Irrigated Agricultural Adaptation to Water and Climate Variability: The Economic Value of a Water Portfolio

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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 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 sources of water. With farm-level information on approximately 2000 agricultural parcels across California, we use a spatial econometric hedonic analysis 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 United States (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 insight 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

[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.

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 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 California State Water Resources Control Board to divert water from a river, the Central Valley Project (CVP), or the California 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 three-fold. First, we provide what appears to be 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

[2] Several adaptation strategies to water supply variability and climate change have been analyzed previously, and include 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.

[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.

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 2,000 farmland parcels across 10 counties of California that were sold between 2004 and 2010. We use a hedonic analysis to relate parcel sale prices to parcel characteristics and isolate the impact of different water supply characteristics and combinations on farmland values. From a policy and methodological perspective, we see two possible contributions of this research. First, the results from this analysis will highlight the value of policies that encourage access to a portfolio of water supplies that 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). Obviously, there are numerous studies 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 within a hedonic framework 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), a limited number of studies 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). Even fewer studies 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 sale prices of 45 farms were estimated as a function of a single water supply source – an irrigation company.

Building upon the Hartman and Anderson work in Colorado, Crouter (1987) investigated the relationship between the sale prices 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 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, stressed 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; p. 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 county-level agricultural land values across approximately 2,800 counties throughout the United States are influenced by the level of fresh water withdrawn by irrigation from surface water and groundwater supplies. Schlenker et al. (2007), using a hedonic approach and a much larger data set, consisting of 2,555 parcels located in California, investigated the impact of average surface water deliveries on farm values reported by growers as part of the June Agricultural Survey, in which 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

[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.

Petrie and Taylor study, which is the first use of the hedonic model to value water for irrigated agriculture in the eastern United States, 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 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. Quality of surface or groundwater sources is likely to influence farmland values in many semi-arid and arid regions, particularly areas in which salinity is present, such as the Murray-Darling River Basin in Australia or the Central Valley in California (Schwabe et al. 2006). As shown in Connor et al. (2012), increases in water supply variability and decreases in groundwater quality,

[5] Crouter (1987) found the 0/1 variable indicating the presence of an irrigation well to be statistically insignificant and drop it from the final results. Mendelsohn and Dinar (2003) similarly test the contribution of groundwater in explaining county-level land values and do not observe statistically significant; 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, yet again not statistically significant. Given that water use permits in the Petrie and Taylor (2007) study 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 value 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. Whether statistical significance is found may largely be influenced by the cost of pumping the groundwater.

trends that are consistent with future expectations surrounding water supplies (e.g., Hansen et al. 2009), can significantly impact farm profitability; as such, in certain regions we would expect to observe such impacts to be capitalized into farmland values.

With this literature in mind, our analysis intends to further investigate these issues. First, by including both the first and second moment conditions for surface water supplies, we identify the importance of water supply variability on land prices. 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 the different water supply sources to test whether or not they have differential impacts on land values. Finally, we investigate whether combinations (i.e., a portfolio) of water supply sources provide additional value above and beyond individual supplies. As our data set includes geo-referenced data on approximately 2,000 parcels located in 10 counties across California, the extent of our spatial coverage might permit our analysis to better capture the underlying effects of these variables on farm values relative to the smaller spatial scale studies, which might lack the appropriate variability, as noted in Schlenker et al. (2007).

3 Data and model

In investigating the value to growers having access to a portfolio of water supply options, as well as identifying the extent to which different characteristics of a 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 sale prices as a function of the parcel's characteristics, which can be represented in general form by the following hedonic equation:

$$(1) \qquad P_i = P(x_{i1}, x_{i2}, \ldots, x_{iN})$$

where P_i is the sale 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:

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

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 supply characteristics, land quality characteristics, 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 variants of the following equation:

$$(3)\quad salevalue_{it} = \beta_0 acres_{it} + \beta_1 orchard_{it} + \beta_2 vineyard_{it} + \beta_3 distance\ from\ freeway_i + \beta_4\, population_i + \beta_5\, Storie\ Index_i + \beta_6\, year\ fixed\ effects_i + \beta_7\, Jan\ Dgd_i + \beta_8\ April\ Dgd_i + \beta_9 JulyDgd_i + \beta_{10}\, OctDgd_i + \beta_{11}\, Jan\ Precip_i + \beta_{12}\, AprilPrecip_i + \beta_{13} JulyPrecip_i + \beta_{14} OctPrecip_i + \beta_{15} Private\ WD_i + \beta_{16} State\ WD\ _i + \beta_{17} Fed\ WD_i + \beta_{18} PrivateState_i + \beta_{19} PrivateFed_i + \beta_{20} State_{othersupplies_i} + \beta_{21} Fed_{othersupplies_i} + \beta_{22} Private_{othersupplies_i} + \beta_{23} MeanWater\ Supply_{SWP_i} + \beta_{24} MeanWater\ Supply_{CVP_i} + \beta_{25} VariabilityWater\ Supply\_SWP_i + \beta_{26} Varibility\ Water\ Supply\_CVp_i\ \beta_{27} groundwater\ depth_i + \beta_{28}\ salinity_i + \varepsilon_{it}$$

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 sale prices and parcel characteristics for 1,900 agricultural land parcels sold in California during the time period ranging from 2004 to 2010. The parcels were selected from three major agricultural regions in California. These regions are the Central Valley, Central Coast, and Southern region of California. These regions rank among the top three agricultural regions in California from 2004-2005 Agricultural Commissioners' Report. These regions are distinctively different from each other in biophysical characteristics and climate patterns. We have parcels from Fresno, Tulare, Kings, Kern, and Merced counties from the Central Valley region; Monterey, Napa and San Luis Obispo from the Central Coast region; and Imperial and Riverside counties from the Southern region of California. The locations of these parcels are illustrated in Figure 1. We selected agricultural parcels from these counties as they rank among the top 18 counties by gross value of agricultural production from California County Agricultural Commissioners' Reports, 2004-2005. From a sampling perspective, 66 percent of our parcels are located in the Central Valley region, 13 percent from the Central Coast region, and 21 percent of our parcels are located in the Southern region. These sample populations are not so different from farm population statistics based on the 2007 Census, which specifies that among the total number of farms in the above three major agricultural production regions, 64 percent, 21 percent, and 15 percent of the farms are located in the Central Valley, Central Coast, and Southern region, respectively.[6]

Sale price information for these parcels was collected from the real estate database LoopNet (www.loopnet.com). All sales reported in LoopNet from 2004-2010 for the above counties were included in our data set. Information on farm characteristics (e.g., presence of permanent structures, and whether a tree crop or orchard is present)[7] 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 geocoding each parcel in ArcGIS. Population by zip code was obtained from the Census 2000 data. The shape files for U.S. national highways were obtained from California-Atlas. Distance from the nearest highway to the farms was spatially computed in ArcGIS.

