in the GSA, however, that are in various stages of planning and development that are intended to help bridge gaps in the area's water supply. Stage 1 of the McMullin Project was completed in 2019 and included a branching canal extending from the James Bypass for diverting floodwater for recharge, and the 2nd and 3rd stages of the project will develop additional canals with a flow capacity of 500cfs extending further north and east to connect lands for on-farm recharge purposes. South Sandridge Canal is a proposed canal expansion with a capacity of about 40cfs that would extend south from the existing Big Sandridge Canal at the border of the McMullin Area and Fresno ID. Stinson North Canal phases 1 and 2 are a pair of proposed canal projects with a 500cfs capacity that would extend from the San Joaquin River to the North Fork Kings River, crossing through the area surrounding the McMullin Project, and would allow for bidirectional flows from each end of the structure. Finally, McMullin GSA seeks to create a 40cfs intertie from the Wristen Ditch, operated by Consolidated ID, which would extend into the area. If realized, these various infrastructure projects could help support both surface water transfers and groundwater recharge efforts within the McMullin Area GSA.

The benefits of opportunistic water transfers are contrasted by costs which can reduce the desirability of these approaches. This study does not consider an explicit transaction cost for water trades and assumes that transfers occur whenever net economic benefits can be attained, however, actual trading behavior is likely to be constrained by a willingness to pay or accept. Willingness to pay is an economic concept defined by the maximum price at which water or another good could be purchased whilst providing perceived net economic benefit (Hanemann, 1991). For example, a farmer capable of generating $10 of profit on one unit of land requiring one unit of water as a production input may be willing to pay *at most* $10 to purchase one unit of water. Conversely, willingness to accept pinpoints a price at or above which a net economic benefit can be obtained by selling that commodity. Both willingness to pay and accept can be influenced by a range of conditions, including competition between buyers/sellers, resource scarcity, and desire to protect assets (e.g. irrigate to maintain the health of perennial crops) including water rights, and represents an acceptable value *subject to those conditions*, meaning that the marginal willingness to pay or accept can shift substantially as exchanges occur. From optimization modeling performed in this study, some farmers might be willing to pay as much as $475/acre-foot for supplies if valuable crops would otherwise be put at risk or as little as $0/acre-foot if their perceived scarcity is negligible. Implementing explicit transaction costs and revising the model structure to support party-to-party trading details could help to interpret the feasibility of behaviors seen in the results of this study, as demonstrated across a multisectoral trading study by Erfani et al. (2014).

This study assumes that each GSA develops a “soft” groundwater market within their boundaries which allows parties to exchange some portion of their historical groundwater use allocations. The parameters defining this market are outlined in Equations 29-31 in the methods section; individual model regions cannot “export” more than three-quarters of their base groundwater use and likewise cannot “import” more than 5%. Total groundwater use in each GSA continues to be constrained by SGMA restrictions, barring improvements in groundwater recharge which partially mitigate these restrictions, however, farmers within each modeling area can rearrange groundwater uses to prioritize valuable crops. In contrast, a groundwater market in a traditional sense would entail setting groundwater use allocations for individual farmers which can be exchanged similarly to surface water in a market system. McMullin Area GSA has explored the benefits of implementing a groundwater market in the context of SGMA implementation. Their findings demonstrated that improved flexibility in distributing groundwater restrictions to retain higher-value crops may halve gross economic losses from about 30% in a no-market scenario to 15% (Geosyntec Consultants, 2021). A no-market, inflexible scenario for McMullin Area GSA in this study would entail a linear relationship in water use reductions and revenues and would result in losses of about 28% while the flexible scenario highlighted in this study reduces losses to 21% in the absence of transaction costs (scenario A). Bruno and Sexton (2020) examined the implementation of groundwater markets, including influences of market power, in California’s Coachella Valley and found economic benefits of over 35% relative to inflexible management approaches.

Groundwater recharge and banking

Successful groundwater recharge programs require a substantial investment of resources into the planning, development, and maintenance of conveyance systems and recharge basins. Many areas in the Kings basin, including North Kings and Central and South Kings GSAs, have developed systems of canals and basins for supporting these activities. According to their GSPs, these areas have historically achieved an average of 82,000 acre-feet and 22,700 acre-feet, respectively, of intentional groundwater recharge each year. Lesser amounts have been captured in the Kings River East (6,700 acre-feet) and North Fork Kings (4,500 acre-feet) GSAs, meanwhile the Tulare Lake basin reports an average of 29,000 acre-feet per year recharged primarily in Corcoran ID (El Rico GSA) ponds. Annual yields of floodwater capture identified in this study suggest that taking full advantage of these supplies could require more than doubling recharge capacity in the Kings basin—assuming recharged water is fully recoverable—with a potential of about 138,000 acre-feet of unclaimed water leaving through the James Bypass per year as compared to the average 116,000 acre-feet captured per year reported in GSPs. Strategies related to groundwater recharge are identified as one of the most substantial tools for combatting overdraft in Kings GSPs, with about three-quarters of planned projects relying in part on these approaches (Jezdimirovic et al., 2020).

Estimating the amount of land needed to dedicate to basins and on-farm programs to reach the volumes of recharge examined in this study is an uncertain endeavor, however, existing projects can provide some insight. For example, the McMullin Project has completed its first stage of implementation and will provide 450cfs capacity for diverting water for on-farm recharge once fully built out. In various trials, the lands in the project program were able to infiltrate water at rates ranging from 2.7 in/day to 15.8 in/day (Bachand et al., 2014) with an estimated average sustained infiltration rate across the project area of 2.5 in/day (Bachand et al., 2016). These infiltration rates were achieved using on-farm recharge methods on fields of alfalfa, almonds, pistachios, and tomatoes. Leaky Acres, a constructed recharge basin in the vicinity of Freno, achieved an average infiltration rate of about 4.7 in/day in its first 10 years of operation (Nightingale et al., 1983). In the Kaweah groundwater basin to the east, infiltration rates in constructed basins with suitable soil classes may reach from about 6.0 in/day to 9.0 in/day (Aaron Fukuda, personal communication). Assuming infiltration rates of about 2.5 in/day for on-farm recharge, approximately 10 acres would be needed to capture each 1cfs of flow diverted, and the equivalent acreage needed in constructed basins might be between 5.0 and 7.5 acres per 1cfs. Thus, the total acreage dedicated to capturing the full discharge through the James Bypass would need to be on the order of 45,000 acres enrolled in on-farm recharge programs or between 15,000 and 30,000 acres using constructed basins. Similarly, Ulibarri et al. (2021) extrapolated relationships between acreage and annual yields for managed aquifer recharge projects proposed in the Kings basin GSPs and estimated that about 28,000 acres could be dedicated to constructed basins within the SGMA timeline.

Assessing the costs of performing groundwater recharge is likewise uncertain due to the wide range of strategies, project lifetimes, and other characteristics that come into play. Yet, previous projects can provide a reference point for estimating expected costs and benefits. Nightingale et al. (1983) examined the establishment and operation of the Leaky Acres recharge basin over the first 10 years of its lifetime from 1971-1981 and estimated a unit cost of about $13.62/acre-foot of water infiltrated, translating to about $84.45/acre-foot in 2018 dollars. More recently, Bachand et al. (2016) estimated unit costs for on-farm recharge in the McMullin Project to be about $36/acre-foot. Statewide assessment of managed aquifer recharge projects using grant applications under Propositions 1E, 84, 50, and 13 by Perrone and Merri Rohde (2016) estimated a median cost of $320/acre-foot for completed projects. Calculated from selected Kings GSPs with available data on planned project benefits on a per-acre foot basis (McMullin, North Fork Kings, and Central and South Kings), median costs for recharge were about $133/acre-foot (minimum $41/acre-foot and maximum $275/acre-foot; Jezdimirovic et al., 2020). Most project estimates do not include recovery costs, which may add another $100/acre-foot or so in pumping costs (author estimates; Bachand et al., 2016). Using unit costs from Kings basin projects and accounting for estimated recovery costs, annual costs to capture the 138,000 acre-feet of James Bypass discharge suggested in this study could cost between $19.4 million and $51.8 million with a median estimate of about $32.2 million per year. In comparison, this study suggests that capturing water leaving the basin could provide average benefits as high as $127 million per year depending on trading behavior and recharge amount, suggesting that net benefits could be on the order of about $75 million to $108 million per year.

McMullin Area GSA is also pursuing the development of the Aquaterra water banking project which would connect with the CVP system through the Delta Mendota Canal. The bank's primary role would be facilitating banking services for users outside the Kings basin which have limited groundwater storage capacity in their own basin. During wet years these users could bank excess surface water in the spacious aquifer underlying the McMullin Area GSA which could be extracted in the future. In the intermediate term, stored supplies would help improve groundwater conditions in the McMullin Area GSA by raising levels and mitigating abstraction from neighboring areas. The bank would provide about 800,000 acre-feet of storage capacity with 770cfs conveyance and spreading capacity and 480cfs recovery capacity, featuring 4,000 acres of recharge basins and 90 recovery wells (McMullin Area GSA, 2021). Currently, the project is undergoing a review of environmental compliance and final design specifications and is expected to begin implementation in 2023.

