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Valuing Groundwater Services and Water Portfolio in Irrigated Agriculture with a Hedonic Pricing Model

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

Doctor of Philosophy

in

Environmental Sciences

by

Monobina Mukherjee

June 2013

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ABSTRACT OF THE DISSERTATION

Valuing Groundwater Services and Water Portfolio in Irrigated Agriculture with a Hedonic Pricing Model

by

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Doctor of Philosophy, Graduate Program in Environmental Sciences
University of California, Riverside, June 2013
Dr. Kurt A. Schwabe, Chairperson

Water plays a vital role in the processes and functioning of the Earth's ecosystems. Only one percent of the earth's fresh water resources are available for human activity. The gap between water supply and demand is increasing due to population growth, development pressure and climate change. Poor water quality aggravates this imbalance even more. A serious concern that naturally arises is how will agriculture, which consumes 70% of world's freshwater withdrawals, respond to these issues. This creates an increasing need for efficient strategies for water management in terms of both water quantity and quality in agriculture. With those needs in mind, the objectives of this research are to, first, better understanding how and the magnitude by which changes in water supply characteristics influence farmland values and second, identify possible adaptation strategies that reduce negative impacts of such changes. With a micro-level data set on approximately 700 agricultural parcels and a hedonic property value model, this dissertation begins by focusing on how groundwater quality and quantity differences and their interactions influence farmland values in the Central Valley, California, a state plagued by both groundwater overdraft and salinity issues. Then this analysis is extended to the entire state of California using information on 1900 agricultural parcels to investigate how different water supply characteristics from different water supply sources influence farmland values and how developing a diversified water portfolio can mitigate the negative changes associated with water supplies. One major conclusion of this dissertation is the importance of recognizing that water is a differentiated product and that there are several pathways in which it can influence irrigated agriculture, including changes in levels, variability and quality. Another major conclusion, and one that can be applied to other regions globally as water becomes scarcer and any particular water supply source becomes less reliable, is that there seem to be significant benefits to water districts and managers in developing a more diversified water portfolio, a lesson embraced all to well in other sectors of the economy, notably the financial sector.

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Chapter 1

Introduction

Water covers two-thirds of the planet’s surface and some of its subsurface too. It is essential to all forms of life and plays a vital role in the processes and functioning of the Earth’s ecosystems (US EPA, 2012). Just three percent of the earth’s water resources are fresh water and only one percent of this is available for human activity, including agriculture. Imbalances between water availability and demand will most likely be exacerbated by climate change, and therefore, water management is becoming one of the main geostrategic challenges of the 21st century. Water scarcity already affects every continent. Around, 1.2 billion people or almost one-fifth of the world’s population lives in areas of physical scarcity, with 500 million more approaching the situation.

Agriculture is just one amongst many users of water, all of whom have to compete for water quantity and quality. Agriculture consumes about 70% of the world’s freshwater withdrawals (FAO, 2007). To keep up with the growing food demand and shifting diets over the next thirty years, FAO estimates that agriculture will require a fourteen percent increase in water use. It should also be remembered that irrigated agriculture provides some forty percent of the global food supply on twenty percent of cultivated land. In many cases, irrigated agriculture has been a major engine for economic growth and has expanded opportunities for employment (FAO, 2007).

Globally, irrigated agriculture is the largest abstractor and predominant consumer of groundwater resources, with predominant groundwater - dependent agroeconomies having widely evolved. The last 20-30 years have witnessed a 'global boom' in groundwater use for irrigation in areas subjected to extended dry seasons and/or regular droughts (Llamas, 2005). In some of these arid and drought-prone areas, unconstrained use is causing serious aquifer depletion and environmental degradation. In arid and semi-arid regions, where water scarcity is almost endemic, groundwater has played a major role in meeting domestic and irrigation demands. In addition to this, salinisation of groundwater systems is another insidious and complex process arising from a variety of physical, economic, and political mechanisms. Drought, water scarcity, and the salinization of groundwater resources present growers with serious consequences, at the very least lower profits; at the most, crop loss.

Surface water is another major source of water supply for agriculture. Intergovernmental Panel on Climate Change (IPCC) projects significant variability in precipitation and an expected rise in mean temperature in the coming years (IPCC, 2001). This is expected to have a direct impact on surface water supply and agricultural productivity (Mendelsohn et al. 1994; Schlenker et al., 2007). For instance, California has experienced drought in the past few years and water supply scarcity and variability is a major issue for California growers (DWR, 2012). Additionally, poor groundwater quality aggravates the water crisis further. This creates an immediate need to develop various adaptation strategies in order to deal with the water supply challenges in agriculture.

1.1. Role of water and water rights in California Agriculture

Water irrigates millions of acres of farmlands, making California the nation’s leading agricultural producer and exporter of agricultural goods (Water Education Foundation, 2007). The largest user of California water is agriculture. In an average year, agriculture uses about 31.1 million acre-feet of water or 80 percent of State’s developed water supply (Littleworth and Garner, 1995). However, California now faces monumental challenges in meeting the water demand of its current and projected population as drought and climate change are reducing the snowpack

California depends on to fill its reservoirs (Water Education Foundation, 2007). Water supply variability is a major issue induced by Climate change and to meet the states demands, water must be stored and transported large distances (Littleworth and Garner, 1995). Indeed, without the development of technology to transport vast quantities of water, California might have remained much as Daniel Webster a prominent senator from New Hampshire described in the 19th century "To what use could we ever hope to put those great deserts and those endless mountains, impenetrable and covered to their base with eternal snow?" (Littleworth and Garner, 1995)

There are different types of water rights associated with distribution and diversion of water in California and most of them are very unique compared to the water rights in the rest of United States. Seasonal, geographic, and quantitative differences in precipitation caused California's system to blend into three different kinds of rights: Appropriative, Riparian and Groundwater (State Water Board, 2012). Each will be discussed briefly in turn.

1.1.1 Appropriative Rights:

Appropriative water rights are the most common use-based water rights in the United States and are most commonly found in the western states where water is scarcest. "The appropriation doctrine confers upon one who actually diverts and uses water the right to do so provided that the water is used for reasonable and beneficial uses" (State Water Resource Control Board, 1986). In California, water can be diverted 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. Appropriative water rights can be used to divert water from three primary sources in California, The Central Valley Project (CVP), the State Water Project (SWP), and private sources.

Central Valley Project

The evolution of water use in California is again evident in the history of water development in the vast Central Valley, the rich agricultural area supplied by the Sacramento and San Joaquin Rivers. The development of centrifugal pumps allowed deep wells to be drilled, and thousands of Central Valley farmers took advantage of the new technology. By the 1930s, the negative effects of groundwater overdraft were being felt in the Central Valley, leading to searches for new sources of water to supply the still-growing agricultural industry (Littleworth and Garner, 1995). The result of this search was the federal Central Valley Project (CVP), now California's largest water supplier. The Central Valley Project is divided into nine divisions; (1) Trinity River (2) Shasta (3) Sacramento River (4) American River (5) Delta (6) West San Joaquin (7) Friant (8) East side (9) San Felipe. The districts diverting water from these sources are typically identified as Federal Water districts. The CVP stores about 13,000,000 acre feet of water in 20 reservoirs in the foothills of the Sierra Nevada, the Klamath Mountains and the California coast ranges, and passes about 7,400,000 acre feet of water annually through its canals. Of the water transported, about 5,000,000 acre feet go to about 3,000,000 acres of irrigated agricultural fields. (Central Valley Project, 2010; California State Water Project, 2010)

State Water Project (SWP)

The California State Water Project, commonly known as the SWP, is a state water management project in California under the supervision of California Department of Water Resources. Construction of State Water Project began in the late 1950's with an original objective to import water from areas of surplus and transfer it to areas of deficient supply in California. . The State Water Project transports 194.2 million acre-feet in an average year and 145.5 million acre-feet in a dry year (State Water Project, 2008). Diversions of water supplied by the SWP are made from the delta (Littleworth and Garner, 1995). SWP now supplies water to some 30 public agencies. The water agencies or districts distributing State Water Project water are typically identified as State Water districts.

Private Water

Water is also diverted through aqueducts from other water supply sources other than the SWP and CVP. These sources constitutes of some of the major rivers in California – Merced River, Tuolumne River, Mokelumne River, Owens River, Colorado River etc (Littleworth and Garner, 1995). The districts diverting water from these sources are typically identified as Private Water districts.

1.1.2 Riparian Rights

Riparian rights do not require permits, licenses, or government approval, but they apply only to water which would naturally flow in the stream. However, California law requires that any person or organization that diverts more than 25 acre-feet of water in a year 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 (State Water Board, 2012).

1.1.3 Groundwater Rights

In most areas of California, overlying land owners may extract percolating groundwater and put it to beneficial use without prior approval from the State Water Board or a court. California does not have a permit process for regulation of ground water use. However, the Groundwater Recordation Program began in 1950s and is applicable only to Los Angeles, Riverside, San Bernardino and Ventura Counties. This reporting program requires those persons/districts with wells with aggregate extractions of more than 25 acre-feet (or 10 acre-feet or more from a single source) to file a report of their extraction with the State Water Board (State Water Board, 2012).

1.2 Motivation and objectives of Chapter 2

Groundwater is important to California in many ways. Roughly 30 percent of water deliveries in California come directly from groundwater, with much more in drought years, particularly long droughts (CDWR, 2005, Megdal et al., 2006). The development of centrifugal pumps allowed deep wells to be drilled, and thousands of Central Valley farmers took advantage of the new technology. It has been estimated that when groundwater pumping began, almost 750 feet million acre-feet of water was present in the aquifers under the Central valley. Over the past 70 years, groundwater pumping has dramatically decreased this amount, and the current overdraft in the Central Valley is estimated to be slightly less than 1 million acre –feet per year (Littleworth and Garner, 1995). In addition to groundwater overdraft, increases in salinity concentrations are another long –term groundwater challenge. Salt accumulation is particularly problematic on the Westside of the San Joaquin Valley (see Figure 1.1), which lack much ability to export salt from imported water or local soils – affecting about 500,000 acres of farmland (SJVSP, 1990). Figure1.1 from Schoups et al. (2006) shows the groundwater salinity in California.

The impact of groundwater salinity in agriculture could be highly influenced by groundwater depth. For example, low groundwater depth or shallow water table could further exacerbate the issue of salinity. On the other hand, groundwater salinity might not be that damaging when groundwater depth is much higher (i.e., a lower water table). The impact of groundwater salinity on farm values can be determined largely by the level of groundwater and vice-versa. This is a critical issue, which has not received adequate attention in the literature and requires more investigation.

A significant number of studies have focused on groundwater issues in agriculture. Studies that focused on the role of groundwater in agriculture include Dinar and Knapp, 1986; Torell et al., 1990; Faux and Perry, 1999; Knapp et al, 2003; Stage and William, 2003; Schwabe et al., 2006, Knapp and Baerenklau, 2006; Schlenker et al., 2007; Brozovich and Islam, 2010, etc. The objective for most of these studies is to identify the potential losses from continued over-extraction of groundwater systems, or the benefits of maintaining them and to investigate how groundwater salinity and drainage issues threaten crop production.

Some of the above studies (Torell et al., 1990; Brozovich and Islam, 2010; Stage and Willams., 2003; Schlenker et al., 2007) find that groundwater has a statistically significant influence on agricultural land values while some studies find that the value of groundwater is statistically insignificant in agriculture. One of the reasons behind this could be that different studies have used different measures for their groundwater variable while estimating its value in agriculture. Such measures have included access to groundwater, saturated thickness of the aquifer, groundwater withdrawal, groundwater allocation, amount of water in the aquifer, fraction of county over aquifer and groundwater depth. Groundwater quality can potentially play a substantial role in determining the value of groundwater in agriculture. A limited number of studies have accounted for groundwater quality and rarely, if ever, have any study accounted for the spatial heterogeneity in groundwater quality while estimating the value of groundwater in agriculture.