Observations on groundwater depth of 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

[6] We chose particular regions in major agricultural production areas to ensure we captured heterogeneous production and environmental conditions. As such, our stratified approach is not random, but the final sample ratios from each stratum relative to our sample total are not so different from the population ratios of each stratum to the population total in terms of farm numbers.

[7] We assume that perennial crops such as orchards or grapes are fixed if identified by either LoopNet or the County Tax Assessors report. This is similar to the assumption of fixed irrigation systems in Mendelsohn and Dinar (2003). Of course, the age of the perennial crop would likely matter. Unfortunately, such information did not exist.

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 geostatistical techniques to overcome issues of endogeneity and measurement error. The groundwater depth and salinity at each farm location is derived as a weighted average of approximately 20,000 wells over our study region, where the weight is the inverse of distance of each well to the farm to a power of two.[8]

To account for differences in land quality, we incorporated the California Revised Storie Index (SI) and Irrigated Capability Class Index (ICC) obtained from the Web Soil Survey from the 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 percent 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 soils for most kinds of field crops. Capability classes are designated by

[8] Our kriging approach, which mimics the approach used in Schlenker et al. (2007), minimizes the sum of prediction errors from cross validation.

numbers 1 through 8. The numbers indicate progressively greater limitations and narrower choices for practical use.[9]

In terms of climate-related variables, 25 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 (e.g., Schlenker et al. 2007). For this present analysis, we use the mean and variance estimates over the 25-year sequence given that long-term climate variables get capitalized into land values (Deschenes and Greenstone 2004). Furthermore, rather than developing climate estimates for each month, we follow the convention in the literature and use time periods that capture seasonal conditions (i.e., fall, winter, spring, and summer).

Water supply data for federal and state water districts were obtained for the time period of 1994 to 2004 from the U.S. Bureau of Reclamation and the California Department of Water Resources to account for the mean and variability of surface water supplies. To geo-code each farm into a water district, federal, state, and private water district files within 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 as shown in Figure 2. To verify the accuracy of this information, the tax bills of the farms, which are available online

[9] 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.

from the county assessor website, were crosschecked. The tax bills have information on the water districts from which the farm obtains its water supplies.

Figures 5 and 6 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 is apparent is the variability in the SWP supplies across districts relative to the consistently low CVP supplies. Figures 7 and 8 compare average water allocations to maximum allowable allocations for both SWP and CVP supplies across districts. As shown, average allocations often are significantly lower than maximum allocations, due to lower-than-expected rainfall and snowmelt conditions in California from 1994 to 2004.

Information on the water rights for the water districts were obtained from the Electronic Water Rights Information Management System (EWRIMS). EWRIMS has information on whether the water districts have appropriative and/or riparian rights, were enrolled in the Groundwater Recordation Program and/or 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, which is 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. 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_Supplies.

4 Functional form

Linear, log-linear, and log-log functional forms were estimated and compared based on goodness-of-fit statistics. [10] 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 the percentage change in the dependent variable with 1 percent increase in the independent variables (i.e., elasticities).

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

[10] 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.

(4) $$P = \rho W_1 P + X\beta + \varepsilon$$ *Spatial Autoregressive Model*

(5) $$P = X\beta + \varepsilon$$

$$\varepsilon = \lambda W_2 \varepsilon + \mu$$ *Spatial Error Model*

(6) $$P = \rho W_1 P + X\beta + \varepsilon$$

$$\varepsilon = \lambda W_2 \varepsilon + \mu$$ *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 and that overlooking these spatial relationships may lead 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; consequently, spatial correlation in the error term may result in 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.[11]

Finally, our model includes a significant number of dummy variables that can lead to substantial multicollinearity. For the year dummy, we identify 2004 as the default year, while for the crop dummy, we identify non-perennials as the default. Multicollinearity was a problem for our multiple interaction terms involving farms that are a member of multiple water districts (e.g., farms that are a member of both a state and private water district, or farms that are a member of both a federal and private water district)[12]. 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. For instance, rather than simply interact Private_WD with State_WD, we interact Private_WD with a terms that captures whether the farm is in the top 25 percent of the water supply received from state water districts.

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 when a farm belongs to a single water district that also has access to riparian or groundwater sources. For example, a farm might be a member of a

[11] In our analysis $W_1 = W_2 = W$. W is a contiguity-based spatial weights matrix, constructed based on Delaunay triangles (Lesage 1999). We also conducted regressions using two different weight matrices for the dependent variable and error terms. We ran GSM regressions using a contiguity-based weights matrix for the dependent variable and distance-based matrix for the error terms and vice-versa. This did not produce any significant change in our results.

[12] Our study includes farms that are members of private and either a federal or state water district, as well as farms that are not a member of any district. No farms were members of both a state and federal water district.

private water district that has appropriative rights but also riparian rights or access to an aquifer; alternatively, the farm might be a member of a state water district that 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 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. 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.

Before presenting the results, it is important to state that the primary objective for breaking up the analysis into four scenarios is to 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 adaptation 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 account for 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; 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 2005 through 2010, relative to 2004 prices; although, in 2009 they were not statistically different from 2004 prices.

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, when it is negatively related – a result similar to the research mentioned above and one that likely captures possible negative impacts of rainfall events in the summer and early fall periods.[13]

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) 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 or low pumping costs. 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 5 and 6). Similarly, being in state water district leads to an 84 percent increase in farm values; whereas being in a federal or private water district leads to an 18 percent and 13 percent increase, respectively, relative to not being in a water district.