Land use transitions

Of the potential land fallowing identified in this study, some may occur under GSA-sponsored programs in the Tulare Lake basin to help reduce demands. Planned management actions described in Tulare Lake basin GSPs include demand reduction and fallowing programs providing an estimated 34,000 acre-feet in offset demand across the El Rico, Mid-Kings, and South Fork Kings GSAs. Under the assumption of 3.0 acre-feet per acre consumptive irrigation demand, these programs might enroll about 11,000 acres, accounting for over half of the 21,000 acres expected to be fallowed in the Tulare Lake basin in the baseline scenario of this study (scenario A). Because these programs have not yet been established, the compensation rate is unclear, however, long-term fallowing agreements between Palo Verde ID and Metropolitan WD beginning in 2004 have had incentives of about $800/acre (2016 dollars; Udall & Peterson, 2017) and during the 2015 drought Oakdale ID sponsored a fallowing program with $400/acre-foot incentives (Ayres & Bigelow, 2022) to provide water for south-of-Delta users. The Sacramento-

San Joaquin Delta Conservancy recently partnered with the Department of Water Resources to being a pilot fallowing program that operates on a reverse-auction system, with bids as high as $900/acre and additional incentives for practices supporting bird habitat (Sacramento-San Joaquin Delta Conservancy, 2023). Preliminary estimates presented in the Tulare Lake GSPs suggest compensation structures on the order of $200/acre-foot to $400/acre-foot. The easements under these programs would serve to provide financial support from the GSA to offset some of the agricultural revenue losses incurred by fallowing. None of the Kings basin GSAs identify land fallowing programs as an intended management action, but other programs such as groundwater allocations may be considered and could indirectly incur fallowing. As discussed above, many GSAs in the study area are focused on groundwater recharge as a tool for mitigating overdraft, a strategy that may require the construction of recharge basins. Ulibarri et al. (2021) estimate from GSPs that about 28,000 acres in the Kings and 4,500 acres in the Tulare Lake basin could be dedicated to constructed recharge basins if proposed projects are realized. Portions of lands that may be retired in the future due to SGMA restrictions overlay areas slated for recharge basin projects, accounting for some repurposing of otherwise idled land.

An adaptive approach to SGMA that focuses on retaining higher value crops—particularly perennials—at the expense of more flexible annual crops creates a less flexible environment for future management decisions. During droughts when water stress constrains the total irrigated crop area, lower-value crops such as alfalfa, pasture, and field and grain crops are often the first to be removed from production as a temporary response (Lund et al., 2018; Medellin-Azuara et al., 2022). While this strategy has been effective in reducing broader economic impacts induced by recent droughts, it may be a less reliable approach in the future because of groundwater pumping limitations under SGMA which could imperil these crops. For example, scenarios examined in this research suggest that between 10% and 30% of the area under these less profitable crop categories could be retired. Mall and Herman (2019) explore conflicts between water demands for tree and vine crops and natural variabilities in water availability considering potential future groundwater restrictions. Their findings show that trends of rapid permanent crop expansion throughout the San Joaquin Valley have placed greater stress on many districts' water supplies and may exacerbate economic losses resulting from compounding drought and groundwater restrictions (Mall and Herman, 2019).

Regulatory and legal barriers to SGMA implementation

As of early 2023, SGMA implementation in the Kings and Tulare Lake basins, along with several other basins in the San Joaquin Valley, face uncertainty because the joint GSPs adopted for each basin were deemed incomplete by the Department of Water Resources following a review in early 2022. An incomplete status reflects that a plan contains some deficiencies in addressing how the guidelines of the Sustainable Groundwater Management Act will be met (CADWR, 2022a). In the case of the Kings GSP, DWR determined that the plan was incomplete because it failed to: establish sufficient criteria for addressing the chronic lowering of groundwater levels; establish sufficient minimum thresholds and measurable objectives for addressing land subsidence; provide adequate supporting information for water quality criteria; and identify and address the depletion of interconnected surface water systems (CADWR, 2022b). Likewise, the

Tulare Lake basin GSP was deemed incomplete following the first three reasons given above for rejecting the Kings plan (CADWR, 2022c). GSAs from both basins revised their respective GSPs and resubmitted within the 180 days allowed by DWR to address shortcomings. Kings GSAs are awaiting the results of a second review from DWR, meanwhile, the Tulare Lake GSP was found to be inadequate due to inconsistencies in the GSPs of individual GSAs in the basin at the time of submission. It is unclear how addressing partially or in full the deficiencies identified in the GSPs will impact the information from the plans that were used in this study. Possible state intervention in the Tulare Lake basin due to the inadequate status of their plan could substantially alter the projects and programs implemented to mitigate SGMA undesirable effects.

Limitations and future work

Climate change impacts on evapotranspiration and hydrology

Trends in warming climates harbor uncertainty in how atmospheric and hydrologic processes will behave in future years, a topic that was not addressed in this study. While climate change induces many impacts within the water-agriculture complex, the most significant will likely be in the timing and magnitude of hydrologic events and the thirst of the atmosphere. Swain et al. (2018) find that shifting climatic conditions are likely to produce more frequent transition events between wet and dry extremes along with changes in precipitation seasonality, which could strain the balance between water management objectives of storage retention and flood control. These impacts could alter flow patterns for the Kings River leading to changes in water available for irrigation as well as in the timing and magnitude of flood discharge through the James Bypass. Climate change is also likely to increase reference evapotranspiration, attributed primarily to increased temperature, resulting in slightly increased evaporative demand in crops of about 2-4% (Albano et al., 2022) which would further exacerbate gaps between available supply and demand in the Kings and Tulare Lake basins. A broader valley-wide study of the agricultural future of the San Joaquin Valley under SGMA suggests that climate change could drive crop evaporative demand shifts of about 0.4%, although uncertainty remains in the magnitude and direction of this potential shift (Escriva-Bou et al., 2023). Although GSPs are required under SGMA to include projected water budgets considering climate change conditions, a reconciliation and incorporation of such climate effects into the employed modeling framework is beyond the scope of this study.

Reservoir reoperations and imported water supplies

As future climate conditions and management objectives change, it is likely that reservoir operation rules will adapt to better suit water user needs, resulting in differences in supplies available for irrigation. Sea level rise will continue as warming progresses and will pose challenges in the management of water supplies passing through the Sacramento-San Joaquin Delta due to saline intrusion and could reduce SWP deliveries on the order of 10-15% (Ray et al., 2020). Whereas SWP deliveries do constitute a significant portion of the total water portfolio used for agriculture in the study area, reductions in this imported water would pose additional stresses for meeting demands of all users including agriculture and cities. Changing environmental flow regulations could also pose changes to water supply availability elsewhere in the San Joaquin Valley but is not expected to significantly impact the GKRB basins (Escriva-Bou et al., 2023). Other future projects could bring new supplies to the Kings and Tulare Lake basins and are not considered in this study. For example, a long-pursued proposed raise of Pine Flat Dam, which impounds the Kings River, could provide an additional 124 thousand acre-feet of storage capacity for flood control (United States Bureau of Reclamation, 2003). Various conveyance infrastructure projects proposed by the McMullin Area GSA intend to access new surface water supplies from the San Joaquin River and improve ties to the greater CVP and SWP water systems. The impact that these regional water supply projects would have on agriculture remains unclear.

Repurposing of retired agricultural land

Among the most important questions spearheading the discussion surrounding SGMA implementation is the fate of agricultural lands removed from production to reduce their water footprint. While transitioning uses of these lands are highly uncertain and beyond the scope of this study, this question should be further explored. As discussed in previous sections, a fair portion of these lands may be repurposed as groundwater recharge basins to support GSA-sponsored projects. Another promising alternative land use is solar energy infrastructure development—Buckey Biggs et al. (2022) conducted interviews with a variety of stakeholders in land use planning sectors throughout California’s San Joaquin Valley and San Francisco Bay Area. In their findings, many farmers acknowledged water availability conflicts with continued agricultural production under SGMA in the future, noting that many interested in solar development would be willing to devote “5% to 10% of their lands for solar generation”, focusing on marginal lands and with over 90% of surveyed farmers noting profitability as a significant deciding factor. Members of the land stewardship community see retirement driven by SGMA as an opportunity to pursue projects aimed at restoring former habitat areas and supporting species recovery (Kelsey et al., 2018). Managing lands for restoration purposes can also serve an important role in reducing dust impacts from leaving farmland idled (Hanak et al., 2019) which is noted as a concern for air quality in the valley. Other researchers (Fernandez-Bou et al., 2022) suggest that targeted reductions in active agricultural land could prioritize boundaries surrounding disadvantaged communities, creating buffers to protect from exposure to poor local air and water quality and generating diversified income opportunities. The Public Policy Institute of California estimates that throughout the San Joaquin Valley, about 535,000 acres of agricultural land is likely to come out of production due to SGMA, but only about 30% of those lands are unlikely to be developed for alternative habitat restoration and solar planning uses by 2040 (Hanak et al., 2019). Exploring innovative and pragmatic ways to put retired lands to use without jeopardizing the welfare of agricultural-dependent communities will continue to be a key topic in SGMA planning efforts.