Chapter 2 investigates the role of groundwater in impacting irrigated agricultural land values. It focuses on estimating the value of groundwater in agriculture while accounting for both groundwater depth and groundwater salinity. A hedonic approach is used to investigate possible reasons driving the mixed results for the value of groundwater to irrigated agricultural that is found in this literature. Considering the fact that the impact of groundwater salinity on farmland values might not be linear and could be highly dependent upon the level of groundwater and vice-versa, groundwater depth and salinity are categorized into different classifications in this chapter. Furthermore, these classifications are incorporated into the analysis to illustrate how the impact of groundwater salinity and groundwater depth on irrigated agriculture are highly dependent upon one another. The result is that there is no single value of groundwater when it comes to measuring its importance to irrigated agriculture as it really depends on the level of its characteristics.

The results confirm the hypothesis that the impact of groundwater salinity significantly varies based on the different levels of groundwater depth and vice-versa. Such information will be useful for water managers to prioritize areas for salinity and drainage mitigation while they confront a limited budget. Moreover, this study also predicts the damage in farmland values with a projected increase in salinity by 2030, if appropriate salinity mitigation strategies are not adopted.

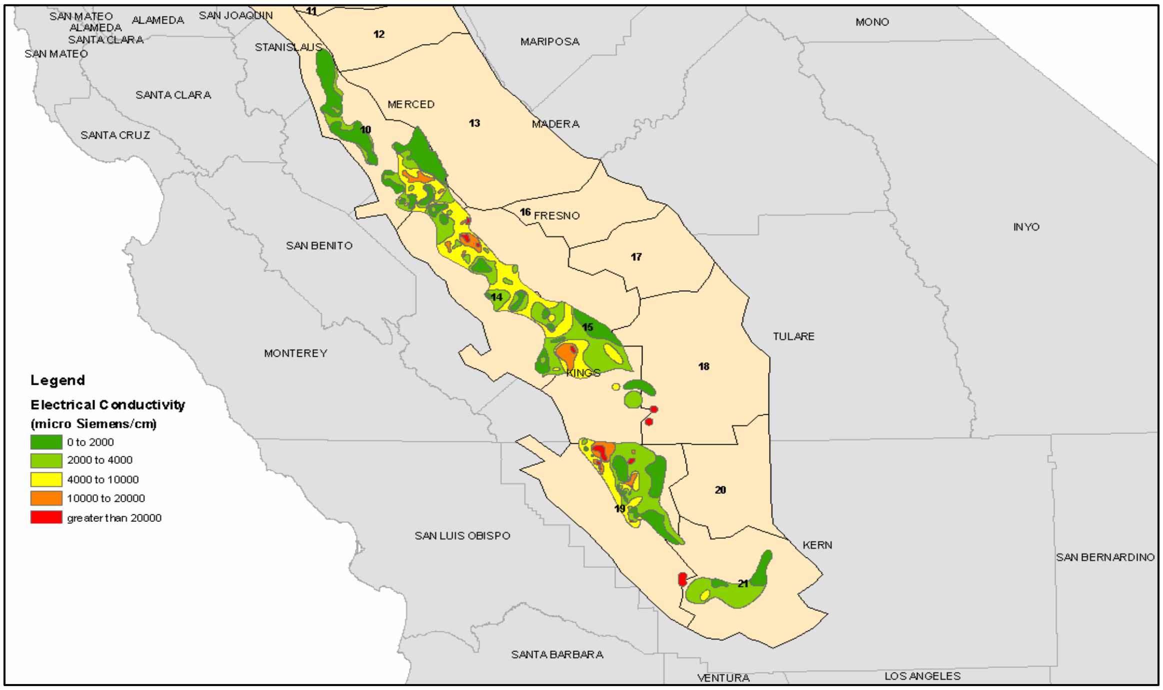

Figure 1.1 Groundwater Salinity in California (Schoups et al., 2006)

1.3 Motivation and Objectives of Chapter 3

Studies that have focused on the role of surface water in agriculture and adaptation strategies include Mendelsohn and Dinar (2003), Schlenker et al. (2007), Petrie and Taylor (2007), Hansen et al. (2009), Connor et al. (2012) etc. These studies find that surface water has a positive and significant value in agriculture. Almost all of these studies treated surface water supply as a single homogeneous source. In reality, though, surface water can be of different types - State, Private or Federal - and each of them can have its unique characteristics. For example, Federal Water has a high variability and a lower average supply compared to State water Project water (see Chapter 3). Several of these studies also focused on how agriculture can adapt to low precipitation and higher temperature with the help of irrigation and through efficient irrigation improvements (e.g., drip irrigation). However, none of the studies has investigated the benefits of a water portfolio in agriculture. More specifically, it has not been analyzed yet whether relying on a single source of water supply versus having access to multiple sources of water supply can make any difference in adaptation to water supply challenges induced by climate change and poor groundwater quality.

In Chapter 3, the possible benefits of a water portfolio in agriculture are investigated while accounting for groundwater salinity, water supply variability and various other relevant factors. The motivation behind this analysis is that any particular single water supply source confronts uncertainty regarding its future quantity, reliability, and quality. Indeed, current trends in most water supply sources suggest concern, as discussed above. In response to these concerns, water users look to other sources of supply as a means of diversification and risk reduction. Such a response—diversification through the development of a portfolio—is not uncommon in other areas of life, with the most notable example being finance. Yet, in most if not all of the hedonic literature that evaluates the impact of climate-induced changes in water supplies on irrigated agriculture, a single water supply source alone is considered. Yet, there are numerous occasions when other sources of supply are being used, perhaps intermittently, but being used nonetheless.

To investigate the role of water supply diversification through access to a water portfolio, this analysis attempts to evaluate how farmland values differ depending on whether the grower has access to multiple water supply sources. The possible sources of water, at least within the particular empirical application focused on here, include groundwater, riparian water and appropriative water. Additionally, in this analysis different source of water supply are differentiated based on Private, State and Federal water. Four different scenarios are analyzed - (i) when growers do not have access to multiple sources of water supply, (ii) when growers are in a district with multiple sources of water supply /water portfolio type 1, (iii) when growers are member of multiple districts/ water portfolio type 2, and (iv) when growers have access to both types of portfolio 1 and 2.

Since the value of any particular portfolio is a function of the quality of its attributes, characteristics of these supplies are also considered. That is, the mean water supply and water supply variability for the State and Federal water are taken into account in the empirical analysis. Results show that water portfolio has a positive and statistically significant value in agriculture and having access to a water portfolio help growers adapt to groundwater salinity, water supply variability and higher temperatures.

The policy and methodological implications of these results are multi-fold. First, the results from this analysis will highlight value of policies that encourage water districts to diversify and increase their portfolio of water supplies as an effective adaptation strategy to poor water quality, water supply variability and climate change. Secondly, our results highlight that in order to accurately estimate the direct and indirect impacts of climate change in agriculture, it is essential to account for the type and combination of available water supply sources along with the salient characteristics of those sources.

Chapter 2

Where's the Salt? A Spatial Hedonic Analysis of the Value of Groundwater to Irrigated Agriculture

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2.1. Introduction

Groundwater constitutes a major part of world's irrigation supply with approximately 40% of the global area equipped with irrigation infrastructure relying on groundwater (Siebert et al. 2010). As pointed out by Tsur and Graham-Tomasi (1991), groundwater provides multiple services to irrigated agriculture, including as a primary and perhaps sole source of water supply in some instances, and as a secondary source, or "buffer," in others. Unfortunately, over-extraction and degradation of groundwater systems threatens their ability to continue to provide such valuable services to society. Between 1960 and 2000, for instance, annual extraction of groundwater resources more than doubled from 126 km^3 to 284 km^3 in semi-humid to arid regions (Wada et al. 2010). Salinity and poor groundwater water supply conditions, meanwhile, affect between 15 to 36% of irrigated lands worldwide (Schwabe et al., 2006). With a future comprised of rising populations, potentially more variable and lower water supplies due to climate change, and more intensively farmed land, the sustainability of groundwater systems is a significant concern in many regions worldwide. Indeed, further groundwater degradation and overdraft will likely lead to losses of large tracts of prime farmland, such as is happening in California's Central Valley, with consequent impacts on food supplies, employment, and income.

In response to these challenges, numerous studies have estimated the economic impact of changes in groundwater supplies on irrigated agricultural sustainability using hedonic methods (Hartman and Taylor, 1989; Torell et al., 1990; Bjornlund, 1995; Faux and Perry, 1999; Mendelsohn and Dinar, 2003, Stage and Williams, 2003; Schlenker et al., 2007; Brozovic and Islam, 2010; Hornbeck and Keskin, 2011) and programming approaches (Dinar and Knapp, 1986; Provencher 1993; Knapp et al., 2003; Characklis et al. 2005; Knapp and Baerenklau, 2006). The motivation behind many of these studies is to identify the potential losses from continued over-extraction of groundwater systems, or the benefits of maintaining them, so as to better inform policy and perhaps justify alternative management strategies or potentially costly mitigative measures.[1] Efforts to justify such costly measures by relying on estimates from the hedonic literature, though, might prove difficult given the mixed results from such studies.[2] Hartman and Taylor (1989), for instance, find a statistically insignificant relationship between groundwater and farmland values while Torell et al. (1990) found a positive effect. Neither Mendelsohn and Dinar (2003) nor Schlenker et al. (2007) find statistically significant signs on their groundwater variables, yet Stage and Williams (2003) and Hornbek and Keskin (2011) find positive and statistically significant relationships.

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[1] Alternatively, many of these studies are investigating the impacts of changing water supply conditions due to increasing water scarcity, environmental restrictions, or climate change.

[2] While there have been number of studies that have used programming approaches to study the impact of groundwater and groundwater salinity on farm profits, crop yields, and regional net benefits, there is a significant literature that has adopted the hedonic approach to evaluate the impacts of changes in water supplies, including groundwater, and climate on agriculture (Deschenes and Greenstone 2004). Our focus is on these latter studies given their prominence in the literature and debate surrounding the impact of changes in water supply characteristics.

While there are a number of reasons why the findings from hedonic valuation studies might give such disparate results as to the value and statistical significance of groundwater, including differences in location and whether one is measuring changes in the depth, access to groundwater, or other characteristics of groundwater (e.g., volume of water in the aquifer, fraction of land over the aquifer etc.), such differences may also arise due to the quality of the groundwater.[3] The main objective of this paper, then, is to highlight the importance of accounting for quality when estimating the value of groundwater to irrigated agriculture. Using a rich geo-spatial data set that includes actual sales data on approximately 700 agricultural parcels in the Central Valley, California (figure 2.1), we illustrate how the value of groundwater can differ greatly depending upon its depth *and* salinity. Our results even show that close proximity to a groundwater table can lower land values if there are limited drainage opportunities available to growers and the groundwater is moderately saline. This information could be useful for better water management and planning within Central Valley. For example, access to alternative sources of water supply, increases in surface water allocation or investment in salinity and drainage mitigation programs could be prioritized for the regions within Central Valley where we find higher damages from groundwater salinity and drainage issues.

As a secondary objective, we then use our model to estimate the damages to irrigated agricultural land values from projected increases in groundwater salinization. Elevated salinity in groundwater is an increasing problem confronting many regions throughout the world. In California's Central Valley, the State Water Board and the Central Valley Water Board are initiating efforts to address this problem and are considering a variety of long-term solutions.

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[3] Bjornlund (1995) found through by investigating two-way correlations that groundwater salinity to be negatively correlated with land prices. The groundwater salinity variable, however, was not included in their hedonic model as it was not found to be statistically significant, an outcome the author suggests might be related to farmers possibly not fully accepting the consequences of increasing salinity.

To provide planners information on the potential impacts of salinity increases, we estimate the impacts on agricultural land values using projected increases in groundwater salinity by 2030 as reported in Schoups and Hopmans (2006). Such estimates can be useful to regional and state agencies as they look to justify costly groundwater salinity management plans.

