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VALUING ACCESS TO MULTIPLE WATER SUPPLY SOURCES IN IRRIGATED AGRICULTURE WITH A HEDONIC PRICING MODEL

Monobina Mukherjee^a and Kurt Schwabe^b

^aPhD Candidate, Environmental Economics and Policy Program, Department of Environmental Sciences, University of California, Riverside, CA 92521,USA. Email: mmukh001@student.ucr.edu
Phone: (909)-254-1222

^bAssociate Professor, Environmental Economics and Policy Program, Department of Environmental Sciences, University of California, Riverside, CA 92521,USA. Email: kurt.schwabe@ucr.edu Phone: (951) 827-2361

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Abstract

Increasing aridity, more frequent and intense drought, and greater degrees of water scarcity create unique challenges for agriculture. In response to these challenges, which often manifest themselves in the form of lower and more variable surface water supplies as well as depleted and degraded ground water supplies, growers are apt to seek out opportunities to adapt. One option confronting growers to reduce their exposure to water scarcity and heightened uncertainty is to diversify. Indeed, having access to a portfolio of supplies is one way in which water and irrigation districts as well as individual growers are responding to the changing landscape of water resource availability. The objective of this paper is to evaluate the benefits to irrigated agriculture from having access to multiple water supply sources, i.e., a water portfolio. With farm-level information on approximately 2000 agricultural parcels across California, we use the hedonic property value method to investigate the extent growers' benefit from having access to multiple sources of water (i.e., a water portfolio). Our results suggest that while lower quality waters, less reliable water, and less water all negatively impact agricultural land values, holding a water portfolio has a positive impact on land values through its role in mitigating the negative aspects of these factors and reducing the sensitivity of agriculture to climate-related factors. From a policy perspective, such results identify a valuable adaptation tool that water and irrigation districts may consider to help offset the negative impacts of climate change, drought, and population increases on water supply availability and reliability.

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1 Introduction

Results of recent computer models suggest that arid and semi-arid regions, including the Southwestern US (Segar et al. 2007), are likely to experience less precipitation, increased aridity, and more frequent and severe drought over the next 40 years (Shindell et al. 2006). One of the potential casualties of this change in climate is agriculture, through both direct effects on crop production and indirect effects on water supplies (e.g., Mendelsohn et al. 1994; Schlenker et al. 2006). While Mendelsohn and Dinar (2003) note and illustrate that implementing and/or improving irrigation is one possible adaptive measure that can partially mitigate the impacts of climate change on agriculture, the sources of supply that provide such irrigation are themselves not immune to climate change, an important point emphasized in Schlenker et al. (2007). Based on a history of research investigating the link between agricultural land values and access to surface water supplies (e.g., Selby 1945; Hartman and Anderson 1962; Crouter 1987; Faux and Perry 1989; Mendelsohn and Dinar 2003; Schlenker et al. 2007; Petrie and Taylor 2007), reductions in mean water supplies will negatively impact farmland values. Furthermore, as suggested and illustrated more recently in Libecap et al. (2011) and Connor et al. (2012), increases in water supply variability can have significant negative impacts on agricultural farm values and productivity as can decreases in water quality.¹

With a tip of the hat to Nordhaus (1994) who, as cited in Pielke (1998), stated, “mitigate we might; adapt we must”, it is increasingly evident that adaptation must be given more consideration due to the combined effects of climate change and increased water demand on water scarcity.² One possible response by irrigated agriculture to lower and less reliable surface water supplies has been to diversify

¹ Indeed, as noted in Hartman and Anderson (1962), a significant driver behind the development of the Colorado-Big Thompson Project, which began in 1933 and took 23 years to build, was water supply shortages due to the natural variability in runoff from precipitation in the local mountains.

² Several adaptation strategies to water supply variability and climate change has been analyzed previously, and includes adopting efficient irrigation strategies, water trading and building infrastructure like dams (Calatrava et al., 2005; Hansen et al., 2009; Connor et al. 2009). Maintaining a water portfolio as a possible adaptation strategy to climate change and poor groundwater conditions received almost no attention in the literature. Our focus in this paper is to analyze the benefits of holding a water portfolio while accounting for types of water supply sources, water supply variability, groundwater depth and quality.

their water supply portfolio, including increased reliance on groundwater pumping, conveyance of alternative water supplies from other regions, or storage of water during periods of less water stress. Within California, for instance, the number of water supply sources often varies across districts and growers. Some water districts and growers may have permits issued by the State Water Board to divert water from a river, the Central Valley Project (CVP), or State Water Project (SWP); in addition, or as an alternative, some may have access to groundwater and/or riparian rights.

The objectives of this research are to three-fold. First, we provide what appears to the first evaluation, using what Mendelsohn and Dinar (2003) would term a cross-sectional approach, of how water supply variability and quality, in addition to mean values, impact farmland values.³ That is, we evaluate whether water supply variability and water quality impact land values above and beyond what is captured by including mean water supplies alone. Second, and following along the suggestions of Crouter (1987) and Faux and Perry (1989), we investigate whether there is heterogeneity across water supply sources in their impacts on farmland values. Finally, we estimate the value to growers of having access to a portfolio of water supply sources. To achieve these objectives, we collected and geo-referenced micro-level data on approximately 2000 parcels across 10 counties of California that were sold between 2004 and 2010. We use a hedonic analysis to relate parcel sales prices to parcel characteristics and isolate the impact of different water supply characteristics and combinations on farmland values.

This research has both policy and methodological implications. First, the results from this analysis will highlight the value of policies that encourage access to a portfolio of water supplies which will likely aid growers in their efforts to adapt to not only the direct (and local) climate-related impacts on agricultural productivity, but to the indirect impacts that include lower, less reliable, and possibly poorer quality water supplies. There have been few, if any studies to date that have analyzed the value of having access to multiple sources of water (i.e., holding a water portfolio). There are several studies in economic

³ Connor et al. (2012) provide a recent analyses using mathematical programming methods to evaluate the additional impact of water supply variability and decreasing water quality above and beyond lower mean values on irrigated agriculture in Australia's Murray Darling Basin.

literature that have analyzed portfolios associated with the financial markets, stock markets and asset pricing models (Hsu et al.,2012); however, water portfolios and their benefits in agriculture have not been analyzed to our knowledge. Second, our results will highlight how research that attempts to estimate the direct and indirect impact of climate change may prove inaccurate if it fails to account for the type and combination of available water supply sources along with the salient characteristics of those sources, which are likely not represented by mean values (or level effects) alone.

2 Literature review

As noted in Schlenker et al. (2007), there are a limited number of studies that have investigated the value of access to irrigation water by focusing on land values, including Selby (1945), Hartman and Anderson (1962), Crouter (1987), Faux and Perry(1999), Mendelsohn and Dinar (2003), Schlenker et al. (2007), and Petrie and Taylor (2007). As an addendum to this statement, there are even fewer studies that have looked at how farmland values differ by the type and number of irrigation sources that are accessible. In Selby (1945), value per acre across 199 counties was correlated with the number of irrigated acres per farm. In Hartman and Anderson (1962), alternatively, the sales prices of 45 farms was estimated as a function of single water supply source—water from an irrigation company. Building upon the Hartman and Anderson work in Colorado, Crouter (1987) investigated the relationship between the sales price of 53 agricultural parcels and the sum of the average acre-feet of water delivered to the parcel from different irrigation supplies. Unique to Crouter (1987) at this stage of the literature was the inclusion of groundwater (in the form of a dummy variable indicating whether an irrigation well was present or not). Crouter, through citing an earlier comment in Brown et al. (1982) who discusses the potential problems with lumping together a public and private water source, stresses the point that different water sources likely have different characteristics; hence, by lumping these sources together one might potentially suffer from specification error and bias. Quoting Crouter (1987; page 267):

If the conclusions of Brown et al. are correct, the estimation equation for the hedonic price function should treat private and [public] water as two separate variables. In this case, failure to use two water variables would result in specification error and bias the results.