Conclusions

This study examined a case study of the implementation of the Sustainable Groundwater Management Act (SGMA) within the Greater Kings River Basin, focusing on implications for agricultural land uses and economic productivity. Groundwater overdraft mitigation required under the SGMA framework is estimated at 285 thousand acre-feet across the two basins, corresponding to about one-fifth of historical groundwater use in the region. Information from Groundwater Sustainability Plans (GSPs) and other publicly available resources was used in developing a hydroeconomic agricultural production model representative of modern conditions which was used as a platform for potential future scenarios under SGMA. An array of 12 scenarios exploring combinations of surface water trading flexibility and supply augmentation through groundwater recharge were modeled to capture ranges of possible impacts corresponding to a variety of management behaviors.

Findings under a baseline 2040 SGMA implementation scenario suggest aggregate losses in agricultural revenue of \$208 million (4%) per year and removal of 76,000 acres (9%) of currently irrigated lands from production to conserve water. Percentage-wise reductions in land and value may concentrate in vulnerable areas such as the isolated and highly groundwater-dependent McMullin Area GSA, reducing farm revenues by nearly one-third. Both surface water trading and the development of new supplies through bolstering groundwater recharge efforts have the potential to significantly reduce pressures on agriculture in the region. In the absence of additional supplies, trading can reduce baseline economic losses by up to \$77 million (37%) annually. On the other hand, recharge capture could provide a maximum of about \$128 million (62%) in reduced losses per year independent of enhanced trading flexibility. Conjunctively, these approaches could yield up to \$151 million (73%) in reduced economic losses with respect to the baseline scenarios. Surface water trading behavior is estimated to result in about 95 thousand acre-feet of net intra-basin trades, or 145 thousand acre-feet when expanded to include cross-basin trades. From floodwater discharge out of the basin through the James Bypass, an annual average of up to 138 thousand acre-feet of water could be captured for recharging aquifers in the Kings basin.

Details surrounding SGMA implementation remain largely uncertain due in part to the ongoing review process by the Department of Water Resources which may result in state intervention for some management areas. In addition, many projects and programs planned by GSAs to support a transition to SGMA culminating in groundwater sustainability in 2040 are yet to be confirmed. A majority of efforts to address overdraft in the Kings basin focus on groundwater recharge projects and other supply augmentation strategies, however, investments in land and infrastructure needed to realize the potential of these projects could be substantial. Meanwhile, water trading approaches particularly at the cross-basin level entail significant coordination efforts and may require expanded water conveyance infrastructure. Future research in this domain should strive to fill knowledge gaps in the ways that climate change, shifting reservoir operation rules, and reductions in imported supplies could influence the outcomes of this study. Finally, addressing how retired farmland could be repurposed beyond recharge basins and in ways that support local communities and provide environmental benefits remains a question at the forefront of SGMA implementation.

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Supplementary Information

SI1: Model crop categories and region organization

Table SI1 outlines the crop groups used in the model framework. Note that lands in the young perennials crop category is distributed into other perennial classes to represent steady state planting and removal of trees and vines and is not explicitly modeled individually. Crop commodities are obtained from the LandIQ 2018 crop mapping dataset (CNRA, 2022a) and grouped following categories based on DWR groupings (CADWR, 2018) with minor changes to highlight crops with important land use and value characteristics. Economic proxy commodities are chosen from county-level USDA reports (USDA, 2022).

Table SI1*: Organization of crop groups employed in PMP modeling framework. Economic proxy commodities are taken as the most representative crop for each group and are used to estimate costs and returns of production.*

Model crop group	LandIQ commodities	Economic proxy commodities
Alfalfa	Alfalfa and alfalfa mixtures	Hay Alfalfa
Almonds	Almonds	Almonds All
Beans Dry	Beans (dry)	Beans Dry Edible Unspecified
Berries	Bushberries Strawberries	Berries Blueberries
Subtropical	Citrus and Subtropical - No Subclass Subtropical Fruits Misc. Olives Kiwis	Oranges Navel
Corn	Corn, Sorghum or Sudan (grouped for remote sensing classification only)	Corn Silage
Cotton	Cotton	Cotton Lint Pima
Cucurbits	Melons, Squash, and Cucumbers	Melons Cantaloupe
Field and Grain	Wheat Field Misc. Grain and Hay - Misc. Grain and Hay - No Subclass	Wheat All
Grapes Wine	Vineyards - No Subclass	Grape Wine
Grapes Table	Vineyards - No Subclass	Grape Table
Lettuce	Cole crops (mixture of T22-T25) Lettuce or Leafy Greens (grouped for remote sensing classification only)	Lettuce Head
Onions and Garlic	Onions and Garlic	Garlic All
Orchards	Apples Avocados Cherries Dates Deciduous - Misc. Deciduous - Mixed Peaches and Nectarines Pears Plums, Prunes or Apricots (grouped for remote sensing classification only)	Peaches Freestone

	Pomegranates	
Pasture	Pasture - Miscellaneous Grasses Pasture - Mixed Pasture - Native Improved	N/A
Pistachios	Pistachios	Pistachios
Safflower	Safflower	Safflower
Tomatoes Fresh	Tomatoes (Processing)	Tomatoes Fresh Market
Tomatoes Processing	Tomatoes (Processing)	Tomatoes Processing
Truck	Carrots Peppers (Chili, Bell, etc.) Truck Crops - Misc. Truck Crops - No Subclass	Peppers Bell
Walnuts	Walnuts	Walnuts English
Young Perennial	Young Perennial (grouped for remote sensing or when CLASS C, D or V is not determined)	N/A

SI2: Model region organizational scheme

Table SI2 presents the three levels of spatial delineation used in the model framework. The model covers two groundwater basins (Kings and Tulare Lake), 11 GSAs (Central and South Kings, James, Kings River East, McMullin Area, North Fork Kings, North Kings, El Rico, Mid-Kings River, South Fork Kings, Southwest Kings, and Tri-County Water Authority), 27 water districts (Alta ID, Angiola WD, Clark's Fork RD, Consolidated ID, Corcoran ID, Dudley Ridge WD, Empire West Side ID, Fresno ID, Garfield WD, Hills Valley ID, James ID, Joh Heinlen MWC, Kings County WD, Kings River WD, Laguna ID, Lemoore Canal & Irrigation Company, Liberty WD, Melga WD, Mid-Valley WD, Orange Cove ID, Raisin City WD, Riverdale ID, Salyer WD, Stinson WD, Stratford ID, Tri-Valley WD, and Tulare Lake Basin WSD), and 7 white areas corresponding to GSAs with irrigated areas not within water district service areas.

***Table SI2**: Organization of modeling spatial units used in organizing water balances and scenario implementation. White areas are created for each GSA and include agricultural land not located within any other water district's service area.*

Groundwater basin	Groundwater Sustainability Agency (GSA)	Model region
Kings	Central and South Kings GSA	Consolidated Irrigation District
		Kings County Water District
	James GSA	James Irrigation District
	Kings River East GSA	Alta Irrigation District
		Hills Valley Irrigation District
		Kings River Water District
		Orange Cove Irrigation District
		Tri-Valley Water District
	McMullin Area GSA	Mid-Valley Water District
		Raisin City Water District

		White Area - McMullin Area GSA
	North Fork Kings GSA	Clark's Fork Reclamation District
		Laguna Irrigation District
		Liberty Water District
		Riverdale Irrigation District
		Stinson Water District
		White Area - North Fork Kings GSA
	North Kings GSA	Fresno Irrigation District
		Garfield Water District
		White Area - North Kings GSA
Tulare Lake	El Rico GSA	Corcoran Irrigation District
		Melga Water District (Exclusive)
		Salyer Water District
		Tulare Lake Basin Water Storage District
		White Area - El Rico GSA
	Mid-Kings River GSA	Kings County Water District
		White Area - Mid-Kings River GSA
	South Fork Kings GSA	Empire West Side Irrigation District
		John Heinlen Mutual Water Company
		Lemoore Canal & Irrigation Company
		Stratford Irrigation District
		White Area - South Fork Kings GSA
	Southwest Kings GSA	Dudley Ridge Water District
		Tulare Lake Basin Water Storage District
		White Area - Southwest Kings GSA
	Tri-County Water Authority GSA	Tulare Lake Basin Water Storage District
		White Area - Tri-County Water Authority GSA

SI3: Assignment of Tulare Lake basin surface diversions

Tulare Lake basin GSPs list surface water diversions primarily using infrastructure names (canals, aqueducts) as opposed to individual water districts. To facilitate creating water balances for the modeling scenarios, surface water diversions were assigned to districts and white areas. **Table SI3** details the process for assigning diversion points and the justification behind each decision.

***Table SI3**: Explanation of diversion attributions for building water balances at the modeling region (water district, white area) scale. Diversion points are taken from information presented in the Kings and Tulare Lake basin GSPs.*

Diversion point	**Attributed to district(s)**	**Explanation of reasoning**
Lone Tree Channel	Consolidated ID	Channel is operated by Consolidated ID and has “church” water rights attributed to landowners within the Consolidated ID service area (Source: KRWA).