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

[13] In certain regions, for example those more northern regions such as Monterey, late summer rains influence the growers' ability to stress the crop (e.g., grapes) as well as to move equipment in and out of the fields. This could also be capturing length of growing season, since areas with lower precipitation in summer likely are those that have longer growing seasons.

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 the 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 that are in a state water district that have access to multiple sources of water have a 52 percent increase in farm value, relative to those farms that are in state water districts with no access to groundwater or riparian water. Similarly, farms that are in a federal or private water district with access to other sources of water have an 11 percent and 9 percent increase in farm values, respectively, although the latter coefficient is not statistically significant. Hence, having access to multiple sources of water increases farmland values, although the magnitude of such an increase is dependent on the type of water district in which a farm resides. The mean supply from CVP is still a positive and statistically significant predictor of farm values. However, the mean supply from SWP becomes statistically insignificant in this scenario.

In response to the question of whether access to multiple water sources serves as an adaptive strategy that reduces 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 reliance on local precipitation. We also observe that when we account 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. With respect to the negative impacts of water supply variability on farmland values, having access to a more diversified water portfolio is shown to reduce 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 dummy variables into different categories using a three-way interaction. We identify the farms that are members of both state and private water districts and that are in the top 25 percent or bottom 25 percent of SWP average water supply recipients (i.e., Private_State_Top25% or Private_State_Bot25%); similarly, we classify farms that are members of both federal and private water districts into farms that are in the bottom 25 percent and top 25 percent of CVP average water supply recipients (Private_Fed_Top25% or Private_Fed_Bot25%). The issue our additional designations address is the following: Fees and administrative costs are involved in being part of a water district, such that farms that receive significant amounts of SWP or CVP water may not benefit greatly from having access to a private water district's supply, although they may bear additional costs. Conversely, farms that do not receive much SWP or CVP water may benefit greatly from such additional access, benefits that exceed the additional fees and administrative costs of being in another water district.[14]

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. When one considers that if the benefits of being a member of more than one district are minimal while there are additional costs, 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, while also being a member of private district, 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 located in state or federal water districts and receive supplies that put them in the lowest quartile of deliveries over the past 10 years, having access to water from 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 the negative impact of July degree days on farmland values. Where we do observe large changes in parameter

[14] This issue came to light upon presentation of initial results to some water district managers and efforts to describe the negative relationship between membership in multiple districts and farmland values. Unfortunately, we do not have information on the level of these fees or costs across districts.

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 among 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 all 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 degree days decreases from -1.92 percent down to -1.12 percent. 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 percent to -0.016 percent under scenario 4, 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. While there is a premium in being in a 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 for those farms in state water districts. Finally, while the value to a farm of having access to water from a private water district if the farm is in a district that receives a quantity of CVP or SWP water that is in the top 25 percent of deliveries does not seem to affect land values, such access for those farms that are in the lower quartile of average supplies from either the CVP or SWP does affect land values in a positive and statistically significant manner.

5.5 Discussion of monetary values

The coefficients on the independent variables in the regression represent the capitalized value of the amenity per acre, not of a single year but rather over the long run availability of the amenity. To calculate net marginal value for a single year of an amenity in a manner that might be useful for comparison with previous studies, we follow the approach used in Schlenkar et al. (2007). [15] The long run and net annual marginal values for water- and climate-related variables are reported in table 3.

5.5.1 Climate variables

As the results from the previous section suggest, access to water portfolios is shown to regulate the sensitivity of irrigated agriculture to climate change as represented by higher temperatures and lower precipitation. For instance, a one-unit increase in July degree days leads to a $133 per-acre annual decrease in land value in scenario 1, yet only a $67 decrease in scenario 4 when access to water portfolios is included. A one-inch increase in January, April, and October precipitation leads to an $89, $1,493 and $1,821 increase in per-acre annual land values in scenario 1, yet only a $48, $843, and $1,685 increase when

[15] That is, for our water supply related values, Net Capitalized Value = (Net Annual Marginal Value – Annual Delivery Cost)/0.05, where we assume a $20 annual delivery cost.

access to water portfolios is included. These results highlight the importance of water portfolios for adapting to climate change and, consequently, the importance of accounting for such strategies when analyzing the potential impacts of climate change.

5.5.2 Surface water supply variables

As shown in table 3, we find that a one-acre-foot increase in State Water Project water supply increases the value of an acre of land by $23,986 in the long run and by $1,219 annually in scenario 1. Quite strikingly, after controlling for the presence of water supply portfolios (scenario 4), the capitalized value drops to only $1,526 in the long run, or $96 annually in scenario 4, although the coefficient is statistically insignificant at the 10 percent level. Alternatively, a one-acre-foot increase in CVP water supply increases the value of an acre of land by $7,850 in the long run, and by $413 annually in scenario 1, yet by only $5,888 and $314, respectively, in scenario 4. These results support the concept that growers have a lower value for a marginal increase in SWP or CVP water when they have access to other water supplies. If these estimates appear high, consider that the annual value of fruit and nut crops per acre in California ranges from $2,500 to $10,000, while field crops have ranges between $1,000 and $20,000 (California Agricultural Statistics Review 2011-12).

Alternatively, consider how these values compare to those from previous studies, in particular Faux and Perry (1999), Mendelsohn and Dinar (2003), and Schlenker et al. (2007). Table 4 presents the annual value of an acre-foot of water in year 2004 dollars. Our scenario 4 results suggest that the annualized value for SWP water is approximately $96 per acre foot, whereas an acre-foot of CVP water is valued at $314. As shown, Schlenker et al. suggest an estimated annual value of around $50 per acre foot, while Mendelsohn and Dinar (2003) suggest an annual value of $213, which is bounded by our estimates. Faux and Perry (1999), meanwhile, provide two estimates: a $69 per acre-foot estimate for the most productive land and a $14 per acre-foot estimate for their least productive land. There are many reasons that might give rise to such differences, as highlighted in the table footnotes, including differences in how the dependent variable is estimated, inclusions of additional water supply characteristics, and institutional variables that might be correlated with mean water supplies, differentiating between water supply type, allowing for groundwater quality, and location (especially with respect to the Faux and Perry study). Furthermore, over the period of our study, much of California found itself in a drought which also resulted in additional water-use restrictions to meet environmental concerns, both of which would be expected to increase the scarcity value of water for irrigated agriculture. Unfortunately, and perhaps more importantly, the more closely our estimation process mimics previous studies, which would be represented by our scenario 1 results, differences in per-acre water values become quite substantial.