While Crouter does not perform such an analysis, Faux and Perry (1999) do by regressing the price per acre of 225 properties from the Treasure Valley, Oregon on soil capability classes that are disaggregated by water supplier.⁴ The authors note, somewhat surprisingly, they cannot reject the null hypothesis that differences in land value are not influenced by type of water source (which they explain might be a consequence of the particular cropping system associated with the Treasure Valley).

Mendelsohn and Dinar (2003), meanwhile, used a Ricardian approach to estimate whether the county-level agricultural land values on approximately 2,800 counties throughout the US are influenced by the level of fresh water withdrawn by irrigation from surface water supplies and groundwater supplies. Schlenker et al. (2007), using a much larger data set consisting of 2555 parcels located in California, investigate the impact of average surface water deliveries on farm values reported by growers as part of the June Agricultural Survey, where deliveries are the combined surface deliveries from both federal and private sources. They also include a variable that allows for groundwater to be a source of irrigation. Petrie and Taylor (2007) investigate the value of water use permits in a Georgia basin for which a moratorium was placed on water use for growers who did not have a permit. Water use permits in the Petrie and Taylor study, which is the first use of the hedonic model to value water for irrigated agriculture in the eastern U.S., are not differentiated by whether they are used to pump surface water or groundwater.

All of the papers identified above find that water supplies are a statistically significant determinate of land values. Yet, the only paper that evaluates the relationship between land values and alternative surface water supply sources— Faux and Perry (1999)—cannot find a statistically significant outcome that the type of water supply matters. For the remaining papers, water sources are combined in

⁴ There are five different water sources in the Faux and Perry (1999) analysis. For each farm, the percentage of land in each land class was disaggregated by water source.

a manner that treats them as perfect substitutes. Furthermore, the three papers that investigated groundwater do not find it to be a statistically significant variable in explaining farmland values.⁵ Finally, none of the analyses include a quality variable for either surface or groundwater supplies, or any other characteristic of supply besides mean values. As stressed and shown in Connor et al. (2012), increases in water supply variability and decreases in groundwater quality, trends that are consistent with future expectations surrounding water supplies (e.g., Hansen et al. 2009), can significantly impact farm profitability; as such, we would expect to observe impacts on farmland values.

With this literature in mind, our analysis intends to further investigate these issues. First, we define surface water supplies by the first and second moment conditions rather than the first alone. Second, and similar to Schlenker et al., we include an estimate of the groundwater levels under a farm. As an extension to Schlenker et al., though, we also include the quality of the groundwater as measured by the salinity concentration (EC). Third, we separate out the different water supply sources to test whether they have differential impacts on land values. Finally, we investigate whether combinations or a portfolio of water supply sources provide additional value above and beyond individual supplies. As our data set includes geo-referenced data on approximately 2000 parcels located in ten counties across California, our larger spatial coverage relative to most of the analyses cited above might permit our analysis to better capture the underlying effects of these variables on farm values relative to the smaller spatial scale studies so often represented which might lack the appropriate variability, as noted in Schlenker et al. (2007)

⁵ Crouter (1987) find the 0/1 variable indicating the presence of an irrigation well to be statistically insignificant and drop it from their final results. Mendelsohn and Dinar (2003) similarly test the contribution of groundwater to explaining county-level land values and do not observe statistical significance; consequently, it is dropped from their analysis. Schlenker et al. (2007) find that the estimated depth to the groundwater well at any particular parcel is negatively related to reported farm values, but not statistically significant. Given water use permits in the Petria and Taylor (2007) do not differentiate between surface or groundwater withdrawals, no conclusion can be made. Two papers that do find a statistically significant relationship between some measure of groundwater and land values is Stage and Williams (2003), who focused on the impact of access to groundwater on farm prices in Namibia, and Hornbeck and Keskin (2011), who provide an analysis of how historical land values on the Great American Plains have been increased by access to the Ogallala aquifer.

3 Model and Data

To investigate the value to growers of having access to a portfolio of water supply options, as well as to identify if and the extent to which different characteristics of water supply source differentially impact land values, we use the hedonic property method. The hedonic property value method, whose theoretical underpinnings can be traced back to Rosen (1974) and Freeman (1974), along with the closely-related Ricardian approach have been employed rather extensively in recent years to investigate the impacts of climate change on agriculture (Mendelsohn et al. 1994 & 1996; Mendelsohn and Dinar 2003; Schlenker et al. 2005 & 2007). The hedonic method allows for the value of a differentiated product to be a function of its characteristics; in the case of agricultural land, the characteristics are assumed fixed and value often is represented by land rental rates or land sale prices (Palmquist 1989).

For the purposes of this paper, we use parcel sale prices and describe these sales prices as a function of the parcel's characteristics, which can be represented in general form by the following hedonic equation:

$$(1) \quad P_i = P(x_{i1}, x_{i2}, \dots, x_{iN})$$

where P_i is the sales prices of the agricultural parcel i and x_{ij} is the j^{th} characteristic of parcel i . Representing equation (1) in the more standard estimating equation, we have:

$$(2) \quad P = X\beta + \varepsilon$$

where the subscripts have been dropped for convenience, and X is now a vector of characteristics x_j , and ε is the error term. The parcel characteristics consist of surface and groundwater water supply characteristics, land quality characteristics (productivity indices), institutional characteristics that capture membership in a type of water/irrigation district (private, state, or federal), crop characteristics, climate characteristics, and other factors that influence land values. Specifically, we estimate the following equation:

$$(3) \quad \text{salevalue}_{it} = \beta_0 \text{acres}_{it} + \beta_1 \text{orchard} + \beta_2 \text{vineyard} + \beta_3 \text{distance from freeway}_i + \beta_4 \text{population}_i + \beta_5 \text{Storie Index}_i + \beta_6 \text{year fixed effects} + \beta_7 \text{Jan Dgd}_i + \beta_8 \text{April Dgd}_i + \beta_9 \text{July Dgd}_i + \beta_{10} \text{Oct Dgd}_i + \beta_{11} \text{Jan Precip}_i + \beta_{12} \text{April Precip}_i + \beta_{13} \text{July Precip}_i + \beta_{14} \text{Oct Precip}_i + \beta_{15} \text{Private WD} + \beta_{16} \text{State WD} + \beta_{17} \text{Fed WD} + \beta_{18} \text{Private State} + \beta_{19} \text{Private Fed} + \beta_{20} \text{State_othersupplies} + \beta_{21} \text{Fed_othersupplies} + \beta_{22} \text{Private_othersupplies} + \beta_{23} \text{MeanWater Supply_SWP}_i + \beta_{24} \text{MeanWater Supply_CVP}_i + \beta_{25} \text{VariabilityWater Supply_SWP}_i + \beta_{26} \text{VariabilityWater Supply_CVP}_i + \beta_{27} \text{Groundwater depth}_i + \beta_{28} \text{Groundwater salinity}_i + \varepsilon_{it}$$

Data

The data used in the estimating equation (3), whose definitions and summary statistics are listed in table 1, were obtained from a real estate database, county tax assessor reports, and through the use of Geographical Information System (GIS) techniques and includes sales price and parcel characteristics for 1900 agricultural land parcels sold in California during the time period ranging from 2004 to 2010. The parcels are located in one of ten counties that span southern, central, and northern California, including the counties of Tulare, Fresno, Kings, Kern, Merced, Napa, San Luis Obispo, Riverside, Monterey and Imperial. The locations of these parcels are illustrated in figure 1.