Stinson Canal & Irrigation Co.	Stinson WD	Company operates primarily within the service area of the Stinson WD (Source: Fresno LAFCo).
Liberty Canal Co.	Liberty WD	Company operates partially within the boundary of Liberty WD (Source: Fresno LAFCo).
International Water District	Fresno ID	International ID is a very small irrigation district located adjacent to the Fresno ID service area boundary.
Crescent Canal Co. Upper San Jose Water Co. Burrel Ditch Company	White Area - North Fork Kings GSA	Shareholder locations are not well documented but appear to cover white areas of the North Fork Kings GSA.
Murphy Slough Association	Riverdale ID White Area - North Fork Kings GSA	Riverdale ID (member of Murphy Slough Association) holds claim to first 15,000af of supply (Source: KRWA, Riverdale ID AWMP) and remainder to collection of landowners in white areas of the North Fork Kings GSA.
Dudley Ridge State Turnout, T201 Dudley Ridge State Turnout, T204 Dudley Ridge State Turnout, T202 Dudley Ridge State Turnout, T205 Dudley Ridge State Turnout, T208	Dudley Ridge WD	Turnouts to Dudley Ridge WD.
Last Chance Water Ditch Co. Peoples Ditch Co. Lakeside Irrigation WD Loon Oak/New Deal Diversion	Kings County WD	Kings County WD is a partial or complete shareholder for water and canal companies (Source: KRWA). Some surface water may be attributed to landowners in white areas of the Central and South Kings GSA.
Lakelands Canal	Corcoran ID	Lakelands Canal supplies water to Corcoran ID (Source: KRWA).
Westlake Canal	John Heinlen MWC	Westlake Canal runs through South Fork Kings GSA and provides wastewater effluent for use on Westlake Farms dairies (Source: CA Waterboards).
Melga Canal Kaweah River - El Rico GSA Other - El Rico GSA	Corcoran ID Melga WD Salyer WD Tulare Lake Basin WSD	Additional supplies unclear. Aggregated and split to districts based on share of demand in El Rico GSA (70% to TLBWSD, 3% to

		Salyer WD, 2% to Melga WD, and 24% to Corcoran ID).
TLBWSD Lateral B, T206 TLBWSD Lateral C, T203 TLBWSD Lateral A, T200 TLBWSD Lateral B, T206.1 Blakeley Canal Tulare Lake Canal Empire Weir No. 2 Other Water - Tri-County White River - Tri-County Tule River - Tri-County Poso Creek - Tri-County Deer Creek - Tri-County Kings River - Tri-County Tule River - El Rico GSA	Tulare Lake Basin WSD	Turnouts to TLBWSD. Blakeley Canal and Tulare Lake Canal deliver water to TLBWSD. Other local diversions in the Tri-County and El Rico GSAs are assumed to be attributed to TLBWSD as it is the primary water district in these areas and has a diverse but erratic portfolio of local supplies (Source: TLBWSD AWMP).

SI4: Modeling results presented by GSA

Table SI4 through **Table SI15** give summarized details of modeling scenario outcomes at the GSA scale. Information pertaining to these results may be referenced in the main text in support of other tables and figures to highlight specific values.

***Table SI4**: Detailed modeling results presented by GSA for scenario A (0cfs, GSA trading).*

Groundwater Sustainability Agency	Land fallow (ac)	Revenue losses ($ thousand)
Central and South Kings GSA	0 (0%)	57 (0%)
El Rico GSA	4,143 (3%)	7,681 (2%)
James GSA	0 (0%)	-7 (0%)
Kings River East GSA	1,101 (1%)	3,560 (0%)
McMullin Area GSA	30,452 (30%)	112,387 (21%)
Mid-Kings River GSA	6,580 (10%)	16,807 (7%)
North Fork Kings GSA	18,028 (14%)	37,236 (6%)
North Kings GSA	0 (0%)	92 (0%)
South Fork Kings GSA	10,568 (27%)	30,007 (21%)
Southwest Kings GSA	0 (0%)	173 (0%)
Tri-County Water Authority GSA	137 (2%)	-97 (0%)
TOTAL	**71,010 (8%)**	**207,896 (4%)**

***Table SI5**: Detailed modeling results presented by GSA for scenario B (1500cfs, GSA trading).*

Groundwater Sustainability Agency	Land fallow (ac)	Revenue losses ($ thousand)
Central and South Kings GSA	0 (0%)	47 (0%)
El Rico GSA	4,143 (3%)	7,681 (2%)
James GSA	0 (0%)	-7 (0%)
Kings River East GSA	0 (0%)	355 (0%)

McMullin Area GSA	22,487 (22%)	71,868 (13%)
Mid-Kings River GSA	6,793 (10%)	18,027 (8%)
North Fork Kings GSA	11,208 (9%)	23,554 (4%)
North Kings GSA	0 (0%)	92 (0%)
South Fork Kings GSA	8,651 (22%)	17,117 (12%)
Southwest Kings GSA	0 (0%)	173 (0%)
Tri-County Water Authority GSA	137 (2%)	-97 (0%)
TOTAL	**53,419 (6%)**	**138,810 (3%)**

***Table SI6**: Detailed modeling results presented by GSA for scenario C (3000cfs, GSA trading).*

Groundwater Sustainability Agency	Land fallow (ac)	Revenue losses ($ thousand)
Central and South Kings GSA	0 (0%)	46 (0%)
El Rico GSA	4,143 (3%)	7,681 (2%)
James GSA	0 (0%)	-7 (0%)
Kings River East GSA	0 (0%)	220 (0%)
McMullin Area GSA	14,365 (14%)	34,339 (6%)
Mid-Kings River GSA	6,224 (10%)	15,906 (7%)
North Fork Kings GSA	6,079 (5%)	13,255 (2%)
North Kings GSA	0 (0%)	92 (0%)
South Fork Kings GSA	10,391 (26%)	31,060 (22%)
Southwest Kings GSA	0 (0%)	173 (0%)
Tri-County Water Authority GSA	137 (2%)	-97 (0%)
TOTAL	**41,340 (5%)**	**102,668 (2%)**

***Table SI7**: Detailed modeling results presented by GSA for scenario D (4500cfs, GSA trading).*

Groundwater Sustainability Agency	Land fallow (ac)	Revenue losses ($ thousand)
Central and South Kings GSA	0 (0%)	46 (0%)
El Rico GSA	4,143 (3%)	7,681 (2%)
James GSA	0 (0%)	-7 (0%)
Kings River East GSA	0 (0%)	220 (0%)
McMullin Area GSA	8,372 (8%)	20,277 (4%)
Mid-Kings River GSA	6,152 (9%)	16,455 (7%)
North Fork Kings GSA	2,663 (2%)	6,547 (1%)
North Kings GSA	0 (0%)	92 (0%)
South Fork Kings GSA	10,242 (26%)	29,264 (21%)
Southwest Kings GSA	0 (0%)	173 (0%)
Tri-County Water Authority GSA	137 (2%)	-97 (0%)
TOTAL	**31,709 (4%)**	**80,650 (2%)**

Table SI8*: Detailed modeling results presented by GSA for scenario E (0cfs, basin trading).*

Groundwater Sustainability Agency	Land fallow (ac)	Revenue losses ($ thousand)
Central and South Kings GSA	3,245 (3%)	13,332 (1%)
El Rico GSA	18,627 (12%)	28,250 (9%)
James GSA	3,339 (15%)	8,147 (7%)
Kings River East GSA	9,321 (8%)	19,083 (2%)
McMullin Area GSA	9,581 (9%)	23,037 (4%)
Mid-Kings River GSA	3,448 (5%)	8,315 (3%)
North Fork Kings GSA	13,186 (10%)	27,629 (4%)
North Kings GSA	8,415 (7%)	20,844 (3%)
South Fork Kings GSA	2,804 (7%)	6,327 (5%)
Southwest Kings GSA	66 (0%)	757 (1%)
Tri-County Water Authority GSA	502 (8%)	251 (1%)
TOTAL	**72,534 (8%)**	**155,972 (3%)**

Table SI9*: Detailed modeling results presented by GSA for scenario F (1500cfs, basin trading).*

Groundwater Sustainability Agency	Land fallow (ac)	Revenue losses ($ thousand)
Central and South Kings GSA	2,134 (2%)	8,358 (1%)
El Rico GSA	17,740 (12%)	27,536 (8%)
James GSA	2,011 (9%)	4,911 (4%)
Kings River East GSA	6,106 (5%)	11,989 (1%)
McMullin Area GSA	5,245 (5%)	12,892 (2%)
Mid-Kings River GSA	3,365 (5%)	8,080 (3%)
North Fork Kings GSA	6,513 (5%)	13,912 (2%)
North Kings GSA	5,261 (4%)	12,748 (2%)
South Fork Kings GSA	2,668 (7%)	5,798 (4%)
Southwest Kings GSA	98 (1%)	950 (1%)
Tri-County Water Authority GSA	446 (7%)	212 (1%)
TOTAL	**51,587 (6%)**	**107,387 (2%)**

Table SI10*: Detailed modeling results presented by GSA for scenario G (3000cfs, basin trading).*