Turning to another characteristic of the water supply – reliability – we see that a one-acre-foot increase in variability of SWP water supply in scenario 1 decreases the value an acre of land by $4,056 in the long run and by $223 annually. In scenario 4, however, the decrease in farm value per acre due to a one-acre-foot increase in variability of SWP is $458 in the long run and $43 annually, although these estimates are statistically insignificant. From a risk and water reliability perspective, this result cannot be over-emphasized: access to additional sources of water supply allows firms to spread out the risk associated with potentially unreliable water sources. Alternatively, we see that a one-acre-foot increase in the variability of CVP water leads to a $22 decrease in the capitalized value of a farm and a $21 decrease annually, an estimate that is significantly less, compared to the negative impact of variability of SWP water on an acre of land. Even this negative impact for CVP water supply variability on agricultural land values goes statistically insignificant when we start accounting for water portfolios in scenario 4. While both of these estimates are statistically insignificant, the magnitudes do differ quite substantially. Given that the mean values from CVP water supply relative to SWP supplies, approximately 1.06 acre foot per acre versus 2.78 acre feet per acre as shown in table 1, fall far short of meeting seasonal plant needs, it is likely that CVP supplies may play the role of a buffer supply to SWP primary water supply status. As such, decreases in the variability of what we might term “buffer” water would be less valuable than a similar decrease in the variability of the primary water source.

5.5.3 Groundwater variables

In terms of groundwater quality, we see that under scenario 1, a one-unit (ds/m) increase in salinity leads to a $637 annual decrease in value per acre; whereas, in scenario 4, after controlling for growers with access to water supply portfolios, this same one-unit increase in salinity leads to a $131 decrease in farmland value per acre annually. Obviously, access to multiple sources of water regulates the impact of salinity on farmland values. For comparison purposes, in their programming approach that analyzes the salinity impacts on various crops in the Central Valley, Kan et al. (2002 find that for an increase in salinity from 0.7 to 4.0 dS/m, annual profits from growing cotton – a moderately salt-tolerant crop – decreases by $135; whereas, the annual profits from growing tomatoes – a relatively salt-sensitive crop – decreases by $482. Hence, the average value per acre for a unit increase in EC for cotton and tomatoes is $36 and $129, respectively.

With respect to groundwater depth, parcel values decrease by approximately $37 in the long run and by $22 annually with one foot increase in groundwater depth in our analysis. This estimate that does not change significantly across scenarios, yet it is consistently statistically significant.[16] For comparison, Schlenker et al. (2007) found that farmland values decrease by approximately $1.1 in the long run for a one-foot increase in groundwater depth, although the results are not statistically significant. Such low values for changes in groundwater depth would seem to be consistent with its unregulated nature and low pumping costs.

5.5.4 Institutional variables

Interestingly, after accounting for both surface and groundwater supply provisions, we find significant value remains in water district membership, relative to not being in a water district. Such values, it should be emphasized, can vary substantially by type of district and by whether or not access to water portfolios is included. For instance, the sale price of an acre of farmland in a state water district increases by $2,768 annually in scenario 1 and by $2,637 annually in scenario 4, compared to farmland that is not a member of a water district. Alternatively, the sale price of an acre of land in a federal

[16] In this calculation, we assume a $20 per-acre-foot pumping cost, which is based on pumping cost calculations and parameters from equation (3) in Knapp et al. (2003). The monetary values of Kan et al.(2002) has been adjusted for inflation to 2004 dollars for comparison purposes.

water district increases annually by $609 in scenario 1 and by $1,459 in scenario 4, again, relative to a parcel that is not in a water district. Even for farms that are in private water districts, land values are on average $445 higher in scenario 1 and $805 higher in scenario 4, compared to those farms not in water districts.

As one would expect, above and beyond the value of being in a state, federal, or private water district, we find that there is a significant premium to having access to another water supply source. For instance, our results show a statistically and economically significant premium for parcels in state water districts that also have access to groundwater supplies or riparian rights, a result that doesn't bear out – at least statistically – for parcels in private and federal water districts. For parcels in state water districts, though, access to groundwater and/or riparian water provides an additional annual per-acre premium of $2,604 under scenario 4. We also find that for parcels that are in state or federal water districts that receive a level of water supply in the lowest quartile of mean deliveries, there is a significant premium for having additional access to a private district's water supply. For instance, our results show that farms in private water districts that also receive CVP supplies in the lowest quartile of deliveries garner a price premium of approximately $3,925 ($236 in annualized value) relative to farms in private districts alone. Similarly, farms that have membership in private water districts as well as state districts, and that receive SWP deliveries in the bottom quartile of deliveries receive a premium of approximately $1,963 ($138 in annualized value) above those that are in private districts alone. Finally, farms that are in state or federal districts that receive supplies in the top quartile of deliveries are not shown to receive additional benefits from being in a private water district, at least statistically.

6 Conclusion

The results from our analysis help to highlight the importance of a water portfolio as an adaptive strategy to combat both the direct and indirect effects of climate change. Our results show that access to multiple sources of water 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 build upon previous analyses, particularly the research by Mendelsohn and Dinar (2003) and Schlenker et al. (2007) which focused on the value of water supplies, as characterized by mean values, on farmland values and as an adaptive 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 surprising, 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 use a hedonic or Ricardian approach that shows a relationship between groundwater quality, water portfolios, 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 additional fees and administrative costs may be incurred 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.

From a methodological perspective, then, we see substantial and significant differences between those specifications that overlook characteristics of water supply other than mean levels, namely reliability and quality, and those that do not. This is not surprising when one considers that while growers do care about mean supplies, they also seem to care about the reliability and quality of those supplies, as well. We also observe the importance of accounting for opportunities to diversify, i.e., gain access to alternative sources of water whether it be through groundwater or riparian opportunities when and where they exist, or through being a member of more than one district. Such opportunities regulate significantly the negative impact of climate and water supply variability on farm sustainability.