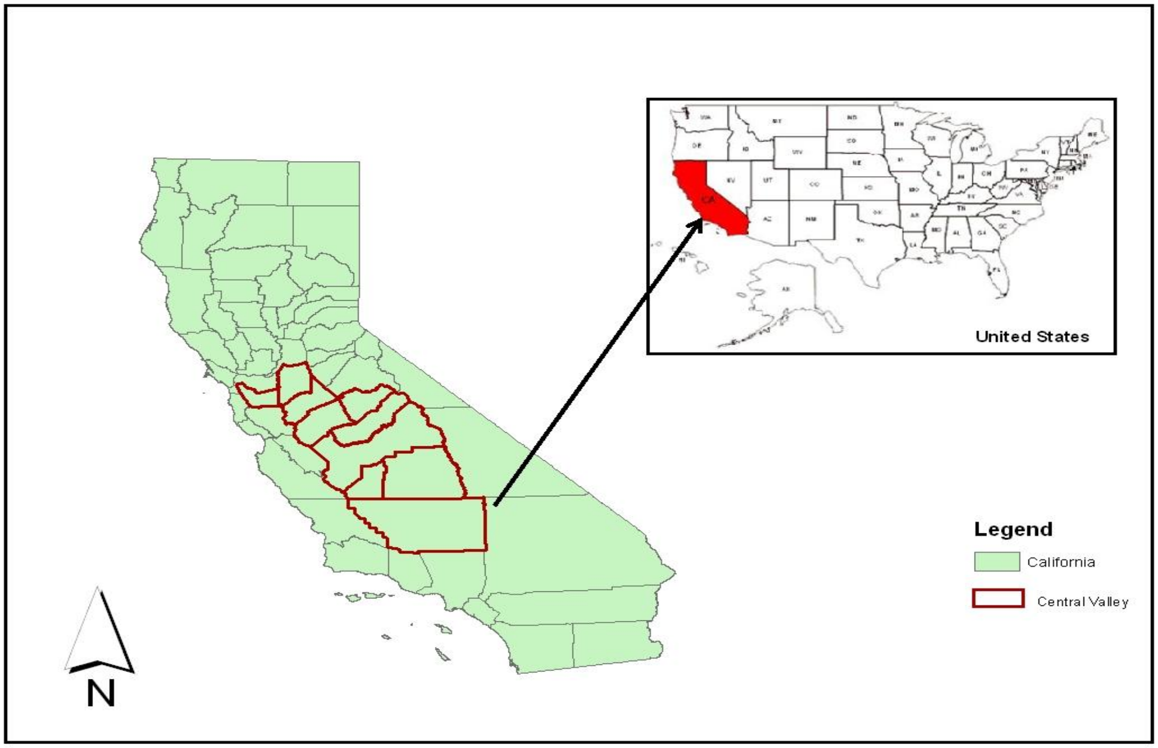

Figure 2.1 Central Valley, California, US

2.2 Literature Review

A number of studies have estimated the value of surface water in irrigation using hedonic methods (Faux and Perry, 1999, Mendelsohn and Dinar, 2003, Schlenker et al., 2007). A consistent finding across these studies is the positive and statistically significant relationship between surface water access, and use, and some measure of farmland value. Somewhat perplexing, then, are the mixed findings from hedonic studies that have estimated the value of groundwater to agriculture (Stage and Williams, 2003; Hornbeck and Keskin, 2011; Schlenker et al., 2007; Brozovic and Islam, 2010). Hartman and Taylor (1989), for instance, find a statistically insignificant relationship between groundwater and farmland values while Torell et al. (1990) find a positive effect. Neither Mendelsohn and Dinar (2003) nor Schlenker et al. (2007) find statistically significant signs on their groundwater variables, yet both Stage and Williams (2003) and Hornbek and Keskin (2011) find positive and statistically significant relationships.

Table 2.1 provides some clarity as to why we might not expect there to be much consistency associated with the estimated results surrounding the value of groundwater to irrigated agriculture. First, the geographic differences, which span from the southwest to the southern corn belt to different countries, are most certainly associated with different levels of water scarcity and marginal productivities. For instance, Sunderland et al. (1987) and Torell et al. (1990) investigate the impact of the Ogallala aquifer on irrigated agricultural land values using the same two groundwater variables (i.e., groundwater depth and volume of water in the aquifer). Sunderland et al. focus their analysis on New Mexico and find no statistically significant relationship between groundwater and land values while Torell et al. expand their analysis to include other states above the aquifer and find that the amount of water in the aquifer does have a statistically significant impact on farm values. Second, the significance of groundwater may depend on the definition of the dependent variable and the unit of analysis. As shown in table 2.1, the dependent variable definition ranges from assessed values, grower-reported values, and sales prices, while the unit of analysis is sometimes at the county level but more often at the farm level.

Third, and more importantly, we see that the definition of the groundwater variable varies quite significantly. Some studies focus on groundwater characteristics like groundwater withdrawal, saturated thickness of the aquifer, fraction of land over the groundwater aquifer. Alternatively, some studies use access to groundwater while others use depth to the groundwater table. Studies such as Hartman and Taylor (1989), for instance, focus on saturated thickness of the aquifer and find that it does not have any impact on agricultural land values in Colorado.

As mentioned above, Sunderland et al. (1987) and Torell et al. (1990) focus both on the amount of water in the aquifer and depth in feet to the aquifer. Hornbeck and Keskin (2011), meanwhile, use information on the fraction of a county's area overlaying the Ogallala aquifer as a measure of access to groundwater. They find that groundwater under this definition has a positive and statistically significant impact on farmland values. Stage and Williams (2003) also find a positive and statistically significant impact of groundwater on farm sales price in Africa, yet their groundwater variable is measured as total groundwater yield/hectare.

Mendelsohn and Dinar (2003), who investigate the impacts of climate change on irrigated agriculture in California, do not find any relationship between groundwater withdrawal and reported land values per acre. The authors ultimately drop the groundwater variable from their analysis, suggesting that its' insignificance is likely due to endogeneity or that it is collinear with local climate. In addition to Sunderland et al. and Torell et al., Schlenker et al. (2007) and Brozovic and Islam (2010) define their groundwater variable using *depth to groundwater*. Brozovic and Islam (2010) account for groundwater depth, pumping rate, and soil quality to estimate the value of groundwater where pumping restrictions are in place.[4] Using propensity-score matching, the authors find that depth to ground water is important in the decision to irrigate, but it does not get capitalized into land values. Schlenker et al. (2007), alternatively, do not find a statistically significant relationship between groundwater depth and farmland values either.

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[4] Pumping restrictions in Brozovic and Islam (2010) implies reduction in pumping volume, metered groundwater use and reduced groundwater allocation.

Table 2.1 Reported Groundwater Significance from a Sample of Hedonic Studies

Study that estimated value of groundwater in irrigation	Location of Study	Dependent Variable	Unit of Analysis	Type of groundwater variable	Account for ground water quality	Sign and Significance on ground water variable
Sunderland et al. (1987)	New Mexico	Assessed Values of farms	Farm	Depth in feet to the Ogallala Aquifer Amount of water in the Aquifer	No	Statistically Insignificant Statistically Insignificant
Hartman and Taylor (1989)	Colorado	Sale Prices of farms	Farm	Saturated thickness of the aquifer	No	Statistically Insignificant
Torell et al. (1990)[a]	New Mexico, Colorado, Kansas, Nebraska, Oklahoma, South Dakota and Wyoming	Sale Prices of farms	Farm	Depth in feet to the Ogallala Aquifer Amount of water in the Aquifer	No	Statistically Insignificant Statistically Significant (+)
Bjorlund (1995)	Angas-Bremer, Australia	Sale prices of farms	Farm	Groundwater Allocation Groundwater Salinity	Yes	Statistically Significant Statistically Insignificant
Stage and Williams (2003)	Namibia, Africa	Sale Prices of farms	Farm	Total GroundwaterYield/hectare	No	Statistically Significant (+)
Mendelsohn and Dinar (2003)	All of US	Farmland values reported by growers	Farm	Groundwater Withdrawal	No	Statistically Insignificant
Schlenker et al. (2007)	California	Farmland values reported by growers	Farm	Groundwater Depth	No	Statistically Insignificant
Brozovic and Islam (2010)	Chase County, Nebraska	Sale Prices of farms	Farm	Groundwater Depth	No	Statistically Insignificant
Hornbeck and Keskin (2011)	Counties over Ogallala Aquifer and non-Ogallala Counties	Farmland Value per county acre	County	Fraction of County area over Ogallala aquifer	No	Statistically Significant (+)

[a] Torell et al. (1990) expanded their previous study area in Sunderland et al. (1987) from New Mexico to include Oklahoma, Nebraska, Kansas and Colorado (all of which use the Ogallala aquifer)

As shown in column 6 of table 2.1, though, most of the studies mentioned do not account for groundwater quality.[5] This can be a serious omission given the issue of omitted-variable bias surrounding hedonic models, as pointed out in Brozovic and Islam (2010). It is our intent to further explore this issue by hypothesizing that an important factor determining the value of groundwater to irrigated agriculture is the salinity of the water, and illustrate empirically how the value of groundwater if a function of often its quality. In our efforts to extend the literature by including quality, we are also wary of the possible variation in marginal impacts of groundwater quality on land values based on the different levels of groundwater depth, and vice versa. That is, there may not be a significant difference between poor quality groundwater that is 200 feet from the surface or 100 feet from the surface, yet highly saline groundwater near plant roots can have significant negative impacts on crop growth and yields. Hence, we also investigate possible variation in the marginal impacts of one groundwater characteristic, either groundwater depth or salinity, on farmland values based on the respective level of the other characteristic.

2.3 Model

The focus of our analysis is on the Central Valley, California, which includes basins and sub-basins with very different groundwater systems and drainage conditions (figure 2.2 and figure 2.3).[6] The Central Valley is approximately 58,000 km^2, produces approximately 8% of the nation's agricultural output ($23.7 million in 2006), as measured by value (Howitt et al. 2009), and comprises approximately 1/6th of the nation's irrigated land (Reilly 2008). The groundwater

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[5] As mentioned previously, the exception is Bjorlund (1995) who finds, using a two-way correlation between groundwater salinity and land prices, a negative relationship. While he finds a negative relationship, the relationship is not statistically significant in his hedonic estimation and thus it is dropped.

[6] Figure A.1 and A.2 in Appendix shows the spatial heterogeneity in estimated contours of groundwater depth and salinity for regions not only in Central valley but also for other parts of California

services and its value to growers may differ significantly within this region due to the heterogeneous biophysical characteristics of groundwater. Within some regions of Central Valley, for instance, the salinity of groundwater is relatively high compared to other regions within the Valley. Furthermore, in areas where there is limited natural drainage opportunities, groundwater tables and their salinity levels often are elevated which consequently threatens crop production. In these instances, significant land retirement is occurring (Schwabe et al. 2006).