Sales price information for these parcels was collected from the real estate database LoopNet (www.loopnet.com). Information on farm characteristics (e.g., presence of permanent structures, and whether a tree crop or orchard is present)⁶ was obtained from the County Assessor's office associated with each parcel. Information on the latitude and longitude for each of these farms was obtained by

⁶ We assume that a perennial crop such as some type of orchard or tree crop is fixed if acknowledged by either LoopNet or the County Tax Assessors report (as opposed to annual crops). This is similar to the assumption of fixed irrigation systems in Mendelsohn and Dinar (2003).

geocoding each parcel in ArcGIS. Population by zip code was obtained from the Census 2000 data. The shape files for US National highways were obtained from California-Atlas. Distance from nearest highway to the farms was spatially computed in ArcGIS.

Observations on groundwater depth for the nearest well to each farm were obtained using GIS techniques from the California Department of Water Resource's Integrated Water Resource Information System (IWRIS). We collected salinity (EC) data for the nearest well to each agricultural parcel using GIS methods and information from the Groundwater Ambient Monitoring and Assessment Program (GAMA) Geotracker of U.S. Geological Survey (USGS). However, instead of using the actual values for groundwater depth and salinity, we used estimated values for groundwater depth and salinity using kriging techniques to overcome issues of endogeneity and measurement errors. The groundwater depth and salinity at each farm location is derived as a weighted average of all well locations, where the weight is the inverse of the distance of each well to the farm to a power of 2 which minimizes the sum of prediction errors from cross validation.⁷

To account for differences in land quality, we incorporated the California Revised Storie Index (SI) and Irrigated Capability Class Index (ICC) obtained from Web Soil Survey of Natural Resources Conservation Service (NRCS), using latitude and longitude information. The Storie Index is a soil rating based on soil properties that govern a soil's potential for cultivated agriculture in California. The Storie Index assesses the productivity of the soil from the following four characteristics—degree of soil profile development, texture of the surface layer, slope and manageable features. A score ranging from 0 to 100% is determined for each factor, and then the scores are multiplied together to derive an index rating. Storie Index ratings have been classified into six grade classes as follows: Grade 1(excellent) 100 to 80, grade 2 (good) 79 to 60, grade 3 (fair) 59 to 40, grade 4 (poor) 39 to 20, grade 5 (very poor) 19 to 10, grade 6 (non-agricultural), less than 10. Irrigated capability class, meanwhile, shows the suitability of

⁷ Our kriging approach follows along the approach as used in Schlenker et al. (2007).

soils for most kind of field crops. Capability classes are designated by numbers 1 through 8. The numbers indicate progressively greater limitations and narrower choices for practical use.⁸

In terms of climate-related variables, both ten years and twenty five years of temperature and precipitation data for the closest weather station to each farm were obtained from California Irrigation Management Information System (CIMIS). Since agronomic research suggests that crop growth is non-linearly related with temperature, our temperature data is converted into degree-days to capture this non-linear relationship (see, e.g., Schlenker et al. 2007). We use 25 years of climate variables for our analysis as long-term climate variables get capitalized into land values (Deschenes and Greenstone, 2004). Furthermore, rather than use each month's average, we follow the convention in the literature and use time periods that capture fall, winter, spring, and summer conditions.

Water supply data for Federal and State Water districts were obtained for the time period of 1994-2004 from Bureau of Reclamation and Department of Water Resources, to account for average surface water supply and variability of surface water supply. To geo-code each farm into a water district, the federal, state and private water districts shape files of California were obtained from California-Atlas. The water district in which the farms were located was identified by overlapping the polygons of agricultural parcels with water districts using GIS spatial intersection tools. To verify the accuracy of this information, the tax bills of the farms, which are available online from the county assessor website, were crosschecked. The tax bills have information on the water districts from which the farm obtains water supply.

Figures 3 and 4 illustrate how the characteristics of the water supplies from the State Water Project (SWP) differ from the federal government's Central Valley Project over the 10-year time period beginning in 1994 and across a number of irrigation districts. What very apparent is the variability in the SWP supplies across districts relative to the consistently low CVP supplies. Figures 5 and 6 compare average water allocations to maximum allowable allocations for both SWP and CVP supplies across

⁸ There may be nonlinear soil quality effects that are not captured with a single variable as shown in Faux and Perry (1989). Such an analysis goes beyond the scope of the present research and will be evaluated in future analyses.

districts. As shown, average allocations often are significantly lower than maximum allocations due to lower than expected rainfall and snowmelt conditions in California over that period.

Information on the water rights for the water districts were obtained from Electronic Water Rights Information Management System (EWRIMS). The EWRIMS has information on whether the water districts have appropriative and/or riparian rights, were enrolled in the Groundwater Recordation Program or/and have claimed riparian rights. Appropriative rights are the right to divert water from a source under a permit provided by the State Water Board. The permit has a face value assigned to it, the value designating the maximum amount of water that can be diverted from a source (and not the amount that is actually diverted). Unfortunately, the Groundwater Recordation Program is applicable only for certain counties (e.g. Riverside County). According to this program, those persons owning wells with aggregate extractions of more than 25-acre feet (or 10-acre feet or more from a single source) should file a report of their extraction with the State Water Board. Similarly, California law requires that any person or organization that diverts surface water or pumps groundwater from a subterranean stream should file a statement of riparian claim with State Water Board. However, these laws are not very strictly imposed and there are districts which divert riparian water but do not file a statement with State Water Board. Since there is no permit required for pumping groundwater, the records of districts which use groundwater may not be found in EWRIMS. As an alternative, then, we contacted each of these districts to obtain information on whether these districts have access to groundwater and/or riparian water. We label this option, Other.

Functional Form

Linear, log-linear, and log-log functional forms were estimated and compared based goodness of fit statistics. Based on the results of these comparisons, we chose the log-log functional form which has the benefit of fitting data well that is of significantly different measurement units. As noted in Hao and Naiman (2007), log transformations often yield a better fit than raw scale data. In a log-log model, the

coefficients of the variables are typically interpreted as percentage change in the dependent variable with 1% increase in the independent variables; in effect, the coefficients are elasticities (Wooldridge, 2006).

Given the potential for spatial dependence and correlation, we estimate the log-log model under four different specifications: Ordinary Least Squares (equation 2), Spatial Autoregressive, Spatial Error, and a General Spatial Model. Following Anselin (1999), the spatial models are represented as:

$$(4) \quad P = \rho W_1 P + X\beta + \varepsilon \quad \text{Spatial Autoregressive Model}$$

$$(5) \quad P = X\beta + \varepsilon \\ \varepsilon = \lambda W_2 \varepsilon + \mu \quad \text{Spatial Error Model}$$

$$(6) \quad P = \rho W_1 P + X\beta + \varepsilon \\ \varepsilon = \lambda W_2 \varepsilon + \mu \quad \text{General Spatial Model} \\ \mu \sim N(0, \sigma^2 I_n)$$

where W_i is a weights matrix, ρ is the spatial lag parameter, λ is the spatial autoregressive error parameter, ε is a first-order autoregressive error process, and μ is assumed to be i.i.d. normal.

The Spatial Autoregressive model assumes that farm values are a function of neighborhood farm values. As shown in equation (4) below, the spatial autoregressive model assumes that the spatial autoregressive coefficient for farm values is statistically significant. Overlooking spatial autoregression in the dependent variable, when it exists, leads to biased estimates (Anselin, 1999). The spatial error model, equation (5), takes into account correlation in error terms, which may occur due to spatial correlation in omitted variables or measurement error of regression variables measured at different geographic levels. The spatial error model shows that the coefficient for the spatial correlation of the error term is statistically significant. Spatial correlation in error leads to inefficient estimates (Anselin, 1999).