What this may mean from a policy perspective is that more coordination among water and irrigation districts may provide growers with enhanced adaptation capacity to address the negative impacts associated with climate change and water scarcity. Indeed, this may even serve to highlight the value of the ultimate form of diversification – water markets – as an effective means to help agriculture adapt to climate change.[17]

[17] Future analyses will endeavor to include more district-level variables that address this issue by accounting for potential water trading opportunities that vary by district.

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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
$Year_t$	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 [ab]

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***	13.407***	10.646***	13.924***
	(0.000)	(0.000)	(0.000)	(0.000)
Acres	-0.541***	-0.572***	-0.542***	-0.569***
	(0.000)	(0.000)	(0.000)	(0.000)
Distance from freeway	-0.012**	-0.004	-0.009*	-0.001
	(0.011)	(0.460)	(0.069)	(0.233)
Population	0.033**	0.067***	0.043***	0.050***
	(0.011)	(0.000)	(0.001)	(0.000)
Storie Index	0.072***	0.069***	0.085***	0.074***
	(0.002)	(0.003)	(0.000)	(0.002)
Orchard	0.058**	0.073**	0.080**	0.099**
	(0.047)	(0.024)	(0.053)	(0.035)
Vineyard	0.011	0.013	0.035	0.046
	(0.825)	(0.819)	(0.525)	(0.925)
Year2005	0.139**	0.148**	0.146***	0.134**
	(0.012)	(0.012)	(0.008)	(0.022)
Year2006	0.135**	0.138**	0.145**	0.131**
	(0.023)	(0.028)	(0.015)	(0.036)
Year2007	0.257***	0.287***	0.242***	0.252***
	(0.000)	(0.000)	(0.000)	(0.000)
Year2008	0.119*	0.162**	0.140**	0.115*
	(0.053)	(0.014)	(0.025)	(0.078)
Year2009	0.068	0.094	0.072	0.094
	(0.385)	(0.234)	(0.393)	(0.240)
Year2010	0.291***	0.201**	0.253**	0.179
	(0.002)	(0.038)	(0.008)	(0.641)
Jan degree days	0.440**	0.503***	0.401**	0.066***
	(0.009)	(0.004)	(0.019)	(0.000)
April degree days	3.750***	3.279***	3.45***	3.723***
	(0.000)	(0.000)	(0.000)	(0.000)
July degree days	-1.916***	- 1.511**	-1.557***	-1.115***
	(0.002)	(0.005)	(0.004)	(0.000)
Oct degree days	5.848***	5.320***	5.367***	5.660***
	(0.020)	(0.000)	(0.000)	(0.000)
Jan precipitation	0.087	0.031	0.079	0.037
	(0.291)	(0.699)	(0.357)	(0.718)
April precipitation	0.315***	0.146**	0.371***	0.183**
	(0.000)	(0.048)	(0.000)	(0.014)

[a] p values reported in parenthesis
[b] (***) indicates significant at 1% , (**) indicates significant at 5%,(*) indicates significant at 10%

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

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)
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)

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

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)
ρ (SAR correlation coefficient)	0.041***	0.037***	0.036***	0.033**
	(0.000)	(0.000)	(0.000)	(0.000)
λ (SEM correlation coefficient)	2.089***	2.074***	2.085***	2.075***
	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.96	0.96	0.96	0.96

Table 3. Monetary Values ($2004)

Variables	Scenario 1 (long run capitalized value)	Scenario 1 (annual value/marginal value at one point of time)	Scenario 4 (long run capitalized value)	Scenario4 (annual value/marginal value at one point of time)
		Climate-related Variables		
Jan Dgd	+2,191**	+110**	+342***	+17***
April Dgd	+9,072***	+454**	+8,883***	+424***
July Dgd	-3,051***	-133***	-1,749***	-67***
Oct Dgd	+11,602***	+580***	+11,403***	+570***
Jan Precipitation	+2,185	+89	+952	+48
April Precipitation	+29,857***	+1493***	+16,857**	+843**
July precipitation	-10,700***	-535***	-13,533***	-677***
Oct precipitation	+36,429***	+1821***	+33,714***	1685***
		Water supply variables		
Mean water supply _SWP	+23,986***	+1219***	+1526	+96
Mean water supply_CVP	+7850***	+413***	+5888*	+314*
Variance Water supply_SWP	-4055***	-223***	-458	-43
Variance Water supply_CVP	-22***	-21***	-44	-22
		Groundwater Variables		
Salinity	-12,349***	-637***	-2,229**	-131**
Groundwater Depth	-37.14***	-22***	-37.14***	-22***
		Institutional Variables		
State Water District	+54,951***	+2768***	+52,334***	+2637***
Federal Water District	+11,775**	+609**	+28,783***	+1459***
Private Water District	+8,504***	+445***	+15,700***	+805***
Privatestate_top25%			-5,233	-302
Privatestate_bot25%			+1,963**	+138**
Privatefed_top25%			+3,925	+236
Privatefed_bot25%			+3,925***	+236***

Table 4. Comparison of the marginal monetary value of water with previous literature (2004 dollars)

	Scenario 4[c]	Schlenkar et al. (2007)[d]	Mendelsohn and Dinar (2003)	Faux and Perry (1999)[e]
Annual Value of Water ($/ac-ft)[f]	SWP water[g]: 96 CVP water : 314	50	213	Most productive land: 69 Least productive land : 14

[c] Schlenker et al.(2007), Mendelsohn and Dinar (2003), and Faux and Perry(1999) define a single water supply measure that is the aggregation of multiple water supply sources.

[d] There is a significant difference between the average price of a farm in Schlenker et al. (2007) and our study. Schlenker et al. truncate their sample to eliminate farms with values above $16,455($ per acre, 2004) so as to reduce the impact of possible development pressures on farmland prices given that population density becomes the variable with the greatest explanatory power. This may be one reason for such large differences in marginal values as we opt to include all farms, which results in an average sales price of approximately $65,418. Of course, we control for urban factors that might influence farm values by using variables such as distance to nearest highway and population in our analysis.

[e] Faux and Perry(1999) do not take into account annual delivery cost of water while calculating annual value of water.

[f] All values were adjusted by the Consumer Price Index to be in 2004 dollars for the purpose of comparison.