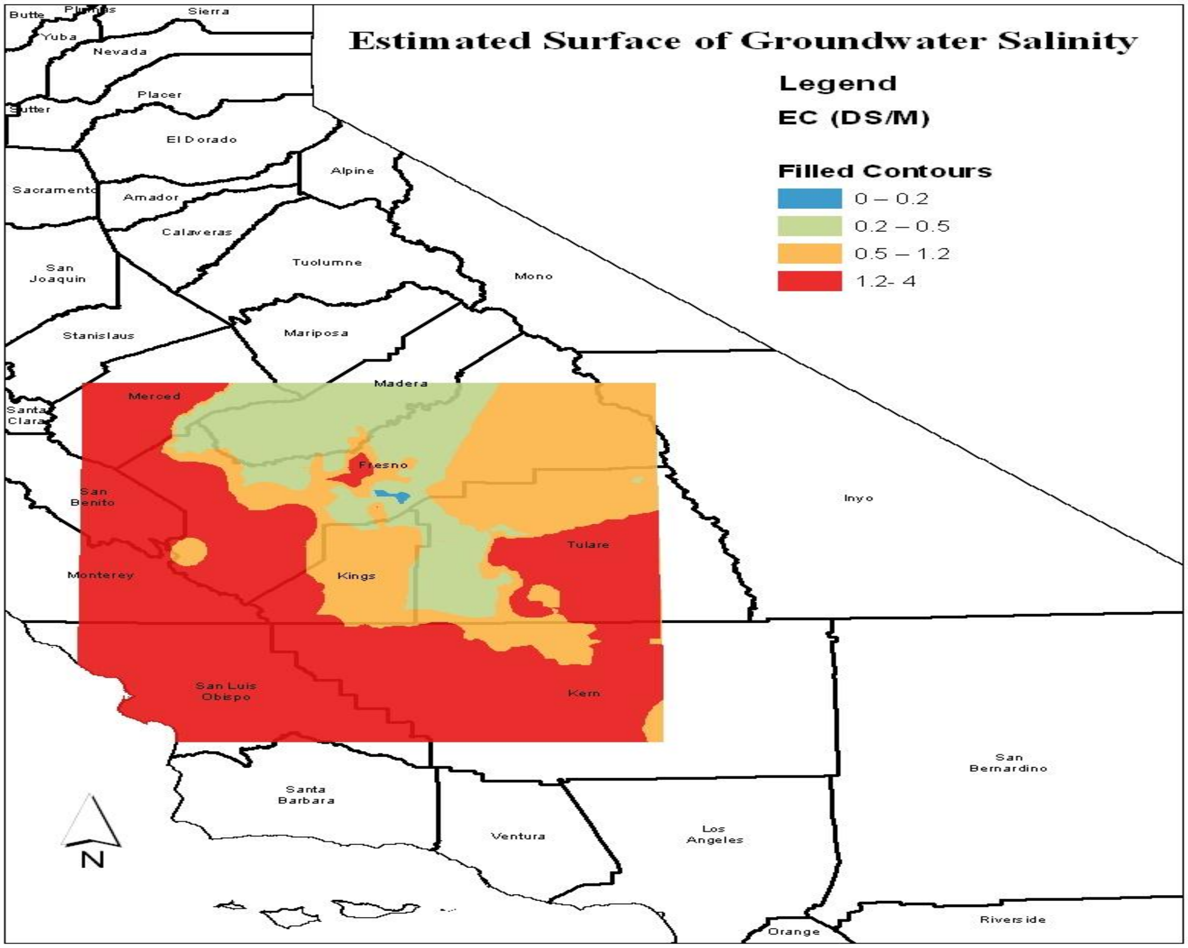

Figure 2.2. Estimated Surface of Groundwater Salinity based on EC (ds/m) Quartiles in Central Valley, California.

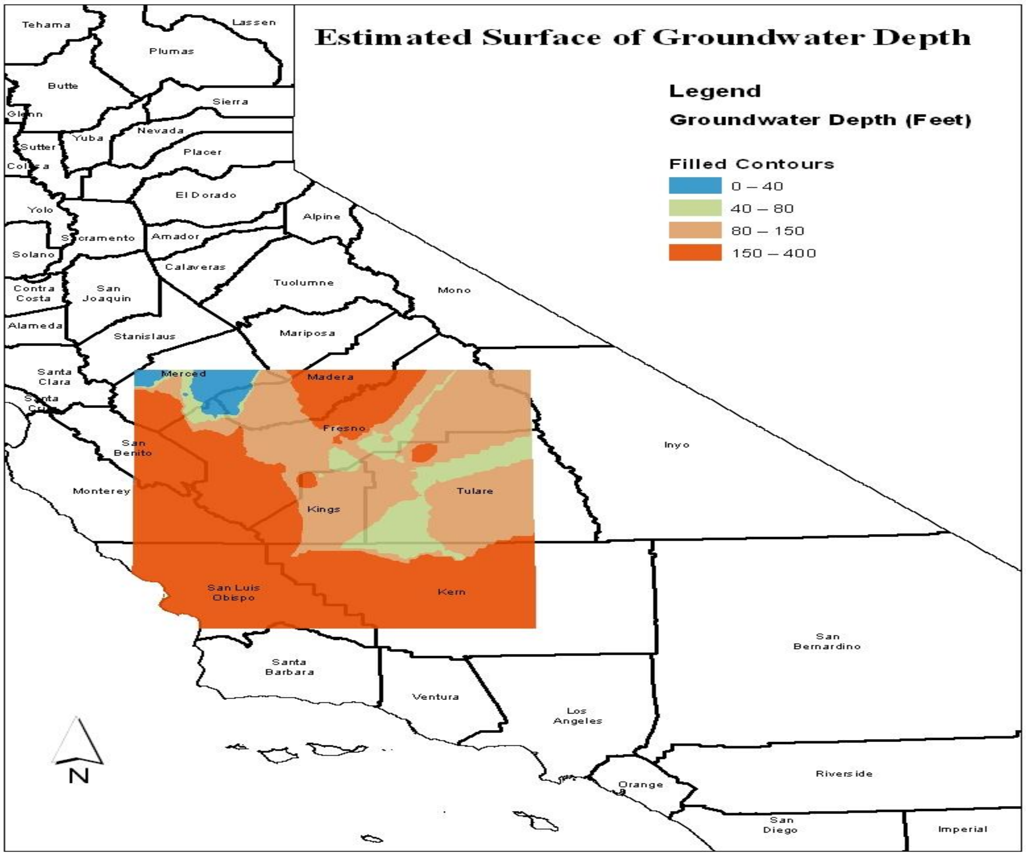

Figure 2.3. Estimated Surface of Groundwater Depth based on Groundwater Depth Quartiles in Central Valley, California.

To investigate the impact of groundwater salinity and groundwater depth on the farm 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:

$$(2.1) \qquad P = P_i(x_{i1,}\ x_{i2}\ ,x_{i3},\ldots\ldots\ldots.x_{in})$$

where P_i is the sales price 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:

$$(2.2) \qquad P = X\beta + \varepsilon$$

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 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 different combinations of the following equation:

(2.3)

$$\begin{aligned}
salevalue_{it} = \ & \beta_0 acres_{it} + \beta_1 orchard_{it} + \beta_2 vineyard_{it} + \\
& \beta_3 distance\ from\ freeway_i + \beta_4\ population_i + \beta_5\ Storie\ Index_i + \\
& \beta_6\ year\ fixed\ effects + \beta_7\ Jan\ Dgd_i + \beta_8\ April\ Dgd_i + \\
& \beta_9\ JulyDgd_i + \beta_{10}\ OctDgd_i + \beta_{11}\ Jan\ Precip_i + \\
& \beta_{12}\ AprilPrecip_i + \beta_{13} JulyPrecip_i + \beta_{14} OctPrecip_i + \\
& \beta_{15} Private\ WD + \beta_{16} MeanWater\ Supply\_CVP_i + \\
& \beta_{17} Varibility\ Water\ Supply\_CVp_i + \beta_{18} groundwater\ depth_i + \\
& \beta_{19}\ salinity_i + \beta_{20}\ (EC\ Quartiles) \times (Groundwaterdepth)_i + \\
& \beta_{21}\ (Groundwater\ Depth\ Quartiles) \times (EC)_i + \varepsilon_{it}
\end{aligned}$$

2.4 Data

The data used in the estimating equation (3), whose definitions and summary statistics are listed in table 2.2, 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 629 agricultural land parcels sold in Central Valley, California during the time period ranging from 2004 to 2010. The parcels are located in one of five counties in the Central Valley, California, including the counties of Tulare, Fresno, Kings, Kern and Merced. There are three reasons we focus on these counties. First, there is significant heterogeneity in both groundwater depth and salinity across theses counties. Second, these counties are heavily reliant on irrigation as they are in the southern part of the Central Valley which receives around 127 mm of rainfall annually. Third, agricultural production in Fresno, Tulare, Kern, and Merced counties consistently ranking in the top five of California counties in terms of agricultural market value, with Kings in the top twenty according to 2004-2005 Agricultural Commissioners' Report.

Sales price information for these parcels was collected from the real estate database LoopNet (www.loopnet.com). A hedonic price equation was specified taking sale price per acre as the dependent variable to reduce possible problems associated with heteroscedasticity. The size of parcel and whether certain types of perennial crops were present (i.e., grapes, orchard) were obtained from both LoopNet and the County Assessor's office. Most of the previous literature found a negative relationship between size of land and sale price per acre (Maddison, 2000).

Table 2.2. Variable descriptions and summary statistics.

Variable Name	Variable Description	Average Value	Minimum Value	Maximum Value
salevalue$_{it}$	Sale Price/acre ($/acre)[a,b]	41,319	1,387	315,436
acres$_{i}$	Parcel Size (acres)	26.53	0.6	542
Orchard$_{i}$	Binary variable capturing whether farm contains an orchard		0	1
Vineyard$_{i}$	Binary variable capturing whether farm contains a vineyard		0	1
Distance$_{i}$	Distance from Highway (meters)	6490.58	5.41	24660.59
Population$_{i}$	Population by zip code area	86,591.85	1,236	427,652
Storie Index$_{i}$	Storie Index	72.74	9	100
Year$_{t}$	Binary variable capturing year in which property was sold (2004-2010)		0	1
Month_Dgd$_{i}$	Degree days recorded at nearest station to farm i (for January, April, July, and October)	28.04	9.21	42.89
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$_{i}$	Binary variable if farm is in a private water district		0	1
Mean_CVP$_{i}$	Average Water Supply_CVP (acre-feet/ acre)	1.06	0.007	3.39
Variability_CVP$_{i}$	Variance Water Supply_CVP (acre-feet/acre)	0.27	0.00	4.64
Depth$_{i}$	Groundwater Well Depth (feet)	80.53	0.18	400
Salinity$_{i}$	Groundwater Salinity Concentration ~ EC (dS/meter)	1.16	0.4	4

[a] We have farms sold from 2004-2010. The monetary value of our estimates should be considered in 2004 dollars.

[b] We have a wide range of farmland values in our study, ranging from approximately $1,000 to $300,000 per acre. It is possible that the value of a parcel is driven by the value of nearby parcels. We do not drop outliers from our analysis as we use an econometric model that controls for spatial spillovers between neighboring land values that could determine possible high or low sale price of a land. As stated earlier, the highest valued parcels are those with vineyards established, followed by orchards.

We justify in more detail in the results section the expected negative relationship between size of land and sale price per acre. To account for the presence of a perennial crop, we include whether there was an orchard or vineyard present on the parcel at the time of the sale.[7] It is expected that both orchards and vineyards will increase land values and will have a positive relationship with sale price per acre. Information on the latitude and longitude for each of these parcels was obtained by geocoding each parcel in ArcGIS. To control for development pressures on land values and parcel sales price, we include two variables—*population* and *distance_from_freeway*. *Population* represents the population density by zip code and was obtained from the 2000 Census. *Distance_from_freeway* is the distance in miles between the farm and the nearest freeway and was spatially computed in ArcGIS using shape files for US National highways that were obtained from California-Atlas. It is essential to control for these factors as it would be expected that land values will increase as population increases (Schlenker et al.,2003) and will decrease as distance from nearest freeway increases as being closer to the highway implies having easier access to the market. The years (2004-2010) in which these parcels were sold were available in the real estate database LoopNet. To account for inflation, we follow the convention and use binary time variables for each year from 2005 to 2010, leaving out year 2004 as the base year (Palmquist 1980).[8]

To account for differences in land quality, we incorporated the California Revised Storie Index (SI), obtained from the Web Soil Survey of the Natural Resources Conservation Service (NRCS),

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[7] We assume that the presence of an orchard or vineyard is similar to other infrastructure items and can be treated as a quasi-fixed factor input and not contemporaneously correlated with the error. Such an assumption is similar to other studies that have, for instance, included other quasi-fixed factors such as irrigation infrastructure as an explanatory variable (e.g., Mendelsohn and Dinar, 2003).

[8] To account for development pressures, in addition to including the Population and Distance variables, we also include a spatial lag that accounts for nearby land values. Admittedly, we do not know if the property remained in agriculture after the sale. Based on the County Assessor reports, and both LoopNet categorization and discussions with LoopNet personnel, these were certainly agricultural parcels at the time of sale.

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 using 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. It is expected that farmland values will increase with an improvement in soil quality, as better soil quality implies increase in agricultural productivity (Schlenker et al., 2007).

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 (see, e.g., Schlenker et al. 2007).[9] Furthermore, rather than use each month's average, we follow the convention in the literature and use averages for October, January, April, and June to capture time periods that represent fall, winter, spring, and summer conditions, respectively. The previous studies that investigated the impact of climate variables on farmland values found that Fall, Winter and Spring degree days are associated with higher land values whereas Summer degree days are associated with lower land values (Schlenker et al., 2007). The previous studies also find that Fall, Winter and Spring precipitation are positively related to land

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[9] If growers have adjusted their climate expectations in recent years, then perhaps using a more recent time frame, or weighting recent years more heavily, is more appropriate. This is a topic we intend to investigate in future analyses.

values and summer precipitation are negatively related to land values (Mendelsohn and Dinar, 2003).