In estimating these four different models, the null hypotheses of ρ and λ equaling zero was rejected. Hence, for the analysis that follows, we use the General Spatial Model (GSM) which controls for both the spatial autocorrelation in farm values and spatial correlation in the error terms.⁹ Our results

⁹ Results of these comparisons as well as the comparisons among the linear, log-linear, and log-log comparisons are available from the authors upon request.

suggest that the General Spatial Model improves the fit of the model significantly and helps to overcome the issues of biasness and inefficiency of the estimators.

Finally, given the significant number of dummy variables that are included in our model (equation 3), we have to drop a few dummy variables to avoid perfect multicollinearity. We drop the year dummy of 2004 and include year dummies from 2005-2010 in our model. We also drop the crop dummy of “other crops” and include the dummies of orchard and vineyard in our model. We also perform an interaction of different dummy variables (e.g., farms that are a member of both a state and private water districts, or farms that are a member of both a federal and private water districts)¹⁰ in our model to estimate the value of a diversified water supply. Again multicollinearity arose in the case of individual and interaction dummy variables, which often lead to signs opposite what was expected or the reversal of a sign on the dummy variables. As a solution, we conducted a three-way classification, using a third interaction or classification term that allowed us to interact the dummy variables with different categories.

5 Results

To investigate whether having access to a water portfolio influences farmland values, and if the type of portfolio matters, we define two types of portfolios. The first type of water portfolio—type 1—arises in the case when a farm belongs to a single water district which has access to multiple sources of water. For example, a farm might be a member of a private water district which has appropriative rights but also possible riparian rights or access to an aquifer; alternatively, the farm might be a member of a state water district which also has access to riparian water. Thus a type 1 portfolio consists of being a member of either a private, state, or federal water district and having access to groundwater and/or riparian water. The second type of portfolio—type 2—arises in the case when a farm is a member of multiple water districts consisting of either a private and state water district, or a private and federal water district. Finally, we will combine both type 1 and type 2 portfolios into the same regression for analysis.

¹⁰ Farms can be a member of a private and either a federal or state water district, but cannot be in both a state and federal water district.

In each of these four scenarios—no portfolio, type 1 portfolio, type 2 portfolio, and type 1 and 2 portfolios—we include expected/average water supplies, water supply variability, groundwater depth and groundwater salinity in addition to the other variables mentioned in equation (3). The results for all four scenarios using the GSM approach (equation 6) are presented in table 2 and discussed below.¹¹

Before presenting the results, it is important to state that the primary objective for breaking up the analysis into four scenarios is illustrate how different water supply sources and combinations of sources affect the value of farmland and, as Mendelsohn and Dinar state (2003; p. 329), “...the climate sensitivity of agriculture.” Additionally, and as an extension to Mendelsohn and Dinar (2003) and Schlenker et al. (2007), we will illustrate how different adaption opportunities reduce the sensitivity of irrigated agriculture to degrading groundwater supplies and more variable surface water supplies.

5.1. Scenario 1: Baseline defined by no water portfolio

In this model, we do not take into account either type of water portfolio; as such, the analysis would be somewhat similar to the analyses by Crouter (1987), Faux and Perry (1989), Mendelsohn and Dinar (2003), and Schlenker et al. (2007) while also including a groundwater quality, water supply variability, and differentiating between types of water supply. Focusing on the non-water-related variables first, the results are consistent with expectations. For example, as the distance to the highway increases, farm values decrease, and as population within the zip code for which the farm is located increases so do farm values. Soil quality is positively related to land values, as is having an established orchard. Perhaps slightly surprising, the presence of a vineyard is not statistically significant, although vineyards do have a positive sign. The year dummy variables indicate that land prices generally increased from 2004 through 2007, at which time they decreased until 2009, at which time they were not

¹¹ For the present version of this paper, mostly elasticities are presented; future versions will translate these estimates into real monetary terms for comparisons. With that said, a few elasticities have been transformed into monetary values in this section.

statistically different from 2004 prices. In 2010, though, we see another surge in land prices relative to 2004.

With respect to the climate-related variables, we see that warmer temperatures and more degree days in January, April, and October are all associated with higher land values, while a warmer temperature in July is negatively related. This is consistent with our expectations and the results in the literature (Mendelsohn and Dinar 2003; Schlenker et al. 2007) in that higher temperatures in the spring and fall extend the growing season while higher temperatures in July typically require more water to meet plant requirements. Precipitation generally is positively related to land values except for July, where it is negatively related, a result similar to the research mentioned above and likely captures the negative impact of rainfall events in the northern water districts where water is not as scarce (e.g., Monterey).

We find that salinity and groundwater depth have statistically significant and negative impacts on farm values, consistent with expectations yet a unique result not found in the literature. That is, Crouter (1987), Mendelsohn and Dinar (2003), and Schlenker et al. (2007) found no statistically significant relationship between groundwater depth and land values, perhaps due to the fact that there was no control for groundwater quality. Focusing on the first and second moments of the water supplies across different irrigation sources we see that mean supplies are positive and statistically significant predictors of farmland values, while variability is a negative and statistically significant predictor. Interestingly, the SWP water has a much greater impact than the CVP supplies on farmland values. This is not surprising when one considers differences in the characteristics of these water supplies as mentioned above (and shown in figures 3 and 4). Similarly, being in state water district leads to a 0.84% increase in farm values, whereas being in a federal or private water district leads to a 0.18% and 0.13% increase, respectively, relative to not being in a water district. These results are statistically significant and amount to an approximate \$34,000 premium for being a member of a state water district, nearly a \$7,500 premium for being in a federal water district, and approximately a \$5,500 premium for being in a private water district, all relative to not being in a district at all.

5.2. Scenario 2: Inclusion of a type 1 portfolio

In this scenario, we account for farms that are members of a water district that has multiple sources of water supply (yet is not a member of another water district). We add three variables that account for whether the farm is in (i) a private water district that has access to “Other” supplies, which include groundwater or riparian water, (ii) a federal water district that has access to “Other” supplies, and (iii) a private water district that has access to “Other” supplies. This means that in addition to the surface water that they receive through permits from State Water Board (for SWP, CVP, or private water use permits), they also have access to ground water and /or riparian water.

We find that the farms which are in a state water district that have access to multiple sources of water has a .52% increase in its farm value, while those that are in a federal or private water district with access to other sources of water have a 0.11% and 0.09% increase in farm values, respectively, although the latter coefficient is not statistically significant. These percentage estimates translate into premiums of approximately \$21,000, \$5,000, and \$3,700 for being in a state, federal, and private water district and having access to other supplies above and beyond being in districts that do not have access to multiple supplies. Hence, having access to multiple sources of water increase farmland values, although the magnitude of such an increase is dependent on the type of water district a farm resides in.

In response to the question whether access to multiple water sources serve as an adaptive strategy serve to reduce the sensitivity of agriculture to climate, we see that such access reduces significantly the negative impact of July degree days on farmland values, and reduces the importance of local precipitation. We also observe that for farms that are in districts with a portfolio of water supply options similar to our type 1 definition, the impact of salinity becomes statistically insignificant relative to the baseline, but no appreciable change in the impact of groundwater depths on land values are observed. Interestingly, the negative impacts of water supply variability are reduced with access to multiple sources

of water. With respect to the negative impacts of water supply variability on farmland values, having access to a more diversified water portfolio reduces such impacts.

5.3. Scenario 3: Inclusion of a type 2 portfolio

In this scenario, we account for farms that have access to multiple sources of water due to their membership in two water districts: state and private (Private_State), or federal and private (Private_Fed). As including interaction dummies and its components in the same regression model may lead to multicollinearity issues, improper signs, and statistical significance, we classify these dummies into different categories using a three-way interaction. We identify the farms which are members of both state and private water districts and which are in the top 25% or bottom 25% of SWP average water supplies recipients (i.e., Private_State_Top25% or Private_State_Bot25%); similarly, we classify farms which are members of both federal and private water districts into farms which are in the bottom 25% and top 25% of CVP average water supply recipients (Private_Fed_Top25% or Private_Fed_Bot25%). The issue our additional designations address is the following: farms that receive significant amounts of SWP or CVP water may not benefit greatly from having access to another water supply; conversely, farms that do not receive much SWP or CVP water may benefit greatly from such additional access.