[g] Value of SWP water is not statistically significant

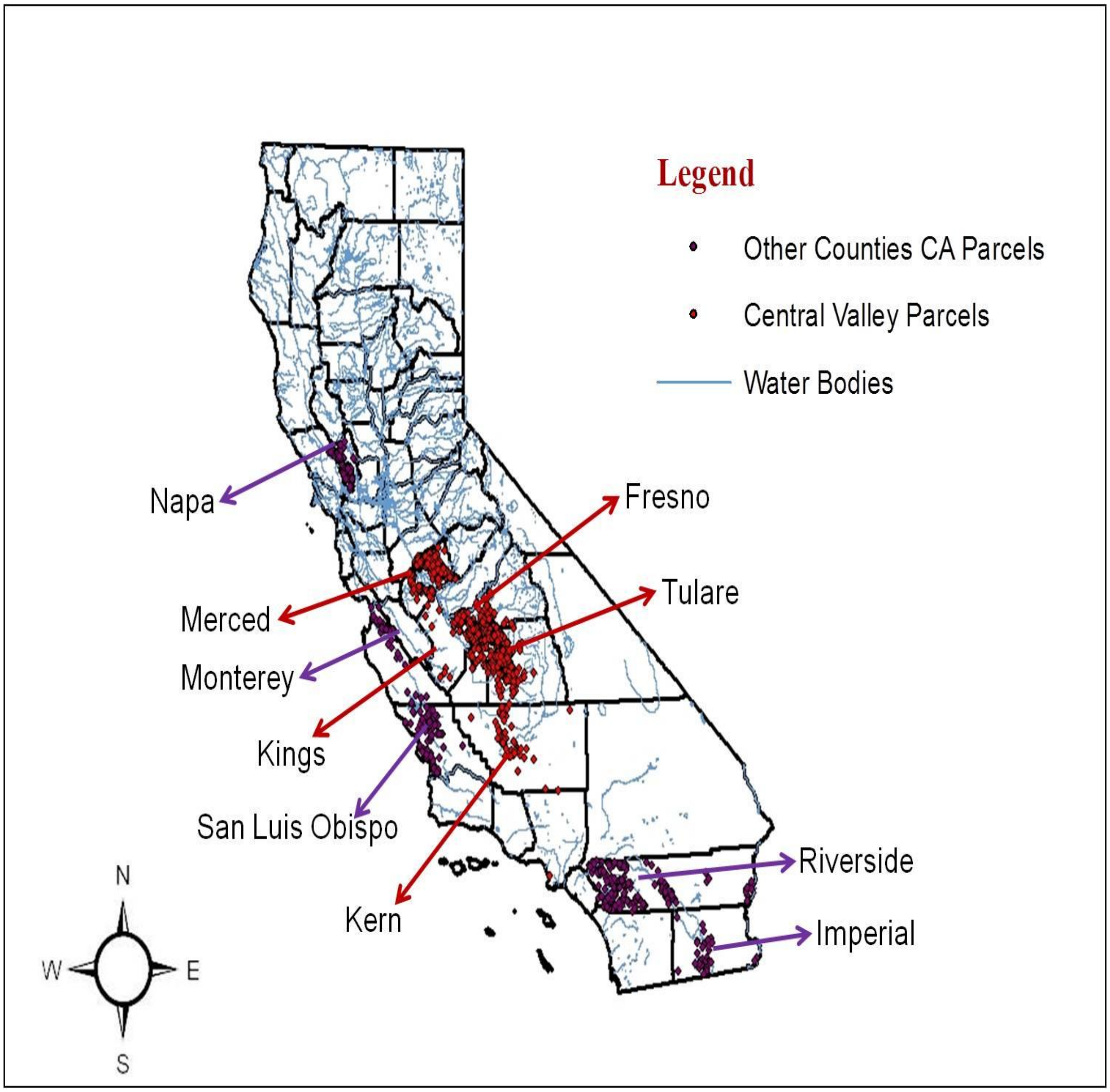

Figure 1. Study region map with farmlands.