Groundwater Sustainability Agency	Land fallow (ac)	Revenue losses ($ thousand)
Central and South Kings GSA	1,222 (1%)	5,684 (1%)
El Rico GSA	17,785 (12%)	26,921 (8%)
James GSA	1,383 (6%)	3,402 (3%)
Kings River East GSA	2,754 (2%)	7,273 (1%)
McMullin Area GSA	2,003 (2%)	5,255 (1%)
Mid-Kings River GSA	3,310 (5%)	7,855 (3%)
North Fork Kings GSA	2,978 (2%)	7,241 (1%)

North Kings GSA	2,669 (2%)	8,082 (1%)
South Fork Kings GSA	2,546 (6%)	5,378 (4%)
Southwest Kings GSA	46 (0%)	592 (0%)
Tri-County Water Authority GSA	434 (7%)	185 (1%)
TOTAL	**37,130 (4%)**	**77,868 (2%)**

***Table SI11**: Detailed modeling results presented by GSA for scenario H (4500cfs, basin trading).*

Groundwater Sustainability Agency	Land fallow (ac)	Revenue losses ($ thousand)
Central and South Kings GSA	565 (0%)	2,769 (0%)
El Rico GSA	17,335 (12%)	27,922 (9%)
James GSA	674 (3%)	1,638 (1%)
Kings River East GSA	1,004 (1%)	3,315 (0%)
McMullin Area GSA	-257 (0%)	-338 (0%)
Mid-Kings River GSA	3,416 (5%)	8,931 (4%)
North Fork Kings GSA	-386 (0%)	-59 (0%)
North Kings GSA	1,035 (1%)	3,568 (0%)
South Fork Kings GSA	2,561 (6%)	5,930 (4%)
Southwest Kings GSA	215 (1%)	1,724 (1%)
Tri-County Water Authority GSA	355 (6%)	206 (1%)
TOTAL	**26,516 (3%)**	**55,606 (1%)**

***Table SI12**: Detailed modeling results presented by GSA for scenario I (0cfs, cross-basing trading).*

Groundwater Sustainability Agency	Land fallow (ac)	Revenue losses ($ thousand)
Central and South Kings GSA	2,434 (2%)	9,169 (1%)
El Rico GSA	34,285 (23%)	40,489 (12%)
James GSA	2,202 (10%)	5,365 (5%)
Kings River East GSA	7,367 (6%)	13,608 (1%)
McMullin Area GSA	5,853 (6%)	14,346 (3%)
Mid-Kings River GSA	4,728 (7%)	9,060 (4%)
North Fork Kings GSA	7,496 (6%)	15,848 (3%)
North Kings GSA	6,110 (5%)	14,195 (2%)
South Fork Kings GSA	4,566 (12%)	7,526 (5%)
Southwest Kings GSA	31 (0%)	379 (0%)
Tri-County Water Authority GSA	1,360 (23%)	894 (3%)
TOTAL	**76,431 (9%)**	**130,878 (3%)**

***Table SI13**: Detailed modeling results presented by GSA for scenario J (1500cfs, cross-basin trading).*

Groundwater Sustainability Agency	Land fallow (ac)	Revenue losses ($ thousand)
Central and South Kings GSA	1,849 (2%)	7,817 (1%)

El Rico GSA	23,005 (15%)	31,688 (10%)
James GSA	1,896 (9%)	4,652 (4%)
Kings River East GSA	4,865 (4%)	10,690 (1%)
McMullin Area GSA	4,817 (5%)	11,941 (2%)
Mid-Kings River GSA	3,731 (6%)	7,513 (3%)
North Fork Kings GSA	5,652 (4%)	12,594 (2%)
North Kings GSA	4,378 (3%)	11,632 (2%)
South Fork Kings GSA	3,313 (8%)	5,945 (4%)
Southwest Kings GSA	-4 (0%)	151 (0%)
Tri-County Water Authority GSA	753 (13%)	422 (1%)
TOTAL	**54,255 (6%)**	**105,044 (2%)**

Table SI14: *Detailed modeling results presented by GSA for scenario K (3000cfs, cross-basin trading).*

Groundwater Sustainability Agency	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Central and South Kings GSA	1,417 (1%)	6,442 (1%)
El Rico GSA	16,611 (11%)	24,927 (8%)
James GSA	1,557 (7%)	3,831 (3%)
Kings River East GSA	3,298 (3%)	8,314 (1%)
McMullin Area GSA	2,533 (2%)	6,540 (1%)
Mid-Kings River GSA	2,769 (4%)	5,863 (2%)
North Fork Kings GSA	3,839 (3%)	9,034 (1%)
North Kings GSA	3,140 (2%)	9,220 (1%)
South Fork Kings GSA	2,303 (6%)	4,427 (3%)
Southwest Kings GSA	-44 (0%)	-119 (0%)
Tri-County Water Authority GSA	412 (7%)	147 (0%)
TOTAL	**37,834 (4%)**	**78,626 (2%)**

Table SI15: *Detailed modeling results presented by GSA for scenario L (4500cfs, cross-basin trading).*

Groundwater Sustainability Agency	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Central and South Kings GSA	1,083 (1%)	5,089 (1%)
El Rico GSA	11,960 (8%)	19,077 (6%)
James GSA	1,225 (6%)	3,013 (3%)
Kings River East GSA	2,318 (2%)	6,367 (1%)
McMullin Area GSA	1,389 (1%)	3,759 (1%)
Mid-Kings River GSA	1,908 (3%)	4,292 (2%)
North Fork Kings GSA	2,196 (2%)	5,556 (1%)
North Kings GSA	2,278 (2%)	7,070 (1%)
South Fork Kings GSA	1,549 (4%)	3,096 (2%)
Southwest Kings GSA	-86 (0%)	-392 (0%)
Tri-County Water Authority GSA	251 (4%)	7 (0%)

TOTAL	**26,072 (3%)**	**56,934 (1%)**

SI5: Modeling results presented by region

Table SI16 through **Table SI27** give summarized details of modeling scenario outcomes at the model region scale. Information pertaining to these results may be referenced in the main text in support of other tables and figures to highlight specific values.

Table SI16*: Detailed modeling results presented by region for scenario A (0cfs and GSA trading).*

Model region	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Alta Irrigation District	771 (1%)	2,747 (0%)
Clark's Fork Reclamation District	132 (8%)	424 (5%)
Consolidated Irrigation District	11 (0%)	80 (0%)
Corcoran Irrigation District	784 (2%)	2,058 (2%)
Dudley Ridge Water District	77 (0%)	509 (0%)
Empire West Side Irrigation District	887 (25%)	2,281 (20%)
Fresno Irrigation District	20 (0%)	86 (0%)
Garfield Water District	0 (0%)	0 (0%)
Hills Valley Irrigation District	-7 (0%)	-45 (0%)
James Irrigation District	0 (0%)	-7 (0%)
John Heinlen Mutual Water Company	1,295 (26%)	4,153 (22%)
Kings County Water District	6,444 (10%)	16,636 (6%)
Kings River Water District	258 (3%)	344 (1%)
Laguna Irrigation District	6,013 (23%)	10,246 (12%)
Lemoore Canal & Irrigation Company	2,901 (25%)	9,041 (19%)
Liberty Water District	772 (4%)	2,863 (3%)
Melga Water District (Exclusive)	-154 (-3%)	-146 (-3%)
Mid-Valley Water District	4,917 (42%)	27,179 (35%)
Orange Cove Irrigation District	70 (0%)	493 (0%)
Raisin City Water District	12,900 (28%)	49,700 (21%)
Riverdale Irrigation District	2,766 (24%)	4,704 (11%)
Salyer Water District	-77 (-2%)	-15 (0%)
Stinson Water District	1,452 (20%)	2,456 (11%)
Stratford Irrigation District	1,686 (26%)	4,533 (21%)
Tri-Valley Water District	10 (1%)	21 (0%)
Tulare Lake Basin Water Storage District	3,753 (4%)	5,803 (3%)
White Area - El Rico GSA	-46 (-1%)	-61 (0%)
White Area - McMullin Area GSA	12,635 (29%)	35,508 (16%)
White Area - Mid-Kings River GSA	124 (6%)	148 (7%)
White Area - North Fork Kings GSA	6,893 (11%)	16,544 (5%)
White Area - North Kings GSA	-20 (0%)	6 (0%)
White Area - South Fork Kings GSA	3,800 (29%)	9,999 (24%)

White Area - Southwest Kings GSA	-26 (-5%)	-118 (-5%)
White Area - Tri-County Water Authority GSA	-33 (-1%)	-273 (-1%)
TOTAL	**71,010 (8%)**	**207,896 (4%)**

Table SI17*: Detailed modeling results presented by region for scenario B (1500cfs, GSA trading).*