As shown in the third column of results in table 2, being a member of two districts, whether private and state or private and federal, has a negative and statistically significant impact on farm values. While this might be surprising at first, when one considers that if the benefits of being a member of more than one district are minimal, but if there are added administrative costs and fees for being in more than one district (which there are), then such a result seems reasonable. For those farms that have a low expected allocation of water supplies from either a state or federal water district, though, being a member of private district as well may be valuable and worth the costs. The coefficients on Private_State_bot25% and Private_Fed_bot25% support such an assessment. That is, for those farms that are located into state or federal water districts and receive supplies that put them in the lowest quartile of deliveries over the

past 10 years, also being a member of a private water district has a positive and statistically significant impact on farmland values. Obviously in these situations the benefits of having access to another water supply source outweigh the costs.

In terms of whether access to water sources in multiple districts serve as an adaptive strategy that might reduce the sensitivity of agriculture to climate, we do not observe any significant differences in the coefficient estimates on the precipitation and degree day variables relative to the baseline model except in the case of reducing, again significantly, the negative impact of July degree days on farmland values. Where we do observe large changes in parameter estimates after accounting for access to multiple districts, both in magnitude and statistical significance, is on the mean and variance variables for state and federal project water. As would be expected, reliance on these sources and the negative impact of variability amongst these sources is reduced. Finally, and similar to the results of a type 1 portfolio, the impact of salinity becomes statistically insignificant relative to the baseline, but no appreciable change in the impact of groundwater depths on land values is noticed.

5.4. Scenario 4: Inclusion of both type 1 and type 2 portfolios

In scenario 4, we allow for the identification of farms that have access to type 1 or type 2 portfolios. Focusing on the climate-related variables, with the exception of July precipitation, the impact of all of the climate-related values on land values is lessened when the full suite of portfolios are considered. In particular, there is a significant decrease in the impact of precipitation in the fall, winter, and spring on farmland values, and the elasticity related to July temperature decreases from -1.92% down to -1.12%. Both of these results suggest that access to portfolios can help reduce the sensitivity of agriculture to climate.

Compared to the baseline, farm vulnerability to poor quality groundwater is reduced from -0.107% to -0.016%, while the impact of lower groundwater tables on farm values is unaffected. Water supply variability, whether from CVP or SWP sources, becomes statistically insignificant relative to the

baseline and practically economically insignificant as well as for the case of the SWP sources as the elasticity decreases from -0.623 down to -0.072. While there is a premium in being in state, federal, or private water district relative to not being in a district, there exists an additional premium above and beyond that if the district has access to groundwater or riparian water. Finally, while the value to a farm of having access to riparian or ground water if the farm receives a quantity of CVP or SWP water that puts it in the top quarter of farms is not statistically significant, for those farms that are in the lower quartile of average supplies from either the CVP or SWP, having access to riparian or groundwater has a positive and statistically significant impact on land values.

6 Conclusion

The results from our analysis help to highlight the importance of a water portfolio as an adaptation strategy to combat both the direct and indirect effects of climate change. Our results show that access to multiple sources of water supplies reduces the impact of climate-related variables on farm values. Furthermore, our results suggest that access to multiple sources of water reduces the vulnerability of farms to less reliable and lower quality water. Such results extend previous analyses, particular the research by Mendelsohn and Dinar (2003) and Schlenker et al. (2007) which focused on the value of water supplies, as characterized by their mean values, on farmland values and as an adaptation strategy to combat climate change.

Compared to the literature to date, we observe several unique, albeit not unexpected, results. First, we find heterogeneity in the impacts of different water supply sources on farmland values. Second, we show that access to groundwater has a statistically significant, robust, and positive impact on farmland values. Third, our results show that water quality, in this case groundwater salinity, has a negative and significant impact on farmland values. While these results are not unexpected, they do illustrate that water supplies are not homogeneous entities. Additional, our results suggest that there exists three pathways through which changes in water supplies can affect farmland values—a level effect, a reliability

effect, and a quality effect. While the first effect has been documented quite well in the literature, there is little to no documentation, at least in cross-sectional studies, that shows a relationship between groundwater quality and access and agricultural land values.

For the specific application here—climate change and California agriculture—we find that the marginal value that the growers attach to average water supplies from the CVP and SWP decreases as access to other sources increase. Additionally, we see that the negative impact of water supply variability associated with SWP supplies decreases substantially for those farms that have access to multiple water districts, while the variability of CVP supplies becomes insignificant. Of course, for the farms that have access and rights to the highest per acre deliveries of CVP or SWP water, access to an additional source has little to no value, and even may result in negative values since there may exist additional fees and administrative costs that are not covered by the returns to this additional source. Yet for those farms that are in the lower quartile of water deliveries from either CVP or SWP supplies, having access to an additional source has a positive and statistically significant impact on land values.

With the help of this study, we conclude that water portfolio seem an attractive adaptation option to help growers mitigate the impacts of changing climates and water supply conditions. As such, these results should provide support for policies that encourage development of an array of water supply sources. These values can direct water district managers and growers to take strategic decisions and, consequently, better adapt to changing water supply conditions.

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Table 1. Variable Descriptions and Summary Statistics

Variable Name	Variable Description	Average Value	Minimum Value	Maximum Value
salevalue _{it}	Sale Price/acre (\$/acre)	41,303	482.45	400,000
acres _i	Parcel Size (acres)	34.54	0.002	1615.06
Orchard _i	Dummy capturing whether farm contains an orchard		0	1
Vineyard _i	Dummy capturing whether farm contains a vineyard		0	1
Distance _i	Distance from Highway (meters)	7006.63	0.40	37563.09
Population _i	Population by zip code area	62587.81	120	427652
Storie _i	Storie Index	59.97	1	100
Year _i	Dummy capturing year in which property was sold (2004-2010)		2004	2010
Month_Dgd _i	Degree days recorded at nearest station to farm i (for January, April, July, and October)	28.61	16.21	43.19
Month_Precip _i	Precipitation (inches) recorded at the nearest station to farm i (for January, April, July, and October)	1.06	0.003	2.72
Private_WD _i	Dummy if farm is in a private water district		0	1
State_WD _i	Dummy if farm is in a state water district		0	1
Fed_WD _i	Dummy if farm is in a federal water district		0	1
Other_Supplies _i	Dummy if farm has access to riparian or groundwater in addition to surface water obtained through permits from State Water Board.		0	1
Allot_SWP _i	Water Allocation_SWP (acre-feet /acre)	4.51	1.56	10.66
Allot_CVP _i	Water Allocation_CVP (acre-feet /acre)	1.93	0.02	5.29
Mean_SWP _i	Average Water Supply_SWP (acre-feet /acre)	2.78	0.08	8.99
Mean_CVP _i	Average Water Supply_CVP (acre-feet/ acre)	1.06	0.007	3.39
Variability_SWP _i	Variance Water Supply_SWP (acre-feet/acre)	0.09	0.00	0.87
Variability_CVP _i	Variance Water Supply_CVP (acre-feet/acre)	0.27	0.00	4.64
Depth _i	Groundwater Well Depth (feet)	105.39	0.18	1803.19
Salinity _i	Groundwater Salinity Concentration ~ EC (dS/meter)	0.583	.102	11

CVP ~ Central Valley Project Water (federal); SWP ~ State Water Project Water (state)