In our study, we limit our sample to parcels that receive irrigation water from the Central Valley Project (CVP) and hence are members of a Federal Water District. While this means that no farms in our sample receive State Water Project Water, the farms may be members of a private water district.[10] The water supply data were obtained for the time period of 1994-2004 from the Bureau of Reclamation which allowed us to characterize surface water supplies with both an expected value (*Mean_CVP*) and reliability (*Variance_CVP*) term.[11] The federal and private water districts shape files of California were obtained from California-Atlas. While mean water supplies are expected to increase agricultural land values, we would expect that increases in water supply variability would have a negative impact as illustrated in Conner et al. (2012) and Chapter 3.

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).[12] We collected salinity (EC)[13] data for the nearest well to each

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[10] The fact that we focus on districts/farms that do not receive State Water Project water simplifies the analysis significantly as we can focus our attention on groundwater rather than issues surrounding state and federal water. Additionally, the main factor determining whether a grower has access to Central Valley Project Water (Federal Water) or State Water Project water is the type of pipeline or connection that is closest to the parcel; hence, the location of the parcel determines what sort of water district it can be a member. Finally, water rights, which get transferred with the land sales, are not homogenous entities. That is, the security of CVP water rights differ across districts, which shows up in the differences in variability of CVP water across districts. Unfortunately, the difficulties of acquiring information on actual security prohibited us from obtaining and using such data.

[11] Unfortunately, we were not able to acquire data on the water supply usage associated with private water districts.

[12] There was no regulated groundwater monitoring or restrictions on pumping groundwater California at the time of this study, unlike other states. Hence, as long as there is groundwater in the area of the farm, which is the case in the Central Valley, growers have access to using the groundwater.

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 error. The groundwater depth and salinity at each farm location is derived as a weighted average of approximately 20,000 well locations all over California.[14] Figures 2.4 and 2.5 provide scatterplots of the distribution of groundwater salinity, as measured by EC, and groundwater depth, as measured by feet from the surface. Figure 2.6 provides a scatterplot of EC vs. groundwater depth.

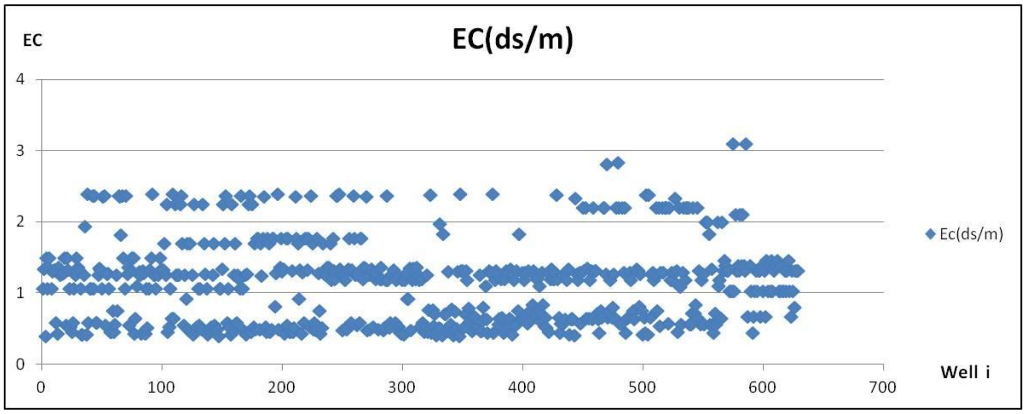

Figure 2.4 Scatter Plot of EC

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[13] EC, or Electrical Conductivity, is a common measure of salinity.

[14] Notice that we use the estimated depth and salinity of the groundwater at the location of the farm based on 20,000 well observations, not the actual values. 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. Our kriging approach is similar to the approach used in Schlenker et al. (2007). The kriging method estimates a surface based on the real observations. The estimated surface extends to some regions of other counties not included in our analysis as they lie close to our sample of observations.

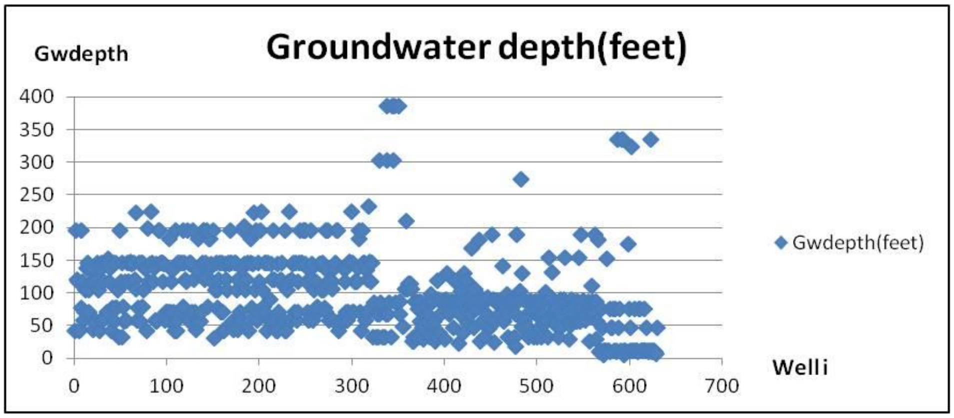

Figure 2.5 Scatter Plot of Groundwater Depth

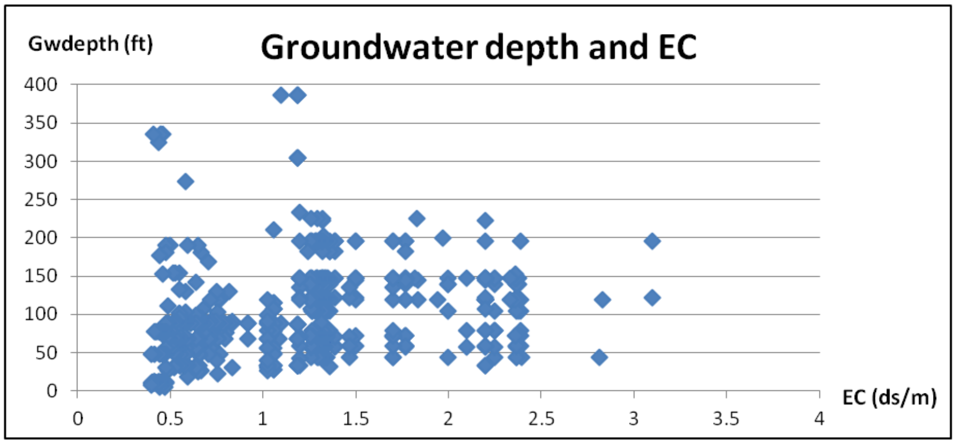

Figure 2.6 Scatter Plot of Groundwater Depth and Electrical Conductivity (EC)

Based on past trajectories of the impact of groundwater salinity and depth in agriculture, these variables should be expected to be associated with lower land values (Water Board Report, 2006). Lower groundwater depths, ceteris paribus, should result in lower land values as cost of pumping should increase with higher groundwater depth. Similarly, higher salinity results in more damages to crops. Therefore, we would expect it to be negatively related to land values. The estimated contours of groundwater depth and salinity from kriging techniques are shown in figures 2.2 and 2.3. As shown, salinity and depth are categorized by the quartile in which the observation is observed as identified by a specific contour. These quartiles, which are discussed in more detail below, allow us to capture the non-linearity in the impacts of groundwater depth and salinity on farmland values. That is, by interacting classifications of different quartiles of groundwater depth and groundwater salinity with continuous variables of groundwater salinity and groundwater depth, respectively, we can highlight the presence of nonlinearities.

2.4.1 Functional Form

Linear, log-linear, and log-log functional forms were estimated and compared based on goodness of fit statistics.[15] 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, variable coefficients 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 (2.2), Spatial Autoregressive (2.4), Spatial Error (2.5), and a General Spatial Model (2.6). Following Anselin (1999), the spatial models are represented as:

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

(2.5) $$P = X\beta + \varepsilon$$
$$\varepsilon = \lambda W_2 \varepsilon + \mu$$ *Spatial Error Model*

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[15] 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.

$$
\begin{aligned}
(2.6) \qquad & P = \rho W_1 P + X\beta + \varepsilon \\
& \varepsilon = \lambda W_2 \varepsilon + \mu \qquad \textit{General Spatial Model} \\
& \mu \sim N(0, \sigma^2 I_n)
\end{aligned}
$$

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 (2.4) above, if the spatial autoregressive coefficient ρ is statistically significant, then overlooking spatial autoregression in the dependent variable leads to biased estimates (Anselin, 1999). The spatial error model, equation (2.5), 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. If the spatial error correlation coefficient is statistically significant, spatial correlation in error will 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) in equation (2.6) which controls for both the spatial autocorrelation in farm values and spatial correlation in the error terms.[16] Our results 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.

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[16] In our analysis, $W_1 = W_2 = W$ 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, none of which produced any significant changes in our results. Of course, an alternative spatial econometric approach would be to investigate this issue using a spatial fixed effects model. For a discussion of the pros and cons of using a spatial fixed effects approach, see Kuminoff et al. (2010) and Anselin and Arribas-Bel (2011).

2.5 Results

To illustrate the importance of groundwater quality in influencing the value of groundwater to irrigated agriculture, we develop four models. The first model, which we refer to as the *Baseline* model, includes groundwater depth as a continuous variable but does not include groundwater quality. The *Baseline* model, then, presents a specification most similar to how the literature has represented groundwater in hedonic studies. The second model, referred to as *Model_2*, adds to the *Baseline* model a continuous salinity variable that captures the quality dimension of the groundwater.

Recognizing that the impacts of salinity on crop yields are potentially very nonlinear and include a threshold level under which yields are not affected (Mass and Hoffman, 1977), we estimate two additional models that categorize salinity and groundwater depth into their respective quartiles. Both the EC and groundwater depth quartiles are designated as binary variables. For the third model, *Model_3*, we interact the salinity quartiles with a continuous groundwater depth variable. The 1st quartile includes those farms with EC values ranging from 0 to 0.2 dS/m, the 2nd quartile ranges from 0.2-0.5 dS/m, the 3rd quartile ranges from 0.5 to 1.2 dS/m, and the 4th quartile ranges from 1.2 to 4 dS/m. For the fourth model, *Model_4*, we interact the groundwater depth quartiles with a continuous groundwater salinity variable. The 1st quartile of groundwater depth includes all farms with groundwater depth from 5 to 40 feet, the 2nd quartile is of the range 40 to 80 feet, 3rd quartile ranges from 80 to 150 feet, and the 4th quartile ranges from 150 to 400 feet. Figures 2.2 and 2.3, again, provide the contours of EC and groundwater depth based on the above quartiles to highlight the level of spatial heterogeneity of these factors throughout our study area. While we categorize the variables by quartile for models 3 and 4, their actual values are used when presented as a continuous variable.[17]

2.5.1 *General Results*

Before discussing the groundwater variables, we briefly address the other variables to ensure that the model results are consistent with our expectations.[18] As the results listed in table 2.3 suggest, regardless of specification, larger farms tend to have lower per acre land values, a result consistent with the fact that landowners cannot costlessly repackage their land (Maddison 2000).[19] Parcels that have established vineyards and orchards, meanwhile, command a higher price per acre relative to those parcels that do not.[20] The coefficients on *Distance_from_Freeway* and *Population* illustrate that development pressures increase agricultural land values, consistent with our expectations. Finally, our measure of land quality, *Storie Index*, is positive and statistically significant which is consistent with expectations and the results from other studies which show land quality is capitalized into land values.

From the perspective of our climate-related variables, we find that January, April and October degree days are all associated with higher land values while July degree days are

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[17] It should be noted that while the estimated surfaces in figures 2.2 and 2.3 extend into regions within other counties not included in our analysis, an outcome that arises due to our kriging technique, our estimates are applicable only for regions within Kern, Kings, Tulare, Merced and Fresno counties of the Central Valley.