Model region	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Alta Irrigation District	19 (0%)	336 (0%)
Clark's Fork Reclamation District	72 (4%)	257 (3%)
Consolidated Irrigation District	11 (0%)	71 (0%)
Corcoran Irrigation District	784 (2%)	2,058 (2%)
Dudley Ridge Water District	77 (0%)	509 (0%)
Empire West Side Irrigation District	565 (16%)	1,194 (11%)
Fresno Irrigation District	20 (0%)	86 (0%)
Garfield Water District	0 (0%)	0 (0%)
Hills Valley Irrigation District	-17 (-1%)	-105 (0%)
James Irrigation District	0 (0%)	-7 (0%)
John Heinlen Mutual Water Company	1,103 (22%)	2,591 (14%)
Kings County Water District	6,601 (10%)	17,789 (7%)
Kings River Water District	-17 (0%)	-24 (0%)
Laguna Irrigation District	3,988 (15%)	6,790 (8%)
Lemoore Canal & Irrigation Company	2,313 (20%)	4,989 (11%)
Liberty Water District	451 (2%)	1,738 (2%)
Melga Water District (Exclusive)	-154 (-3%)	-146 (-3%)
Mid-Valley Water District	2,272 (20%)	11,875 (15%)
Orange Cove Irrigation District	17 (0%)	151 (0%)
Raisin City Water District	10,406 (23%)	37,539 (16%)
Riverdale Irrigation District	1,712 (15%)	2,869 (7%)
Salyer Water District	-77 (-2%)	-15 (0%)
Stinson Water District	849 (12%)	1,521 (7%)
Stratford Irrigation District	1,348 (21%)	2,881 (13%)
Tri-Valley Water District	-2 (0%)	-2 (0%)
Tulare Lake Basin Water Storage District	3,753 (4%)	5,803 (3%)
White Area - El Rico GSA	-46 (-1%)	-61 (0%)
White Area - McMullin Area GSA	9,809 (23%)	22,454 (10%)
White Area - Mid-Kings River GSA	180 (8%)	214 (10%)
White Area - North Fork Kings GSA	4,135 (7%)	10,378 (3%)
White Area - North Kings GSA	-20 (0%)	6 (0%)
White Area - South Fork Kings GSA	3,322 (26%)	5,462 (13%)
White Area - Southwest Kings GSA	-26 (-5%)	-118 (-5%)
White Area - Tri-County Water Authority GSA	-33 (-1%)	-273 (-1%)

TOTAL	**53,419 (6%)**	**138,810 (3%)**

***Table SI18**: Detailed modeling results presented by region for scenario C (3000cfs, GSA trading).*

Model region	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Alta Irrigation District	34 (0%)	243 (0%)
Clark's Fork Reclamation District	36 (2%)	153 (2%)
Consolidated Irrigation District	11 (0%)	70 (0%)
Corcoran Irrigation District	784 (2%)	2,058 (2%)
Dudley Ridge Water District	77 (0%)	509 (0%)
Empire West Side Irrigation District	802 (23%)	2,289 (20%)
Fresno Irrigation District	20 (0%)	86 (0%)
Garfield Water District	0 (0%)	0 (0%)
Hills Valley Irrigation District	-17 (-1%)	-108 (0%)
James Irrigation District	0 (0%)	-7 (0%)
John Heinlen Mutual Water Company	1,225 (25%)	4,394 (23%)
Kings County Water District	6,112 (9%)	15,774 (6%)
Kings River Water District	-33 (0%)	-48 (0%)
Laguna Irrigation District	2,374 (9%)	4,148 (5%)
Lemoore Canal & Irrigation Company	2,960 (26%)	9,581 (21%)
Liberty Water District	224 (1%)	907 (1%)
Melga Water District (Exclusive)	-154 (-3%)	-146 (-3%)
Mid-Valley Water District	721 (6%)	2,608 (3%)
Orange Cove Irrigation District	17 (0%)	134 (0%)
Raisin City Water District	5,384 (12%)	13,422 (6%)
Riverdale Irrigation District	872 (7%)	1,464 (4%)
Salyer Water District	-77 (-2%)	-15 (0%)
Stinson Water District	443 (6%)	868 (4%)
Stratford Irrigation District	1,706 (26%)	4,985 (23%)
Tri-Valley Water District	-2 (0%)	-2 (0%)
Tulare Lake Basin Water Storage District	3,753 (4%)	5,803 (3%)
White Area - El Rico GSA	-46 (-1%)	-61 (0%)
White Area - McMullin Area GSA	8,261 (19%)	18,309 (8%)
White Area - Mid-Kings River GSA	101 (5%)	108 (5%)
White Area - North Fork Kings GSA	2,128 (3%)	5,715 (2%)
White Area - North Kings GSA	-20 (0%)	6 (0%)
White Area - South Fork Kings GSA	3,699 (29%)	9,811 (23%)
White Area - Southwest Kings GSA	-26 (-5%)	-118 (-5%)
White Area - Tri-County Water Authority GSA	-33 (-1%)	-273 (-1%)
TOTAL	**41,340 (5%)**	**102,668 (2%)**

***Table SI19**: Detailed modeling results presented by region for scenario D (4500cfs, GSA trading).*

Model region	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Alta Irrigation District	34 (0%)	243 (0%)
Clark's Fork Reclamation District	16 (1%)	87 (1%)
Consolidated Irrigation District	11 (0%)	70 (0%)
Corcoran Irrigation District	784 (2%)	2,058 (2%)
Dudley Ridge Water District	77 (0%)	509 (0%)
Empire West Side Irrigation District	877 (25%)	2,337 (21%)
Fresno Irrigation District	20 (0%)	86 (0%)
Garfield Water District	0 (0%)	0 (0%)
Hills Valley Irrigation District	-17 (-1%)	-108 (0%)
James Irrigation District	0 (0%)	-7 (0%)
John Heinlen Mutual Water Company	1,224 (24%)	3,899 (21%)
Kings County Water District	6,014 (9%)	16,291 (6%)
Kings River Water District	-33 (0%)	-48 (0%)
Laguna Irrigation District	1,233 (5%)	2,389 (3%)
Lemoore Canal & Irrigation Company	3,006 (26%)	9,761 (21%)
Liberty Water District	78 (0%)	361 (0%)
Melga Water District (Exclusive)	-154 (-3%)	-146 (-3%)
Mid-Valley Water District	366 (3%)	1,444 (2%)
Orange Cove Irrigation District	17 (0%)	134 (0%)
Raisin City Water District	3,390 (7%)	8,348 (3%)
Riverdale Irrigation District	238 (2%)	497 (1%)
Salyer Water District	-77 (-2%)	-15 (0%)
Stinson Water District	210 (3%)	473 (2%)
Stratford Irrigation District	1,578 (24%)	4,405 (20%)
Tri-Valley Water District	-2 (0%)	-2 (0%)
Tulare Lake Basin Water Storage District	3,753 (4%)	5,803 (3%)
White Area - El Rico GSA	-46 (-1%)	-61 (0%)
White Area - McMullin Area GSA	4,616 (11%)	10,485 (5%)
White Area - Mid-Kings River GSA	128 (6%)	140 (6%)
White Area - North Fork Kings GSA	889 (1%)	2,740 (1%)
White Area - North Kings GSA	-20 (0%)	6 (0%)
White Area - South Fork Kings GSA	3,557 (28%)	8,863 (21%)
White Area - Southwest Kings GSA	-26 (-5%)	-118 (-5%)
White Area - Tri-County Water Authority GSA	-33 (-1%)	-273 (-1%)
TOTAL	**31,709 (4%)**	**80,650 (2%)**

***Table SI20**: Detailed modeling results presented by region for scenario E (0cfs, basin trading).*

Model region	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Alta Irrigation District	6,220 (7%)	14,258 (2%)
Clark's Fork Reclamation District	98 (6%)	329 (4%)
Consolidated Irrigation District	3,054 (3%)	12,687 (1%)
Corcoran Irrigation District	2,660 (8%)	6,314 (6%)
Dudley Ridge Water District	138 (1%)	1,065 (1%)
Empire West Side Irrigation District	152 (4%)	483 (4%)
Fresno Irrigation District	7,813 (6%)	19,883 (3%)
Garfield Water District	9 (1%)	64 (2%)
Hills Valley Irrigation District	114 (5%)	188 (1%)
James Irrigation District	3,339 (15%)	8,147 (7%)
John Heinlen Mutual Water Company	247 (5%)	595 (3%)
Kings County Water District	3,640 (5%)	8,946 (3%)
Kings River Water District	2,509 (30%)	2,621 (5%)
Laguna Irrigation District	4,565 (17%)	7,789 (9%)
Lemoore Canal & Irrigation Company	802 (7%)	1,969 (4%)
Liberty Water District	560 (3%)	2,125 (2%)
Melga Water District (Exclusive)	130 (3%)	185 (4%)
Mid-Valley Water District	568 (5%)	2,122 (3%)
Orange Cove Irrigation District	389 (2%)	1,903 (1%)
Raisin City Water District	2,930 (6%)	7,264 (3%)
Riverdale Irrigation District	2,014 (17%)	3,402 (8%)
Salyer Water District	268 (5%)	553 (7%)
Stinson Water District	1,018 (14%)	1,787 (8%)
Stratford Irrigation District	343 (5%)	917 (4%)
Tri-Valley Water District	89 (11%)	114 (2%)
Tulare Lake Basin Water Storage District	15,435 (15%)	20,523 (10%)
White Area - El Rico GSA	619 (7%)	997 (6%)
White Area - McMullin Area GSA	6,083 (14%)	13,650 (6%)
White Area - Mid-Kings River GSA	-1 (0%)	15 (1%)
White Area - North Fork Kings GSA	4,931 (8%)	12,196 (3%)
White Area - North Kings GSA	592 (11%)	897 (3%)
White Area - South Fork Kings GSA	1,261 (10%)	2,361 (6%)
White Area - Southwest Kings GSA	-24 (-5%)	-111 (-5%)
White Area - Tri-County Water Authority GSA	-33 (-1%)	-268 (-1%)
TOTAL	**72,534 (8%)**	**155,972 (3%)**