Table 2. Estimates from GSM Hedonic Regression Model

Variables	Baseline (No portfolio)	Access to multiple sources of water within a district (Portfolio Type 1)	Member of multiple water districts (Portfolio Type 2)	Access to and member of multiple supply sources (Portfolio Type 1 &2)
Constant	10.747*** (0.000)	13.407*** (0.000)	10.646*** (0.000)	13.924*** (0.000)
Acres	-0.541*** (0.000)	-0.572*** (0.000)	-0.542*** (0.000)	-0.569*** (0.000)
Distance from freeway	-0.012** (0.011)	-0.004 (0.460)	-0.009* (0.069)	-0.001 (0.233)
Population	0.033** (0.011)	0.067*** (0.000)	0.043*** (0.001)	0.050*** (0.000)
Storie Index	0.072*** (0.002)	0.069*** (0.003)	0.085*** (0.000)	0.074*** (0.002)
Orchard	0.058** (0.047)	0.073** (0.024)	0.080** (0.053)	0.099** (0.035)
Vineyard	0.011 (0.825)	0.013 (0.819)	0.035 (0.525)	0.046 (0.925)
Year2005	0.139** (0.012)	0.148** (0.012)	0.146*** (0.008)	0.134** (0.022)
Year2006	0.135** (0.023)	0.138** (0.028)	0.145** (0.015)	0.131** (0.036)
Year2007	0.257*** (0.000)	0.287*** (0.000)	0.242*** (0.000)	0.252*** (0.000)
Year2008	0.119* (0.053)	0.162** (0.014)	0.140** (0.025)	0.115* (0.078)
Year2009	0.068 (0.385)	0.094 (0.234)	0.072 (0.393)	0.094 (0.240)
Year2010	0.291*** (0.002)	0.201** (0.038)	0.253** (0.008)	0.179 (0.641)
Jan degree days	0.440** (0.009)	0.503*** (0.004)	0.401** (0.019)	0.066*** (0.000)
April degree days	3.750*** (0.000)	3.279*** (0.000)	3.45*** (0.000)	3.723*** (0.000)
July degree days	-1.916*** (0.002)	- 1.511** (0.005)	-1.557*** (0.004)	-1.115*** (0.000)
Oct degree days	5.848*** (0.020)	5.320*** (0.000)	5.367*** (0.000)	5.660*** (0.000)
Jan precipitation	0.087 (0.291)	0.031 (0.699)	0.079 (0.357)	0.037 (0.718)
April precipitation	0.315*** (0.000)	0.146** (0.048)	0.371*** (0.000)	0.183** (0.014)

Table 2. Estimates from GSM Hedonic Regression Model (continued)

July precipitation	-0.487*** (0.000)	-1.178 (0.224)	-0.512*** (0.000)	-0.621*** (0.000)
Oct precipitation	0.385*** (0.000)	0.367*** (0.000)	0.391*** (0.000)	0.355*** (0.000)
Salinity of Groundwater (dS/m)	-0.107*** (0.001)	-0.096 (0.114)	-0.047 (0.394)	-0.016** (0.037)
Groundwater Depth (feet)	-0.056*** (0.000)	-0.065*** (0.000)	-0.057*** (0.000)	-0.056*** (0.000)
State Water District	0.840*** (0.000)	0.901*** (0.000)	0.542** (0.014)	0.795** (0.018)
Federal Water District	0.183** (0.011)	0.198** (0.016)	0.368*** (0.000)	0.436*** (0.000)
Private Water District	0.130*** (0.004)	0.219*** (0.000)	0.115** (0.051)	0.235*** (0.001)
Mean_SWP	1.101*** (0.000)	0.067 (0.840)	1.021*** (0.003)	0.070 (0.834)
Mean_CVP	0.122*** (0.002)	0.148*** (0.000)	0.074 (0.130)	0.087* (0.077)
Variance_SWP	-0.623*** (0.000)	-0.059 (0.743)	-0.590*** (0.001)	-0.072 (0.695)
Variance_CVP	-0.012*** (0.000)	-0.003 (0.885)	-0.025 (0.307)	-0.018 (0.466)
State_Other		0.517*** (0.007)		0.789*** (0.007)
Fed_Other		0.112* (0.088)		0.059 (0.371)
Private_Other		0.087 (0.162)		0.006 (0.928)
Private_State			-1.171** (0.035)	-0.622** (0.014)
Private_Fed			-0.326** (0.023)	-0.631** (0.000)
Private_State_top25%			-0.056 (0.514)	-0.084 (0.337)
Private_State_bot25%			0.012** (0.008)	0.026** (0.040)
Private_Fed_top25%			0.047 (0.531)	0.062 (0.421)
Private_Fed_bot25%			0.039*** (0.000)	0.061*** (0.000)
ρ (SAR correlation coefficient)	0.041*** (0.000)	0.037*** (0.000)	0.036*** (0.000)	0.033** (0.000)
λ (SEM correlation coefficient)	2.089*** (0.000)	2.074*** (0.000)	2.085*** (0.000)	2.075*** (0.000)
R ²	0.96	0.96	0.96	0.96