[18] To increase the ease at which our results can be compared across specifications, we left out the binary time variables from our table of results. The coefficients were all positive yet the statistical significance varied depending on specification (which captures whether nominal increases in land values from years 2005 to 2010 where different from land values in 2004). Results are available from the authors upon request.

[19] Maddison (2000) suggests that higher transaction costs might prevent farmers from combining land with others to form a plot with a higher value per acre. Xu et al. (1993), meanwhile, suggests that a likely reason for the inverse relationship between saleprice/acre and acres is that the market for large parcels is generally thinner with fewer buyers due to the need for access to more financial resources.

[20] We observe that the highest land values are those associated with parcels that have planted vineyards, followed by parcels with orchards.

negatively related to land values. This is consistent with our expectations and the literature (Mendelsohn and Dinar, 2003; Schlenker et al., 2007) and suggests 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. We find that precipitation in January, April and October is positively related to land values, while precipitation in July is negatively related, yet statistically insignificant. There is very little precipitation in the Central Valley in July, and some crops, especially table grapes, respond negatively to summer and early fall precipitation. All in all, the signs of the climate variables are consistent with the above literature.

We find that being a member of private water district for all but our baseline model leads to statistically significant higher land values. Indeed, our results suggest that parcels that are both within a private water district and receive CVP water sell for approximately 22% more than those farms that are members of a federal water district alone. Given the negative impacts of less reliable CVP water on land values, it is easy to understand the potential benefits of having access to another water supply source.[21] And while the variability in CVP water supply has a negative and statistically significant impact on land value, increases in the mean supply has a positive and statistically significant impact.

We now turn our attention to how the characterization of groundwater influences its value and statistical significance.

2.5.2 *Baseline Model*

As the first column of results in table 2.3 illustrates, the impact of increases in groundwater depth have a negative, albeit statistically insignificant, impact on parcel sales price. Such a result is

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[21] Mukherjee and Schwabe (2012) provide more details on the variability and mean water supply of CVP water.

consistent with the findings of the previous literature (Schlenker et al., 2007; Brozovic and Islam, 2010).

2.5.3 *Model 2: Incorporating groundwater quality*

From previous research, we know that soil and groundwater salinity can severely impact agricultural land productivity, especially in semi-arid and arid regions such as Murray-Darling River Basin in Australia or the Central Valley of California (Schwabe et al., 2006). In model 2, then, both groundwater depth and groundwater quality (salinity) are included as separate continuous variables. As shown in the third column of table 2.3, when groundwater quality is accounted for, we see that not only does it have a negative and statistically significant impact on land values, the coefficient on groundwater depth becomes positive and statistically significant. So, for a particular level of groundwater salinity, increases in depth increase land values; conversely, for a particular groundwater depth, increases in salinity decrease land values. These results are certainly in line with our expectations and illustrate that when salinity is not included, the model suffers from omitted variable bias that influences the coefficient on the groundwater depth variable. Empirically, the results are consonant with the fact that along the westside of the Central Valley, crop production is threatened by a very saline high groundwater table.[22]

Recalling figures 2.2 and 2.3 we see that groundwater salinity and depth varies significantly within Central Valley. From figure 2.2, we also observe that salinity in groundwater increases as we move towards the westside of the Valley. A natural question to ask is whether the responsiveness of land values to changes in one particular groundwater characteristic—depth or quality—is influenced by the level of the other groundwater characteristic? Including salinity and depth in an additive fashion as in model 2 fails to capture this possibility. Therefore, we use

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[22] Part of the region overlays an impervious clay layer with no natural drainage outlet. Consequently, the deep percolation flows from irrigation, flows that contain salts, perch on top of the clay layer. Over time, the groundwater table has risen to a point where a significant amount of land is being retired.

models 3 and 4 to capture the variation in the marginal impacts of groundwater salinity and depth by interacting each with the respective quartiles of the other.

2.5.4 *Model 3: Valuing groundwater depth based on groundwater salinity quartiles*

With this model, we categorize groundwater salinity based on quartile as illustrated in figure 2.2. and interact it with a continuous groundwater depth variable. As shown in the fourth column of table 2.3, as groundwater depth increases for high quality groundwater (*BotquartEC*Gwdepth*), land values decrease, although less so than for groundwater that is of slightly less quality (*MedquartEC*Gwdepth*). That is, we find that a 1% increase in groundwater depth for farms which lay above groundwater in the bottom quartile of EC results in a 0.06% (statistically significant) decrease in saleprice/acre. Yet for farms that lie above slightly more saline groundwater, as represented by the medium quartile, we see that a 1% increase in groundwater depth results in a 0.04% statistically significant decrease in saleprice/acre.

For salinity levels that begin to have a more significant impact on crop growth, increases in depth increase, not decrease, land values (*ThirdquartEC*Gwdepth*), although again by not as much as for those parcels that lay above the highest EC values (*TopquartEC*Gwdepth*). That is, farms with groundwater EC in the third quartile experience a 0.04% statistically significant increase in saleprice/acre with 1% increase in groundwater depth whereas the farms with access to groundwater with salinity in the top quartile experience a 0.05% increase in saleprice/acre. Consequently, growers' likely benefit from rising groundwater depth as it reduces the possibility that the saline groundwater will percolate up into the rootzone and reduce yields. In figure 2.2, those regions where growers will benefit from increases in groundwater depth are illustrated by the yellow and red regions of Kern, Kings, Fresno, Tulare and Merced counties. These are regions that would benefit from salinity and drainage management programs. The blue and green areas within these counties, alternatively, represent regions which have very low to moderate EC in groundwater and thus are of lesser importance when it comes to investments in salinity management.

2.5.5 *Model 4: Valuing groundwater salinity based on groundwater depth quartiles*

Another way of illustrating the importance of groundwater quality is to interact groundwater quality with depth where depth is categorized by quartile (see figure 2.3) As the fourth column in table 2.3 illustrates, for those farms confronting the highest water tables, increases in salinity lead to lower land values. Specifically, our results show that a 1% increase in EC for such farms leads to a 0.09% (statistically significant) decrease in saleprice/acre. This is as expected as lower groundwater depth (i.e., higher water tables) could be damaging for crops if it is high in salinity and reaches the crop root zone. From a monetary perspective, a 1-unit increase in EC for these farms leads to an approximate average decrease of $3,718 in sale price/acre based on the average saleprice/acre of the farmland in our sample.[23]

For farms that confront groundwater depth in the median quartile, land values decrease by 0.09% for a 1% increase in EC. Again, if groundwater depth is low, a marginal increase in salinity could harm the crops and hence have a negative impact on farm values. From a geographic perspective, the blue and green regions of Kern, Kings, Fresno, Tulare and Merced counties as shown in figure 2.3 indicate regions that would benefit from lower water tables and, consequently, drainage and salinity mitigation programs.

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[23] Recall that given our specification is in a log-log format, marginal impacts are a function of the level of the dependent variable.

Table 2.3. GSM Estimates for Alternative Hedonic Specifications[24]

Variable	Baseline	Model 2	Model 3	Model 4
Constant	-75.00*** (0.00)	205.621*** (0.000)	64.582* (0.017)	104.727* (0.097)
Acres	-0.363*** (0.000)	-0.315*** (0.000)	-0.371*** ((0.000)	-0.356*** (0.000)
Orchard	0.197*** (0.009)	0.362*** (0.000)	0.383*** (0.000)	0.383*** (0.000)
Vineyard	0.152* (0.069)	0.259*** (0.004)	0.389*** (0.000)	0.389*** (0.000)
Distance from freeway	-0.097*** (0.000)	-0.068** (0.006)	-0.066* (0.011)	-0.075*** (0.004)
Population	0.119*** (0.000)	0.103*** (0.000)	0.089*** (0.000)	0.118*** (0.000)
Storie Index	0.076*** (0.000)	0.076*** (0.002)	0.066*** (0.000)	0.084*** (0.000)
Jan degree days	13.691*** (0.000)	21.99*** (0.000)	17.611*** (0.004)	18.643*** (0.000)
April degree days	59.119*** (0.000)	89.354*** (0.000)	84.167*** (0.004)	78.732*** (0.000)
July degree days	-58.418 (0.011)	-61.328*** (0.000)	-93.794*** (0.000)	-66.046*** (0.001)
Oct degree days	59.241*** (0.000)	101.643*** (0.000)	79.622** (0.044)	86.946*** (0.000)
Jan precipitation	1.093*** (0.000)	2.376*** (0.000)	1.609*** (0.001)	1.861*** (0.000)
April precipitation	0.432* (0.099)	-0.345 (0.152)	0.704** (0.015)	0.094 (0.684)
July precipitation	3.338 (0.483)	-8.593*** (0.000)	-2.89 (0.731)	-2.043 (0.470)
Oct precipitation	0.784*** (0.000)	0.804*** (0.000)	0.917*** (0.001)	0.689*** (0.002)
Private Water District	0.118 (0.278)	0.216** (0.024)	0.331*** (0.001)	0.200* (0.068)
Mean_CVP	0.182*** (0.005)	0.194*** (0.005)	0.287*** (0.000)	0.293*** (0.000)
Variance_CVP	-0.012*** (0.010)	-0.017*** (0.000)	-0.015*** (0.000)	-0.020*** (0.000)

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

Table 2.3 (continued). GSM Estimates for Alternative Hedonic Specifications

Variable	Baseline	Model 2	Model 3	Model 4
Groundwater depth	-0.030 (0.459)	0.344*** (0.000)		
EC		-0.401*** (0.000)		
BotquartEC*Gwdepth			-0.060*** (0.006)	
MedquartEC*Gwdepth			-0.037** (0.010)	
ThirdquartEC*Gwdepth			0.044* (0.081)	
TopquartEC*GWDepth			0.052*** (0.008)	
BotquartGWD*EC				-0.089*** (0.001)
MedquartGWD*EC				-0.085** (0.045)
ThirdQuartGWD*EC				-0.019 (0.701)
TopQuartGWD*EC				0.019 (0.687)
ρ (SAR correlation coefficient)	0.03*** (0.000)	0.04*** (0.000)	0.04*** (0.000)	0.05*** (0.000)
λ (SEM correlation coefficient)	0.90*** (0.000)	0.90*** (0.000)	0.90*** (0.000)	0.90*** (0.000)
R^2	0.95	0.95	0.95	0.95
Observations	629	629	629	629

For farms with groundwater depths in the third or top quartile, though, increases in EC do not seem to matter. This is not surprising as the water table in this case is too low to cause any damage to the crops. The brown and orange regions of Kern, Kings, Tulare, Merced and Fresno counties as shown in figure 2.3 indicate areas that would likely not benefit significantly from drainage or salt mitigation programs.

2.6. Impact on Farmland Values with Projected increase in Salinity

Worsening groundwater salinity and drainage conditions can impact agriculture in a number of ways. First, it can reduce the quality of available irrigation water which leads to profit losses via lower yields, require higher water application rates to leach salts out of the soil, or necessitate the need to switch to more salt-tolerate, albeit lower-valued, crops. Second, when salinity concentrations in the groundwater reach a certain level, the aquifer may transition from initially serving as an irrigation source to serving as a drainage sink. Consequently, in drainage-impaired regions, a rising saline water table can percolate up into the root zone and, at the very least, lower crop yields.

The groundwater system in the Central Valley serves both purposes—as a source of irrigation water and as a drainage sink. In response to rising salinity levels in the groundwater, the State Water Board and the Central Valley Water Board are initiating efforts to address the problem and are considering a variety of long-term solutions (Howitt et al., 2009). To provide planners information on the potential impacts of salinity increases, we estimate the impacts on agricultural land values using projected increases in groundwater salinity (table 2.4).