Table SI21: *Detailed modeling results presented by region for scenario F (1500cfs, basin trading).*

Model region	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Alta Irrigation District	3,815 (4%)	8,742 (1%)
Clark's Fork Reclamation District	47 (3%)	186 (2%)
Consolidated Irrigation District	2,030 (2%)	7,976 (1%)
Corcoran Irrigation District	2,627 (8%)	6,227 (6%)
Dudley Ridge Water District	173 (1%)	1,283 (1%)
Empire West Side Irrigation District	121 (3%)	288 (3%)
Fresno Irrigation District	5,112 (4%)	12,313 (2%)
Garfield Water District	-3 (0%)	35 (1%)
Hills Valley Irrigation District	27 (1%)	37 (0%)
James Irrigation District	2,011 (9%)	4,911 (4%)
John Heinlen Mutual Water Company	232 (5%)	574 (3%)
Kings County Water District	3,465 (5%)	8,440 (3%)
Kings River Water District	1,968 (23%)	1,923 (4%)
Laguna Irrigation District	2,531 (10%)	4,323 (5%)
Lemoore Canal & Irrigation Company	787 (7%)	1,917 (4%)
Liberty Water District	251 (1%)	1,006 (1%)
Melga Water District (Exclusive)	135 (3%)	192 (4%)
Mid-Valley Water District	297 (3%)	1,203 (2%)
Orange Cove Irrigation District	266 (1%)	1,238 (1%)
Raisin City Water District	1,426 (3%)	3,605 (2%)
Riverdale Irrigation District	998 (9%)	1,589 (4%)
Salyer Water District	266 (5%)	535 (7%)
Stinson Water District	459 (6%)	893 (4%)
Stratford Irrigation District	311 (5%)	719 (3%)
Tri-Valley Water District	30 (4%)	49 (1%)
Tulare Lake Basin Water Storage District	14,588 (14%)	20,021 (10%)
White Area - El Rico GSA	550 (7%)	807 (5%)
White Area - McMullin Area GSA	3,522 (8%)	8,084 (4%)
White Area - Mid-Kings River GSA	5 (0%)	23 (1%)
White Area - North Fork Kings GSA	2,226 (4%)	5,915 (2%)
White Area - North Kings GSA	152 (3%)	400 (2%)
White Area - South Fork Kings GSA	1,218 (9%)	2,300 (5%)
White Area - Southwest Kings GSA	-23 (-4%)	-106 (-4%)
White Area - Tri-County Water Authority GSA	-32 (-1%)	-261 (-1%)
TOTAL	**51,587 (6%)**	**107,387 (2%)**

***Table SI22**: Detailed modeling results presented by region for scenario G (3000cfs, basin trading).*

Model region	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Alta Irrigation District	1,948 (2%)	5,600 (1%)
Clark's Fork Reclamation District	20 (1%)	101 (1%)
Consolidated Irrigation District	1,155 (1%)	5,424 (1%)
Corcoran Irrigation District	2,542 (8%)	5,974 (6%)
Dudley Ridge Water District	126 (1%)	951 (1%)
Empire West Side Irrigation District	105 (3%)	246 (2%)
Fresno Irrigation District	2,607 (2%)	7,801 (1%)
Garfield Water District	-5 (-1%)	22 (1%)
Hills Valley Irrigation District	3 (0%)	-15 (0%)
James Irrigation District	1,383 (6%)	3,402 (3%)
John Heinlen Mutual Water Company	224 (4%)	551 (3%)
Kings County Water District	3,387 (5%)	8,111 (3%)
Kings River Water District	649 (8%)	794 (2%)
Laguna Irrigation District	1,326 (5%)	2,545 (3%)
Lemoore Canal & Irrigation Company	745 (7%)	1,795 (4%)
Liberty Water District	109 (1%)	478 (0%)
Melga Water District (Exclusive)	131 (3%)	185 (4%)
Mid-Valley Water District	47 (0%)	294 (0%)
Orange Cove Irrigation District	139 (1%)	865 (0%)
Raisin City Water District	645 (1%)	1,841 (1%)
Riverdale Irrigation District	287 (2%)	581 (1%)
Salyer Water District	256 (5%)	509 (6%)
Stinson Water District	232 (3%)	511 (2%)
Stratford Irrigation District	284 (4%)	642 (3%)
Tri-Valley Water District	15 (2%)	29 (1%)
Tulare Lake Basin Water Storage District	14,690 (14%)	19,624 (10%)
White Area - El Rico GSA	577 (7%)	837 (5%)
White Area - McMullin Area GSA	1,311 (3%)	3,120 (1%)
White Area - Mid-Kings River GSA	-10 (0%)	5 (0%)
White Area - North Fork Kings GSA	1,004 (2%)	3,025 (1%)
White Area - North Kings GSA	67 (1%)	258 (1%)
White Area - South Fork Kings GSA	1,188 (9%)	2,145 (5%)
White Area - Southwest Kings GSA	-25 (-5%)	-114 (-5%)
White Area - Tri-County Water Authority GSA	-33 (-1%)	-268 (-1%)
TOTAL	**37,130 (4%)**	**77,868 (2%)**

***Table SI23**: Detailed modeling results presented by region for scenario H (4500cfs, basin trading).*

Model region	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Alta Irrigation District	706 (1%)	2,579 (0%)
Clark's Fork Reclamation District	-5 (0%)	16 (0%)
Consolidated Irrigation District	542 (0%)	2,655 (0%)
Corcoran Irrigation District	2,492 (8%)	5,832 (6%)
Dudley Ridge Water District	283 (2%)	2,022 (2%)
Empire West Side Irrigation District	125 (4%)	322 (3%)
Fresno Irrigation District	1,045 (1%)	3,451 (0%)
Garfield Water District	-8 (-1%)	7 (0%)
Hills Valley Irrigation District	-12 (0%)	-68 (0%)
James Irrigation District	674 (3%)	1,638 (1%)
John Heinlen Mutual Water Company	235 (5%)	631 (3%)
Kings County Water District	3,411 (5%)	8,996 (3%)
Kings River Water District	240 (3%)	321 (1%)
Laguna Irrigation District	292 (1%)	749 (1%)
Lemoore Canal & Irrigation Company	771 (7%)	1,941 (4%)
Liberty Water District	-63 (0%)	-205 (0%)
Melga Water District (Exclusive)	124 (3%)	175 (4%)
Mid-Valley Water District	-71 (-1%)	-194 (0%)
Orange Cove Irrigation District	66 (0%)	471 (0%)
Raisin City Water District	-142 (0%)	-156 (0%)
Riverdale Irrigation District	-261 (-2%)	-385 (-1%)
Salyer Water District	296 (6%)	546 (7%)
Stinson Water District	-21 (0%)	75 (0%)
Stratford Irrigation District	263 (4%)	640 (3%)
Tri-Valley Water District	5 (1%)	11 (0%)
Tulare Lake Basin Water Storage District	14,206 (14%)	20,729 (10%)
White Area - El Rico GSA	548 (7%)	839 (5%)
White Area - McMullin Area GSA	-45 (0%)	12 (0%)
White Area - Mid-Kings River GSA	27 (1%)	49 (2%)
White Area - North Fork Kings GSA	-329 (-1%)	-309 (0%)
White Area - North Kings GSA	-2 (0%)	110 (0%)
White Area - South Fork Kings GSA	1,167 (9%)	2,396 (6%)
White Area - Southwest Kings GSA	-20 (-4%)	-91 (-4%)
White Area - Tri-County Water Authority GSA	-24 (-1%)	-200 (-1%)
TOTAL	**26,516 (3%)**	**55,606 (1%)**