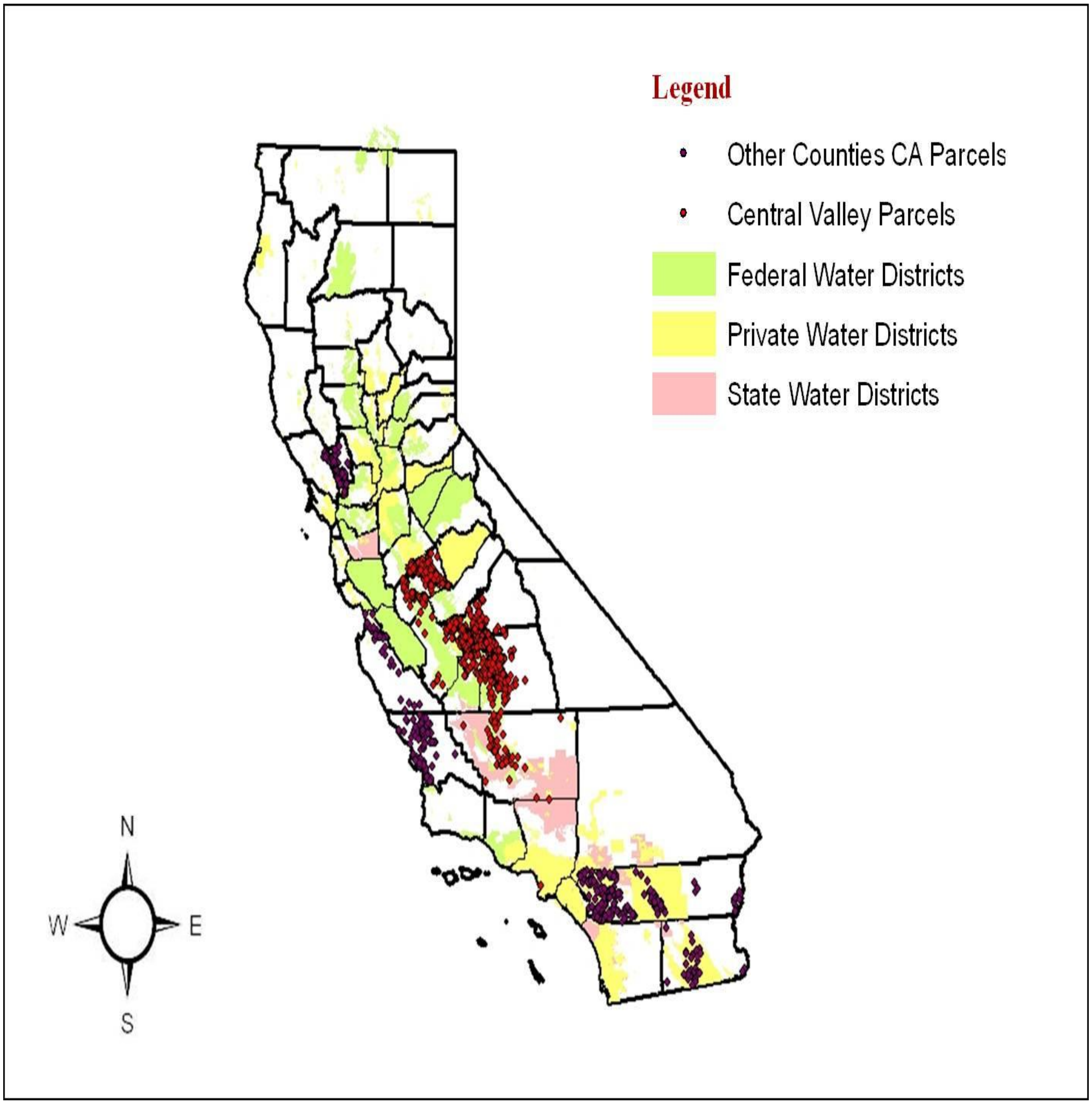

Figure 2. Location of water districts and farmlands

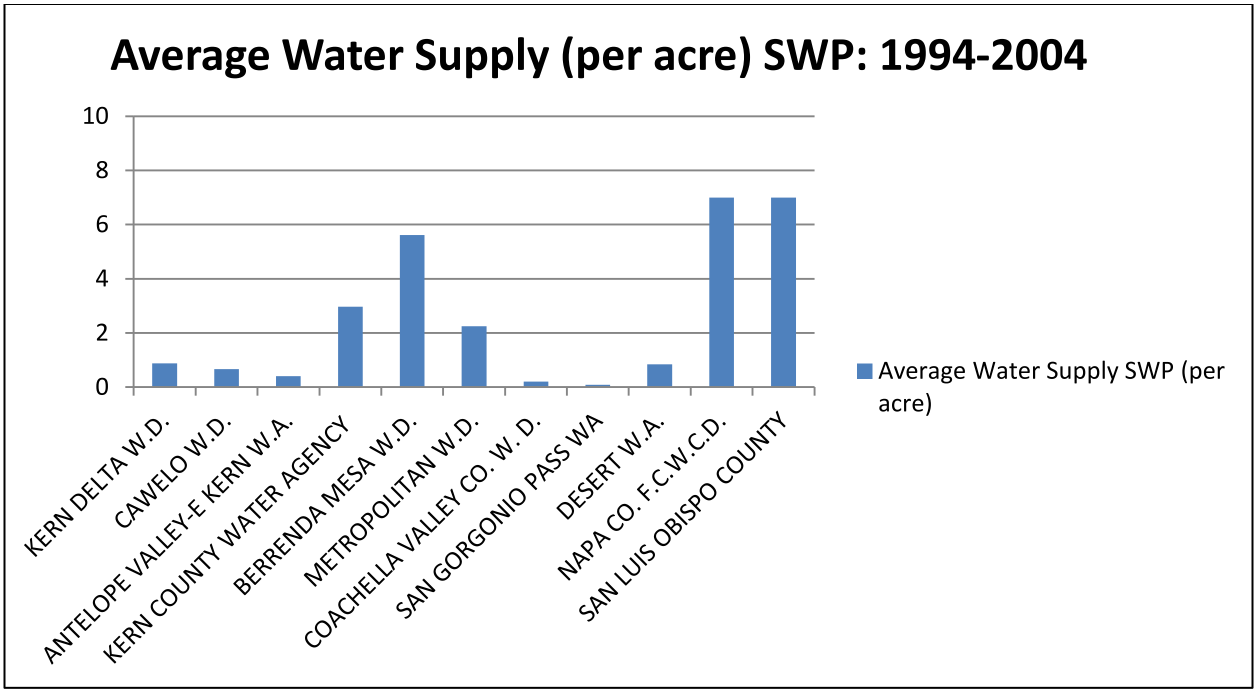

Figure 5. Average water supply for State Water Project (SWP) in acre-feet per acre.