Groundwater salinity in the Central Valley is expected to increase by 0.265 ds/m (175ppm) by the year 2030 (Schoups et al., 2006), which translates into an increase of approximately 30% compared to the average groundwater salinity in our current sample. If we use the coefficients estimated in *Model_2*, then a 30% increase in salinity will result in a 12% decrease, or $4,958 per acre loss, in agricultural land values (table 2.4). Alternatively, if we use the coefficients estimated from *Model_4*, then the sales price per acre is expected to decrease by 3% ($1,240/acre) for those farms in the bottom and medium quartiles of groundwater depth when salinity increases by 30%. Finally, and again using *Model_4*, for those farms with groundwater depth ranging in the third or top quartiles, a 30% increase in salinity results in a decrease 0.6% in agricultural land values, or approximately $248 per acre on average.

For an average size farm of in our sample, then, the estimated decrease in sales price from this projected increase in salinity ranges from $131,500 under *Model_2* to only $6,600 under *Model_4* for farms with a low water table versus around $32,900 for farms with a high water table, again using *Model_4*. The nearly 3 to 20-fold difference between estimates suggests caution in how one decides to value groundwater and account for salinity.

Table 2.4. Impact on sale price per acre with a projected increase of 30% in groundwater EC

EC Classifications	**Model**	**Percentage Impact on sale price per acre**	**Impact in dollar value based on average sale price per acre**	**Impact in dollar value based on maximum sale price per acre**
Overall EC	Model 2	-12%	-$4,958	-$37,852
Botquart*GWD	Model 4	-3%	-$1,240	-$9,463
Medquart*GWD	Model 4	-3%	-$1,240	-$9,463
Thirdquart*GWD	Model 4	-0.6%	-$248	-$1,893
Topquart*GWD	Model 4	-0.6%	-$248	-$1,893

2.7 Conclusions

Rising populations, environmental requirements, and changing climates all are likely to place additional stress on groundwater systems. To best understand the efficiency surrounding possible investments into preserving such systems for irrigated agriculture, information on the benefits such efforts might provide is needed. In looking to the hedonic valuation literature for insight into such values, one immediately notices the mixed results surrounding the significance of groundwater to irrigated agriculture. While there are a number of factors that could give rise to such disparities, our hypothesis is that groundwater quality, and in particular salinity, can play a major role in influencing groundwater's value to irrigated agriculture. We find that particular measures of groundwater, such as its volume or depth, are influenced by its salinity; hence, hedonic models of regions where groundwater quality is of concern likely suffer from omitted-variable bias if quality is not included. We also show that the marginal value of changes in groundwater depth on land values is dependent upon the salinity of the water; similarly, the marginal damages associated with changes in salinity depend on the depth to the water table. Such information, as stressed in Bjornlund (1995), can help growers, irrigation districts and policy makers in their efforts to manage groundwater systems and mitigate the adverse effects surrounding its degradation.

Within the Central Valley, California, our results are consistent with the fact that groundwater systems provide multiple services. That is, in some instances we find that higher water tables lead to lower land values, a result that is consistent with the groundwater system serving as a sink for drainage water. Similarly, we find instances where higher water tables lead to higher land values, a result consistent with the groundwater system serving as a source of irrigation water. Groundwater systems, then, can be recognized as a differentiated product that may vary significantly with respect to quality, volume, and available of drainage services. As such, hedonic analyses that overlook particular characteristics of a groundwater system may end up with insignificant and/or inaccurate results due more so to specification choices rather than as an accurate representation of the system's value to growers. Indeed, in an effort to identify the possible damages associated with projected increases in salinity over the next 30 years, we find that the impact on land values can vary by 20-fold depending on model specification.

Chapter 3

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

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3.1 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 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.[25]

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.[26] 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 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.[27]

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[25] 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.

[26] 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.

[27] 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.

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 farmland 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.

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 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). 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.

3.2 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); 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 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 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 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.[28] 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 US 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 2555 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, 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

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[28] 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.

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.[29] 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 in areas where salinity is present as in 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, 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 out the different water supply sources to test whether they have

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[29] 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 in explaining county-level land values and do not observe statistical 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) 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.

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 2000 parcels located in ten 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).

3.3 Model

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 a water supply source differentially impact land values, we use the hedonic property method similar to Chapter 2.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 similar to equation (2.1) and (2.2) in Chapter 2.The parcel characteristics in this chapter consist of surface and groundwater water supply characteristics, land quality characteristics, institutional characteristics that capture membership in a type of water/irrigation district (private, state, or federal), portfolio characteristics, crop characteristics, climate characteristics, and other factors that influence land values. Specifically, we estimate variants of the following equation:

(3.1)

$$
\begin{aligned}
salevalue_{it} = {} & \gamma_0 acres_{it} + \gamma_1 orchard_{it} + \gamma_2 vineyard_{it} + \gamma_3 distance\ from\ freeway_i + \\
& \gamma_4\, population_i + \gamma_5\ Storie\ Index_i + \gamma_6\, year\ fixed\ effects_i + \gamma_7\, Jan\ Dgd_i + \\
& \gamma_8\ April\ Dgd_i + \gamma_9\, JulyDgd_i + \gamma_{10}\, OctDgd_i + \gamma_{11}\, Jan\ Precip_i + \\
& \gamma_{12} April\ Precip_i + \gamma_{13} JulyPrecip_i + \gamma_{14} OctPrecip_i + \gamma_{15} Private\ WD_i + \\
& \gamma_{16} State\ WD_i + \gamma_{17} Fed\ WD_i + \gamma_{18} PrivateState_i + \gamma_{19} PrivateFed_i + \\
& \gamma_{20} State_{othersupplies_i} + \gamma_{21} Fed_{othersupplies_i} + \gamma_{22} Private_{othersupplies_i} + \\
& \gamma_{23} MeanWater\ Supply_{SWP_i} + \gamma_{24} MeanWater\ Supply_{CVP_i} + \\
& \gamma_{25} VariabilityWater\ Supply\_SWP_i + \gamma_{26} Varibility\ Water\ Supply\_CVp_i \\
& \gamma_{27} groundwater\ depth_i + \gamma_{28}\ salinity_i + \varepsilon_{it}
\end{aligned}
$$

3.4 Data

The data used in the estimating equation (3.1), whose definitions and summary statistics are listed in table 3.1, 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 ten counties of California during the time period ranging from 2004-2010. The parcels used in Chapter 2 are a subset of the data set used in this chapter, i.e., parcels only belonging to Central Valley counties and receiving CVP water. Since the focus of Chapter 2 is primarily to estimate value of groundwater services in agriculture, we do not add more complexity to our model in Chapter 2 by using this data set which has a wider variety of water supply and portfolio characteristics.

The parcels used for analysis in this chapter 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 amongst 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 3.1

Table 3.1. 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)

We selected agricultural parcels from these counties as they rank amongst the top 18 counties by gross value of agricultural production from California County Agricultural Commissioners' Reports, 2004-2005. From a sampling perspective, 66% of our parcels are located in the Central Valley region, 13% from the Central Coast region, and 21% 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%, 21%, and 15% of the farms are located in the Central Valley, Central Coast and Southern region, respectively.[30]

Sales 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)[31] 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 US National highways were obtained from California-Atlas. Distance from nearest highway to the farms was spatially computed in ArcGIS. The logic behind including these variables in the hedonic model and their expected impact on farmland values are provided in Chapter 2.

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[30] 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.

[31] 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.

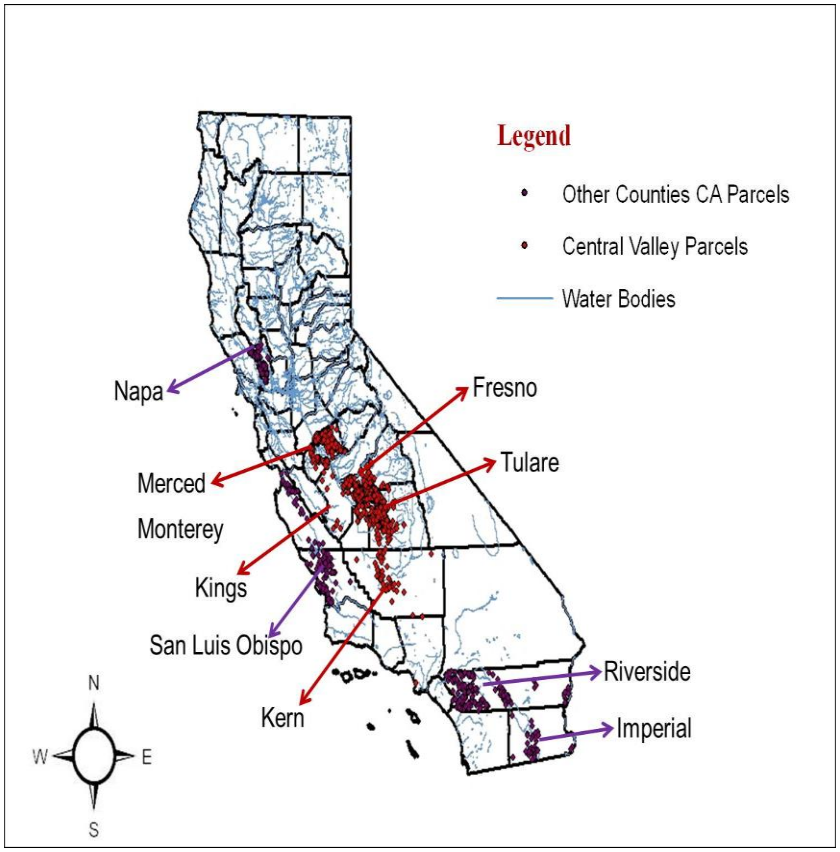

Figure 3.1 Study region map with Farmlands

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 Groundwater Ambient Monitoring and Assessment Program (GAMA) Geotracker of U.S. Geological Survey (USGS). Similar to Chapter 2, 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 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.[32] Again, as already discussed in Chapter 2, an increase in groundwater salinity and groundwater depth is expected to be negatively associated with land values (Water Board Report, 2006). Although, as discussed in Chapter 2 the marginal impacts of each of these variables could vary depending on the level of the other characteristics. We include only a single variable for groundwater salinity and depth and do not include their quartile interactions in this analysis. We do not include the details of spatial heterogeneity of groundwater salinity and depth in this analysis so that we can focus primarily on the benefits of water portfolio with a parsimonious model.

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. Again, as discussed in Chapter 2 it would be expected that better soil quality would have a positive influence on farmland values. 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 soils for most kind of field crops. Capability classes are

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

designated by numbers 1 through 8. The numbers indicate progressively greater limitations and narrower choices for practical use.[33]

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 (see, 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). The expected impact of the above climate variables on farmland values are discussed in detail in Chapter 2.

Water supply data for Federal and State Water districts were obtained for the time period of 1994 to 2004 from US Bureau of Reclamation and the California Department of Water Resources to account for the mean and variability of surface water supplies. As discussed in Chapter 2, while mean water supplies are expected to increase agricultural land values, we would expect that increases in water supply variability would have a negative impact as illustrated in Conner et al. (2012). To geo-code each farm into a water district, federal, state and private water district shape 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 3.2.

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[33] 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.

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 its water supplies.