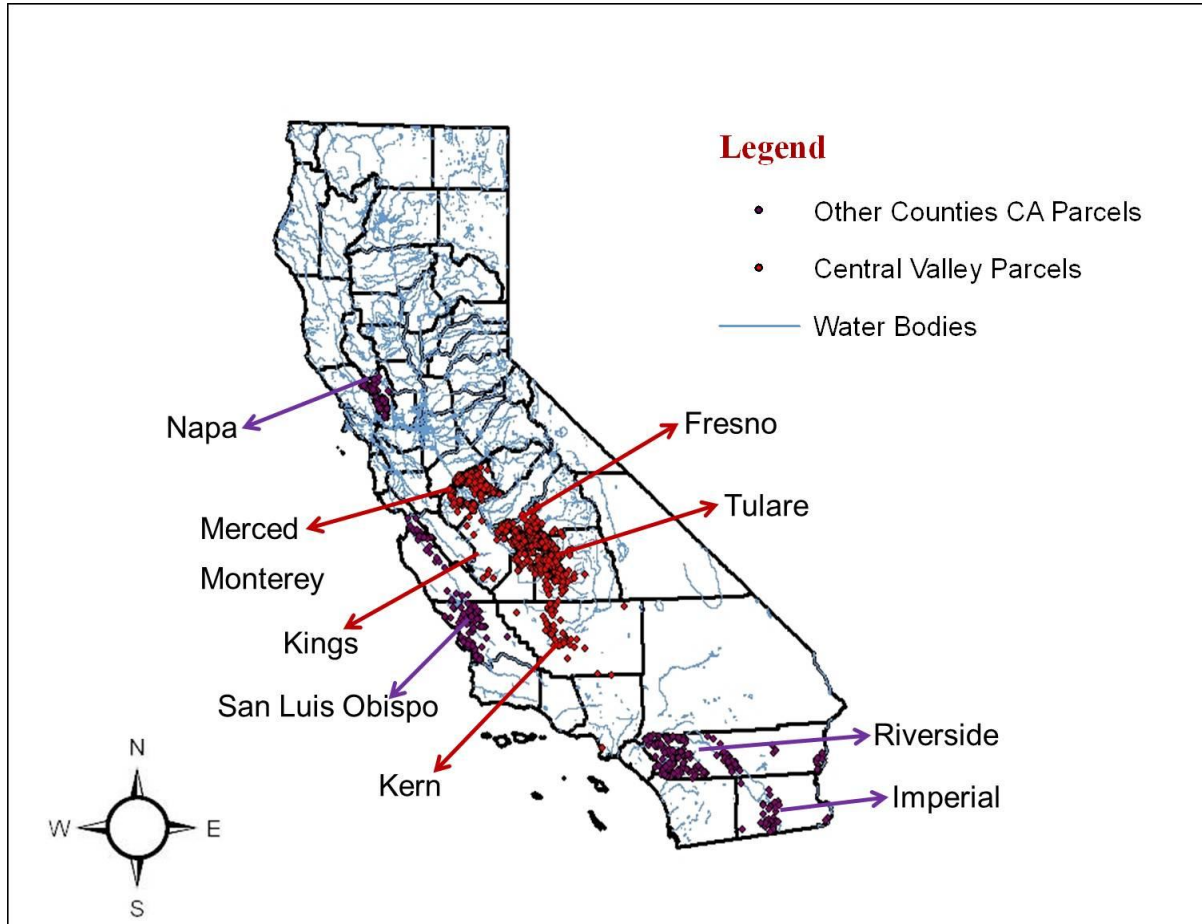


Figure 1. Study region map with farmlands

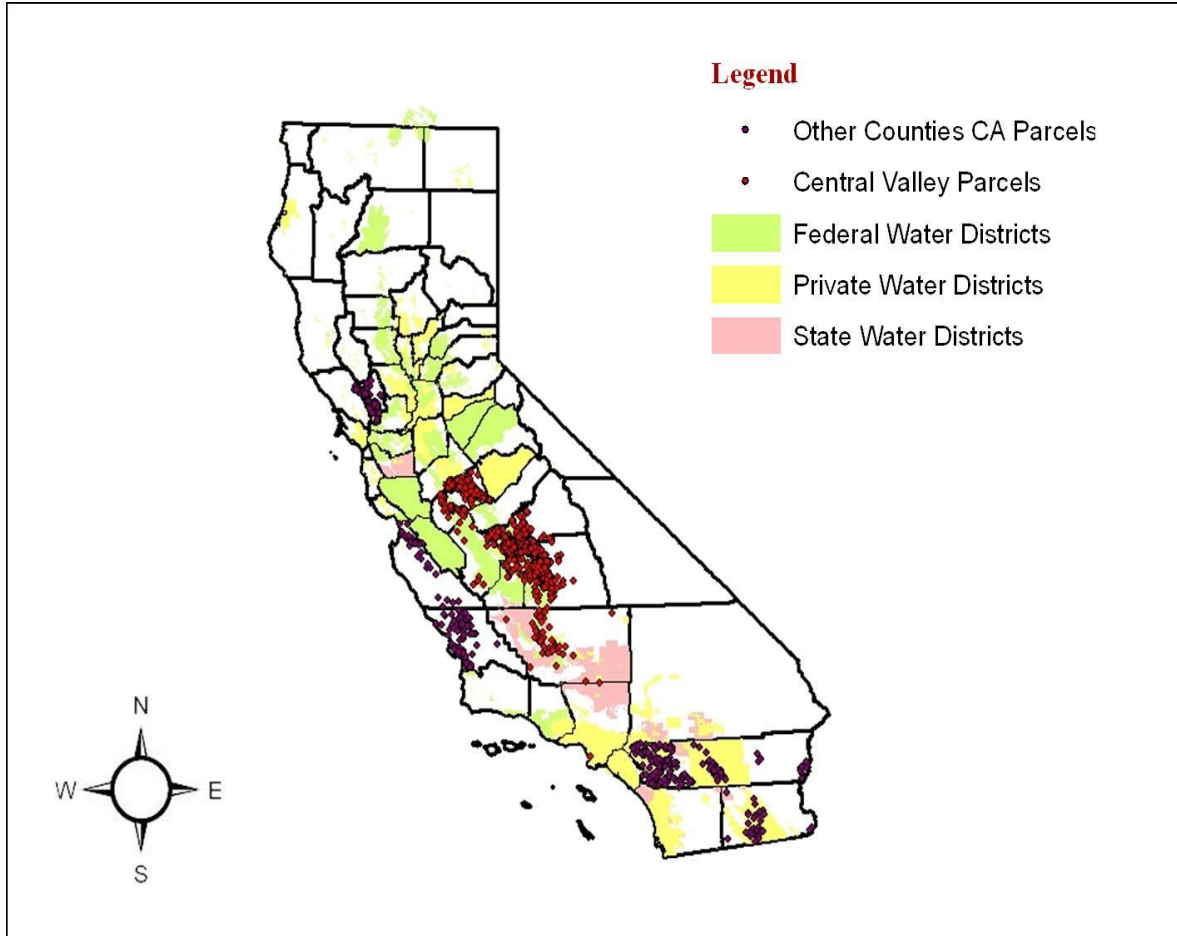


Figure 2. Location of Water Districts and Farmlands

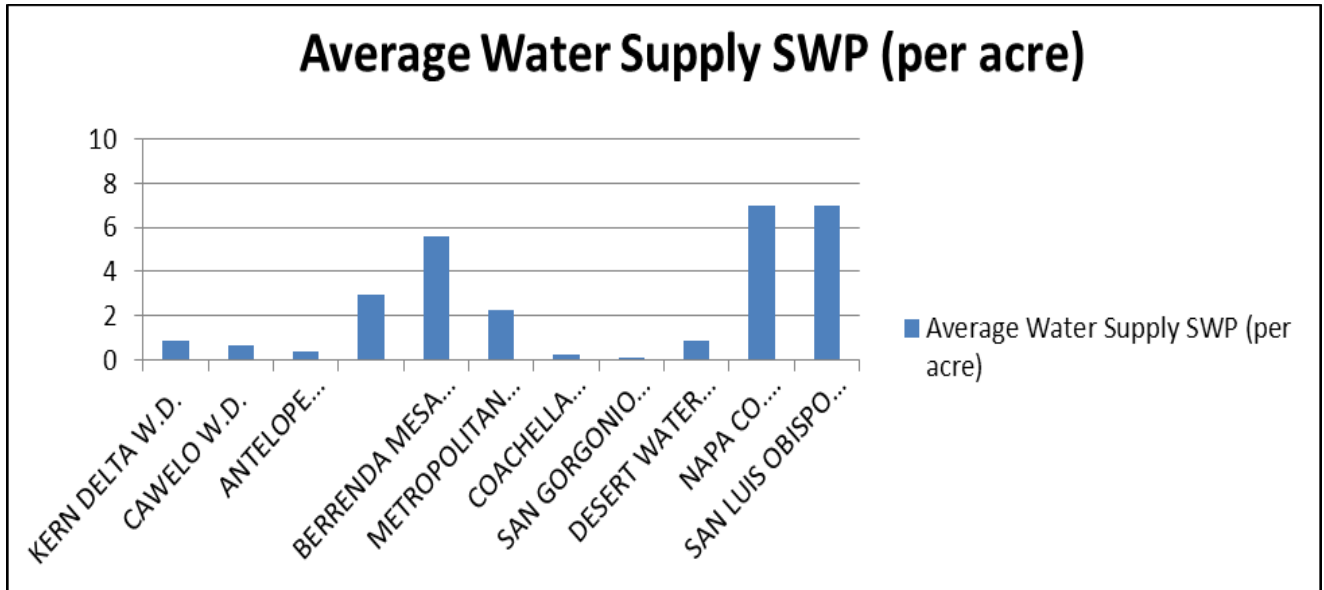


Figure 3. Average Water Supply for State Water Project in acre-feet per acre (SWP).