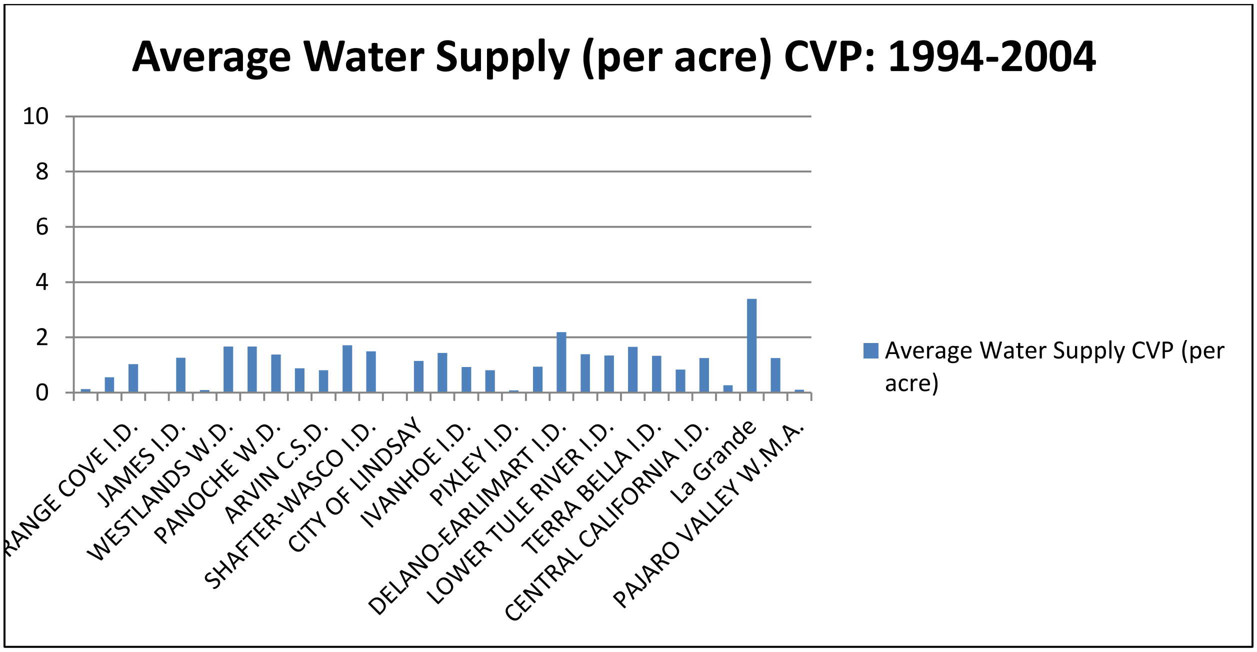

Figure 6. Average water supply for Central Valley Project (CVP) in acre-feet per acre.

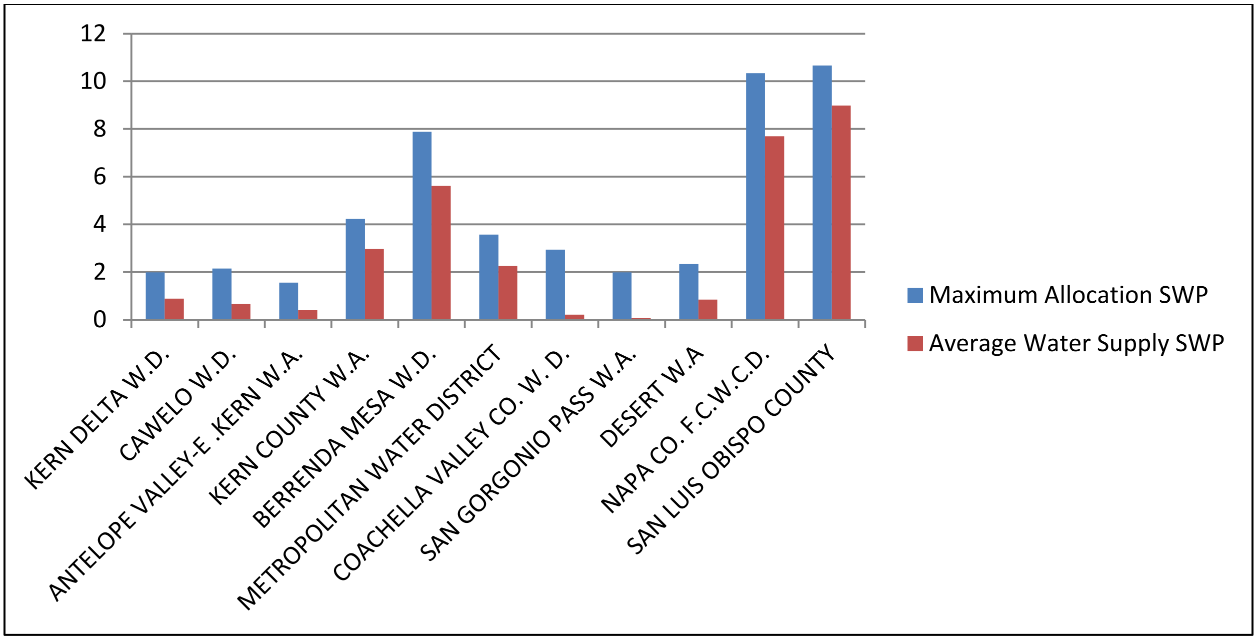

Figure 7. Comparing average water supply versus maximum allocation from 1994-2004 for SWP in acre-feet per acre.

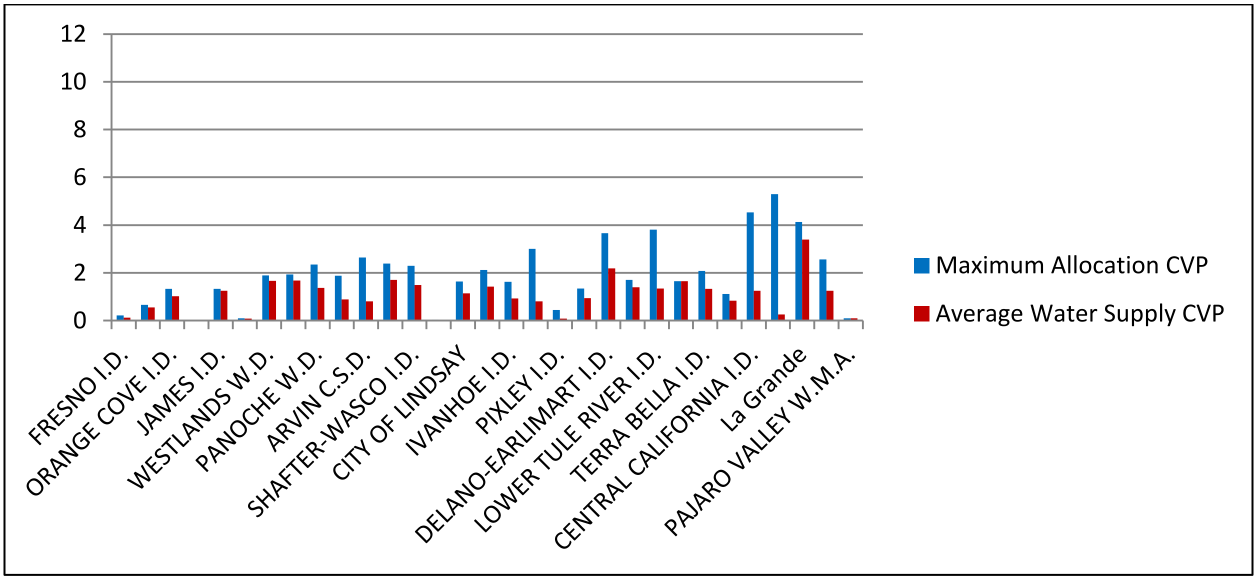

Figure 8. Comparing average water supply versus maximum allocation from 1994 to 2004 for CVP in acre-feet per acre.