***Table SI24**: Detailed modeling results presented by region for scenario I (0cfs, cross-basin trading).*

Model region	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Alta Irrigation District	4,467 (5%)	9,748 (1%)
Clark's Fork Reclamation District	54 (3%)	206 (2%)
Consolidated Irrigation District	2,318 (2%)	8,750 (1%)
Corcoran Irrigation District	3,517 (11%)	7,324 (7%)
Dudley Ridge Water District	115 (1%)	758 (1%)
Empire West Side Irrigation District	262 (7%)	430 (4%)
Fresno Irrigation District	5,915 (5%)	13,694 (2%)
Garfield Water District	-1 (0%)	39 (1%)
Hills Valley Irrigation District	107 (4%)	123 (1%)
James Irrigation District	2,202 (10%)	5,365 (5%)
John Heinlen Mutual Water Company	429 (9%)	907 (5%)
Kings County Water District	4,795 (7%)	9,402 (3%)
Kings River Water District	2,392 (28%)	2,283 (5%)
Laguna Irrigation District	2,889 (11%)	4,855 (6%)
Lemoore Canal & Irrigation Company	1,191 (10%)	2,207 (5%)
Liberty Water District	293 (2%)	1,162 (1%)
Melga Water District (Exclusive)	349 (8%)	410 (9%)
Mid-Valley Water District	349 (3%)	1,387 (2%)
Orange Cove Irrigation District	315 (1%)	1,356 (1%)
Raisin City Water District	1,636 (4%)	4,113 (2%)
Riverdale Irrigation District	1,133 (10%)	1,833 (4%)
Salyer Water District	426 (9%)	768 (10%)
Stinson Water District	532 (7%)	1,012 (5%)
Stratford Irrigation District	567 (9%)	1,045 (5%)
Tri-Valley Water District	85 (11%)	97 (2%)
Tulare Lake Basin Water Storage District	30,319 (30%)	31,581 (16%)
White Area - El Rico GSA	1,008 (12%)	1,311 (8%)
White Area - McMullin Area GSA	3,868 (9%)	8,846 (4%)
White Area - Mid-Kings River GSA	50 (2%)	78 (4%)
White Area - North Fork Kings GSA	2,595 (4%)	6,780 (2%)
White Area - North Kings GSA	196 (3%)	462 (2%)
White Area - South Fork Kings GSA	2,117 (16%)	2,937 (7%)
White Area - Southwest Kings GSA	-26 (-5%)	-118 (-5%)
White Area - Tri-County Water Authority GSA	-33 (-1%)	-273 (-1%)
TOTAL	**76,431 (9%)**	**130,878 (3%)**

***Table SI25**: Detailed modeling results presented by region for scenario J (1500cfs, cross-basin trading).*

Model region	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Alta Irrigation District	3,215 (4%)	8,001 (1%)
Clark's Fork Reclamation District	43 (3%)	175 (2%)
Consolidated Irrigation District	1,749 (2%)	7,450 (1%)
Corcoran Irrigation District	2,931 (9%)	6,339 (6%)
Dudley Ridge Water District	81 (0%)	532 (0%)
Empire West Side Irrigation District	168 (5%)	310 (3%)
Fresno Irrigation District	4,247 (3%)	11,225 (2%)
Garfield Water District	-3 (0%)	33 (1%)
Hills Valley Irrigation District	21 (1%)	27 (0%)
James Irrigation District	1,896 (9%)	4,652 (4%)
John Heinlen Mutual Water Company	311 (6%)	685 (4%)
Kings County Water District	3,814 (6%)	7,838 (3%)
Kings River Water District	1,380 (16%)	1,459 (3%)
Laguna Irrigation District	2,206 (8%)	3,931 (5%)
Lemoore Canal & Irrigation Company	898 (8%)	1,806 (4%)
Liberty Water District	227 (1%)	918 (1%)
Melga Water District (Exclusive)	206 (4%)	272 (6%)
Mid-Valley Water District	243 (2%)	1,011 (1%)
Orange Cove Irrigation District	221 (1%)	1,158 (1%)
Raisin City Water District	1,245 (3%)	3,272 (1%)
Riverdale Irrigation District	766 (7%)	1,334 (3%)
Salyer Water District	327 (7%)	624 (8%)
Stinson Water District	419 (6%)	827 (4%)
Stratford Irrigation District	402 (6%)	789 (4%)
Tri-Valley Water District	27 (3%)	45 (1%)
Tulare Lake Basin Water Storage District	19,508 (19%)	23,851 (12%)
White Area - El Rico GSA	761 (9%)	1,035 (6%)
White Area - McMullin Area GSA	3,329 (8%)	7,658 (3%)
White Area - Mid-Kings River GSA	17 (1%)	42 (2%)
White Area - North Fork Kings GSA	1,991 (3%)	5,409 (1%)
White Area - North Kings GSA	134 (2%)	374 (1%)
White Area - South Fork Kings GSA	1,534 (12%)	2,355 (6%)
White Area - Southwest Kings GSA	-26 (-5%)	-118 (-5%)
White Area - Tri-County Water Authority GSA	-33 (-1%)	-273 (-1%)
TOTAL	**54,255 (6%)**	**105,044 (2%)**

***Table SI26**: Detailed modeling results presented by region for scenario K (3000cfs, cross-basin trading).*

Model region	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Alta Irrigation District	2,304 (3%)	6,368 (1%)
Clark's Fork Reclamation District	26 (2%)	120 (1%)
Consolidated Irrigation District	1,324 (1%)	6,099 (1%)
Corcoran Irrigation District	2,354 (7%)	5,265 (5%)
Dudley Ridge Water District	41 (0%)	265 (0%)
Empire West Side Irrigation District	90 (3%)	193 (2%)
Fresno Irrigation District	3,057 (3%)	8,897 (1%)
Garfield Water District	-5 (-1%)	26 (1%)
Hills Valley Irrigation District	8 (0%)	-2 (0%)
James Irrigation District	1,557 (7%)	3,831 (3%)
John Heinlen Mutual Water Company	195 (4%)	442 (2%)
Kings County Water District	2,877 (4%)	6,203 (2%)
Kings River Water District	807 (10%)	953 (2%)
Laguna Irrigation District	1,598 (6%)	2,998 (3%)
Lemoore Canal & Irrigation Company	661 (6%)	1,419 (3%)
Liberty Water District	150 (1%)	630 (1%)
Melga Water District (Exclusive)	94 (2%)	150 (3%)
Mid-Valley Water District	77 (1%)	405 (1%)
Orange Cove Irrigation District	161 (1%)	961 (1%)
Raisin City Water District	842 (2%)	2,327 (1%)
Riverdale Irrigation District	433 (4%)	826 (2%)
Salyer Water District	225 (5%)	465 (6%)
Stinson Water District	295 (4%)	619 (3%)
Stratford Irrigation District	246 (4%)	517 (2%)
Tri-Valley Water District	18 (2%)	34 (1%)
Tulare Lake Basin Water Storage District	13,796 (13%)	18,456 (9%)
White Area - El Rico GSA	529 (6%)	746 (5%)
White Area - McMullin Area GSA	1,614 (4%)	3,808 (2%)
White Area - Mid-Kings River GSA	-15 (-1%)	4 (0%)
White Area - North Fork Kings GSA	1,337 (2%)	3,841 (1%)
White Area - North Kings GSA	88 (2%)	296 (1%)
White Area - South Fork Kings GSA	1,110 (9%)	1,856 (4%)
White Area - Southwest Kings GSA	-26 (-5%)	-118 (-5%)
White Area - Tri-County Water Authority GSA	-33 (-1%)	-273 (-1%)
TOTAL	**37,834 (4%)**	**78,626 (2%)**

Table SI27*: Detailed modeling results presented by region for scenario L (4500cfs, cross-basin trading).*

Model region	**Land fallow (ac)**	**Revenue losses ($ thousand)**
Alta Irrigation District	1,651 (2%)	4,920 (1%)
Clark's Fork Reclamation District	13 (1%)	76 (1%)
Consolidated Irrigation District	1,011 (1%)	4,814 (1%)
Corcoran Irrigation District	1,836 (6%)	4,231 (4%)
Dudley Ridge Water District	-1 (0%)	-8 (0%)
Empire West Side Irrigation District	36 (1%)	95 (1%)
Fresno Irrigation District	2,234 (2%)	6,827 (1%)
Garfield Water District	-6 (-1%)	19 (0%)
Hills Valley Irrigation District	-2 (0%)	-28 (0%)
James Irrigation District	1,225 (6%)	3,013 (3%)
John Heinlen Mutual Water Company	90 (2%)	206 (1%)
Kings County Water District	2,025 (3%)	4,599 (2%)
Kings River Water District	535 (6%)	672 (1%)
Laguna Irrigation District	1,088 (4%)	2,141 (2%)
Lemoore Canal & Irrigation Company	476 (4%)	1,069 (2%)
Liberty Water District	55 (0%)	275 (0%)
Melga Water District (Exclusive)	8 (0%)	49 (1%)
Mid-Valley Water District	8 (0%)	147 (0%)
Orange Cove Irrigation District	121 (1%)	778 (0%)
Raisin City Water District	468 (1%)	1,400 (1%)
Riverdale Irrigation District	160 (1%)	363 (1%)
Salyer Water District	127 (3%)	309 (4%)
Stinson Water District	175 (2%)	414 (2%)
Stratford Irrigation District	118 (2%)	267 (1%)
Tri-Valley Water District	12 (2%)	25 (0%)
Tulare Lake Basin Water Storage District	9,884 (10%)	14,023 (7%)
White Area - El Rico GSA	331 (4%)	480 (3%)
White Area - McMullin Area GSA	913 (2%)	2,212 (1%)
White Area - Mid-Kings River GSA	-45 (-2%)	-32 (-1%)
White Area - North Fork Kings GSA	706 (1%)	2,286 (1%)
White Area - North Kings GSA	50 (1%)	224 (1%)
White Area - South Fork Kings GSA	827 (6%)	1,459 (3%)
White Area - Southwest Kings GSA	-26 (-5%)	-118 (-5%)
White Area - Tri-County Water Authority GSA	-33 (-1%)	-273 (-1%)
TOTAL	**26,072 (3%)**	**56,934 (1%)**