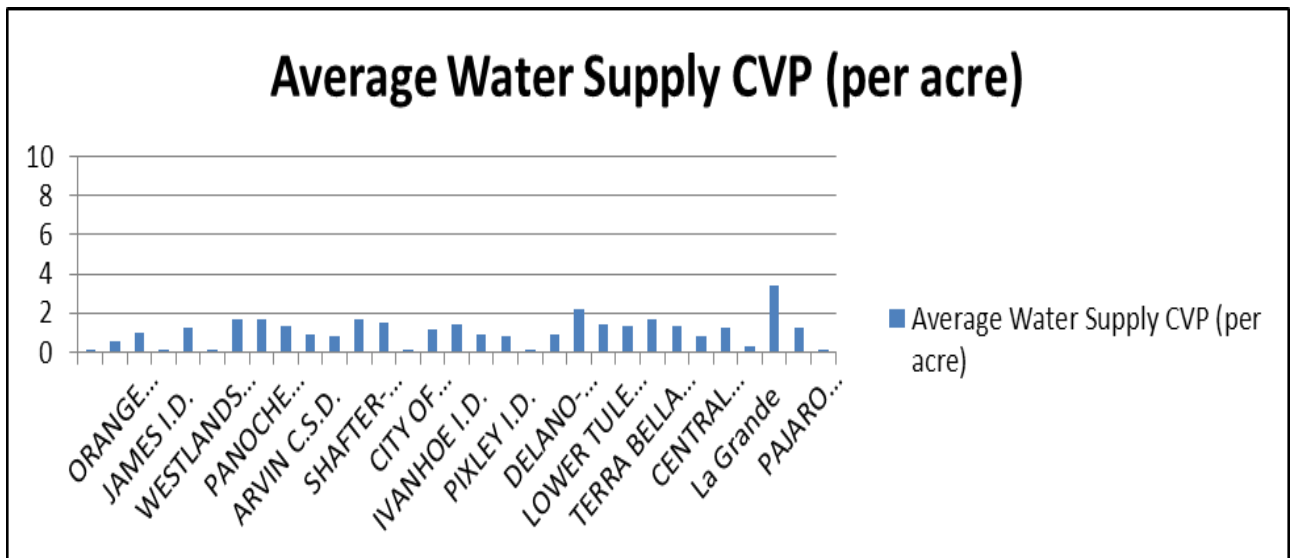


Figure 4. Average Water Supply for Central Valley Project in acre-feet per acre (CVP)

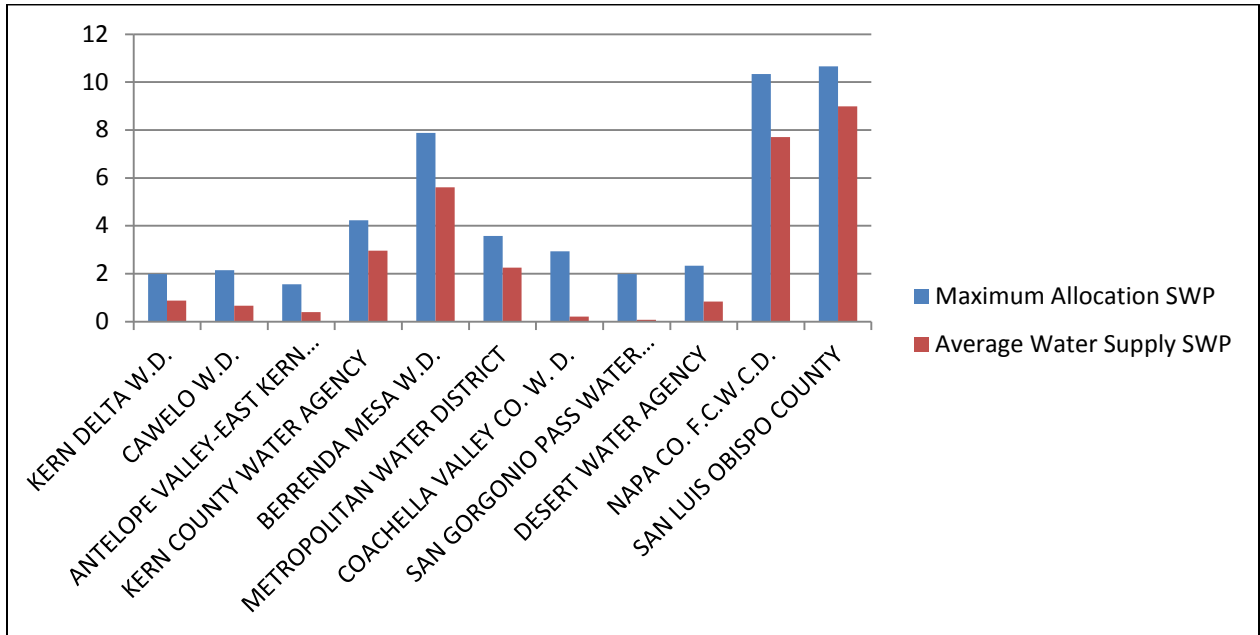


Figure 5: Comparing Average Water Supply versus Maximum Allocation for SWP in acre-feet per acre

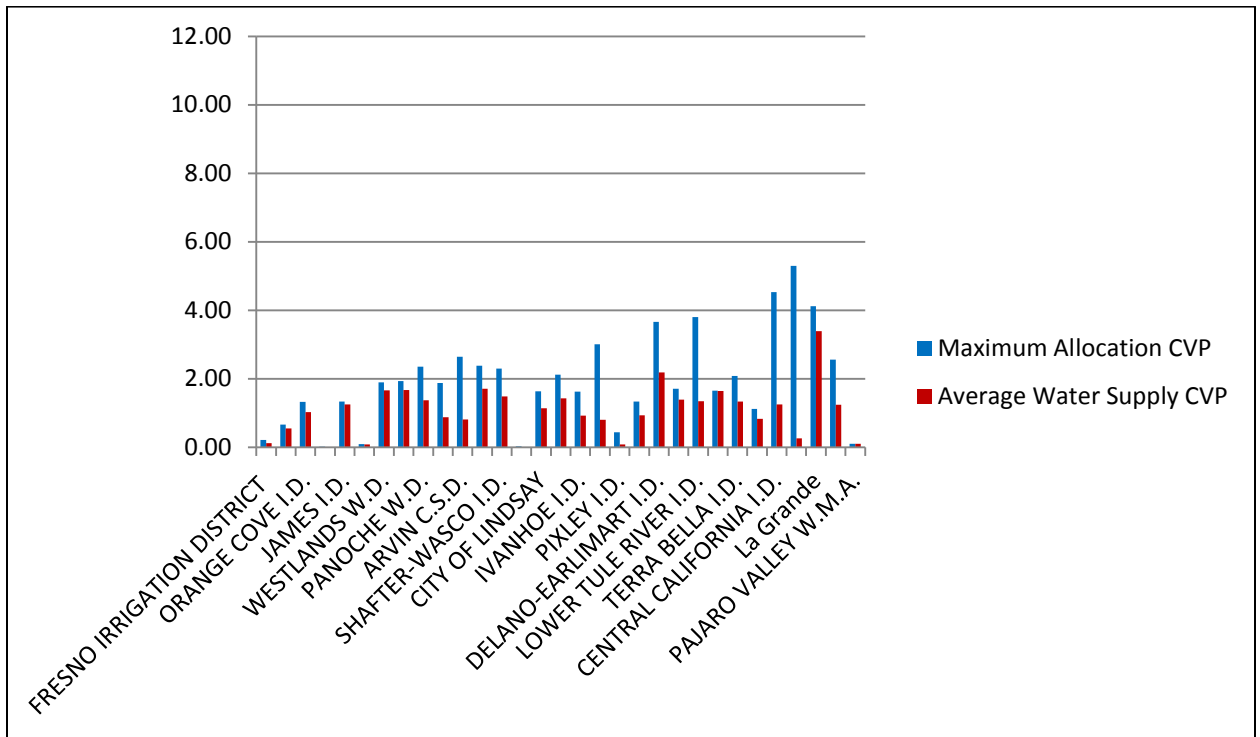


Figure 6: Comparing Average Water Supply versus Maximum Allocation for CVP in acre-feet per acre