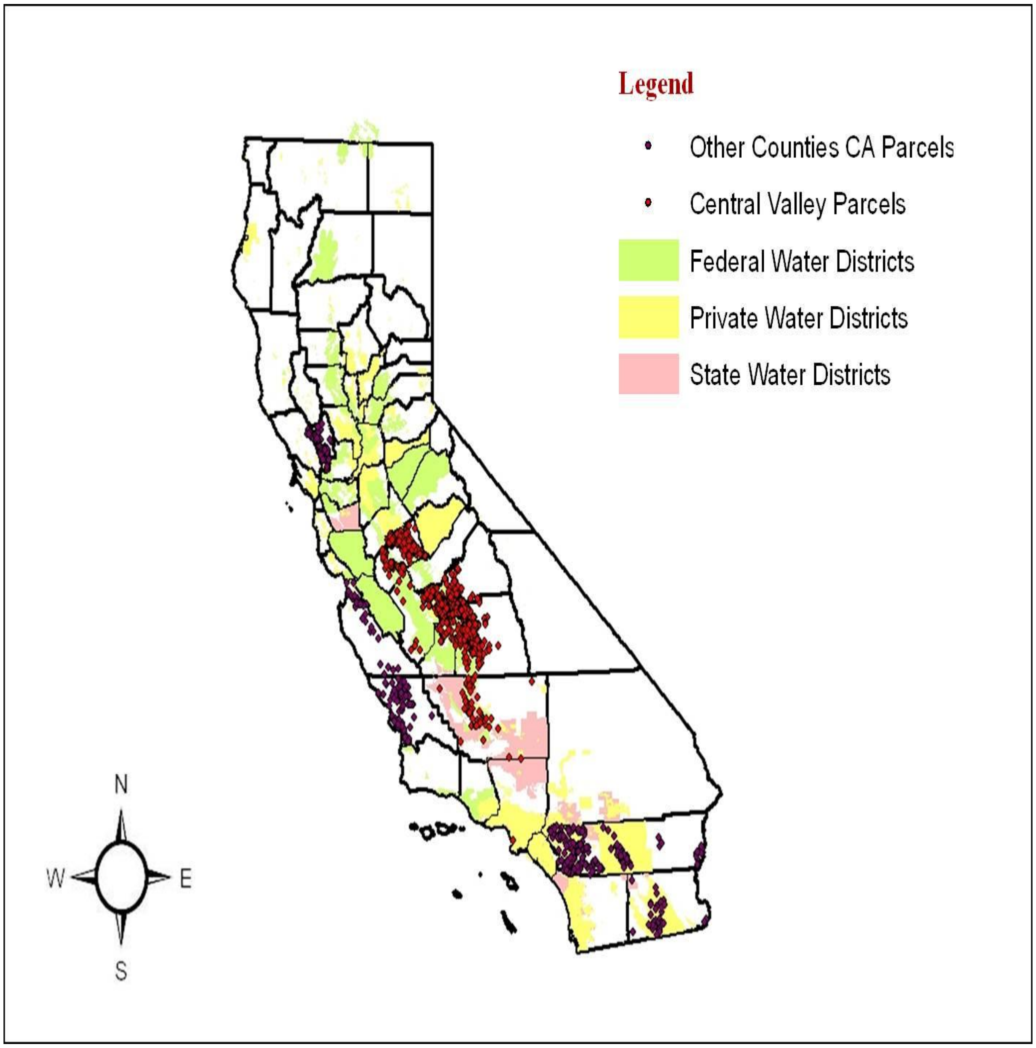

Figure 3.2 Location of Water Districts and Farmlands

Figures 3.3 and 3.4 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 is apparent is the variability in the SWP supplies across districts relative to the consistently low CVP supplies. Figures 3.5 and 3.6 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. Figures A.3 and A.4 in Appendix also shows the variability in SWP and CVP water supply from 1994-2004. As observed from the whisker plots CVP seems to have a more variable water supply compared to SWP. Based on these statistics, we would expect that State Water district would naturally be associated with higher farmland values compared to Federal Water district. 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 that 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.

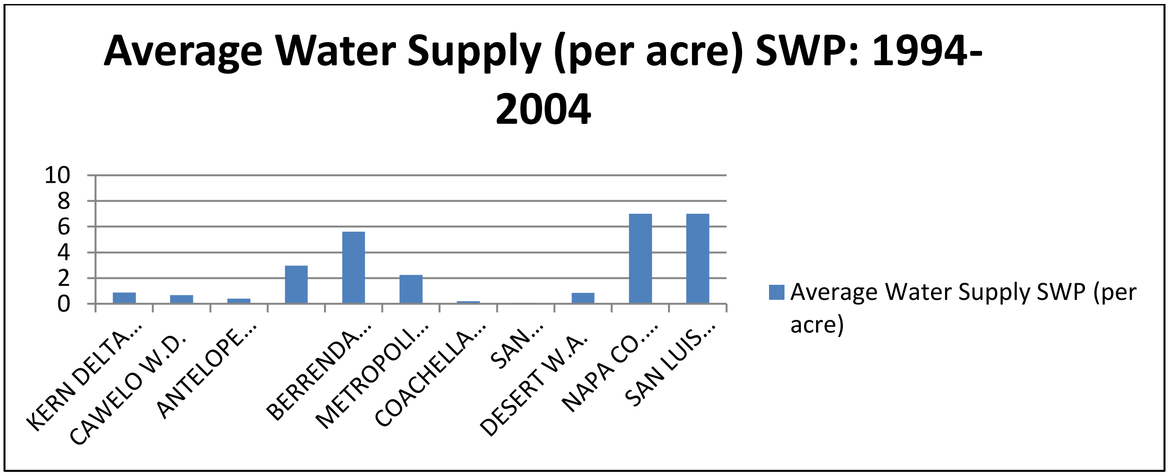

Figure 3.3. Average Water Supply for State Water Project (SWP) in acre-feet per acre

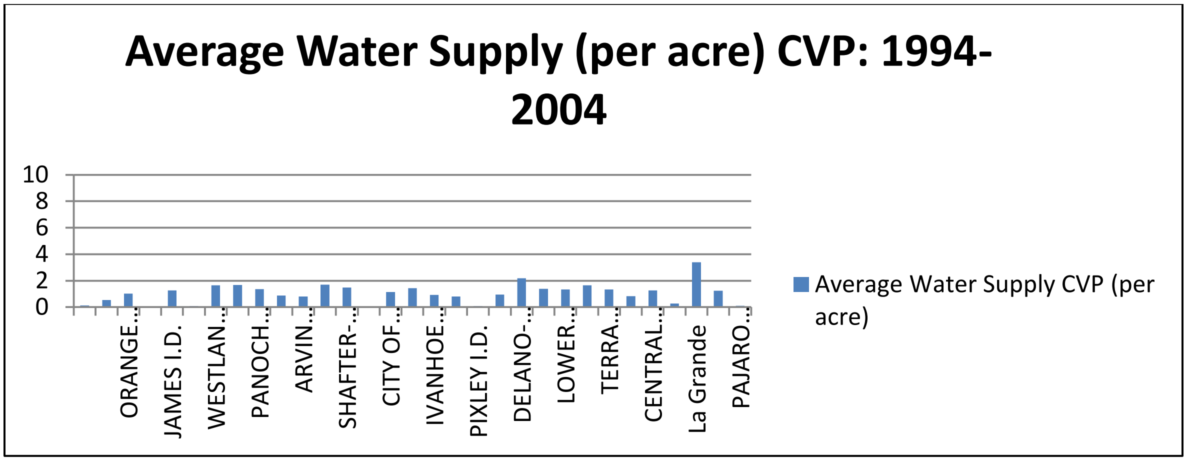

Figure 3.4. Average Water Supply for Central Valley Project (CVP) in acre-feet per acr

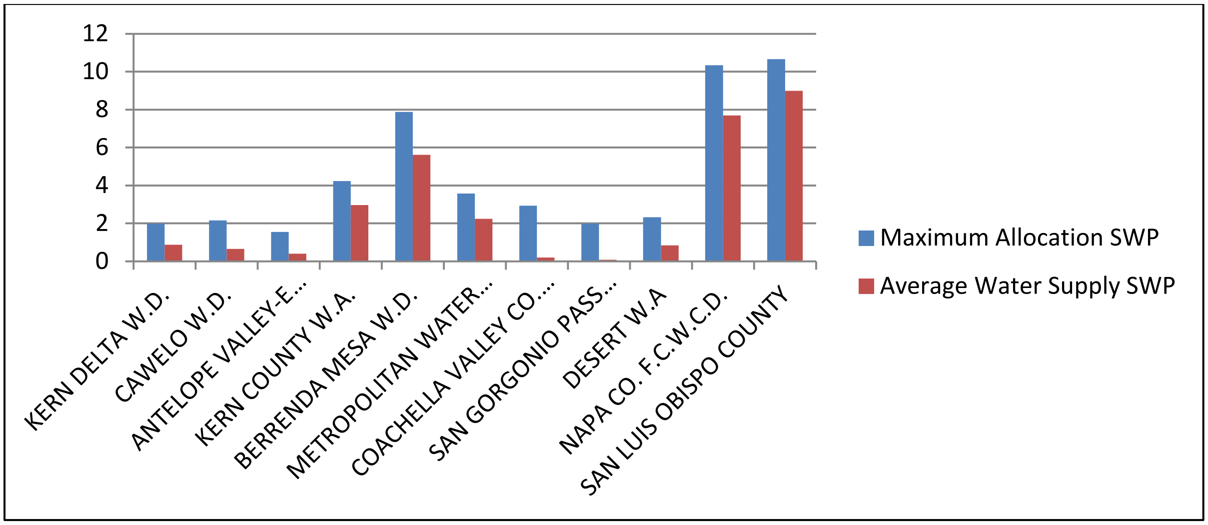

Figure 3.5: **Comparing Average Water Supply versus Maximum Allocation from 1994-2004 for SWP in acre-feet per acre.**

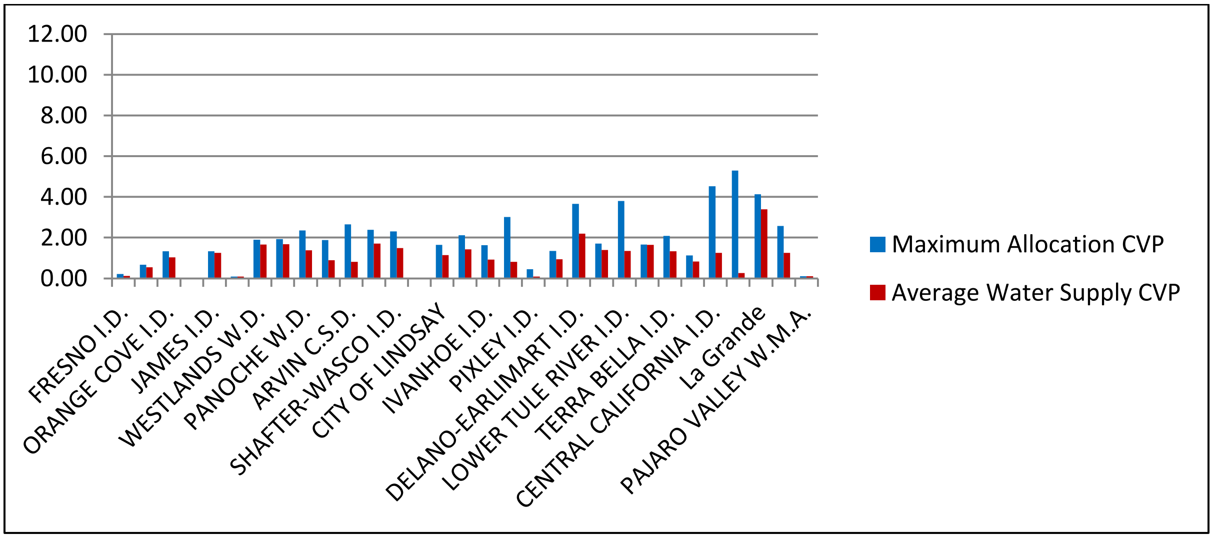

Figure 3.6: **Comparing Average Water Supply versus Maximum Allocation from 1994-2004 for CVP in acre-feet per acre**

3.4.1 Functional Form

Similar to Chapter 2, we use a log-log General Spatial Model in this analysis. The econometric advantages of using this functional form and the General Spatial model are discussed in detail under "Functional Form" in Chapter 2. Our model in this chapter includes a significant number of dummy variables which 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. The reason behind including the crop and year dummies in the model and their expected impacts on farmland values are similar to the details provided in Chapter 2. 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)[34]. 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% of the water supply received from State water districts.

3.5 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 which also has access to riparian or groundwater sources. For example, a farm might be a member of a private water district which has appropriative rights but also riparian rights or access to an aquifer; alternatively, the farm

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[34] In our study there are farms which are a member of a 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.

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 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 3.2 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.

3.5.1. 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, where 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/early fall periods.[35]

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

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[35] 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 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.

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 3.3 and 3.4). Similarly, being in state water district leads to a 84% increase in farm values, whereas being in a federal or private water district leads to an 18% and 13% increase, respectively, relative to not being in a water district.

3.5.2. 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 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% and 9% increase in farm values, respectively, although the latter coefficient is not statistically significant. 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 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 whether access to multiple water sources serve as an adaptive strategy which serves 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 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.

3.5.3. 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 which are members of both state and private water districts and which are in the top 25% or bottom 25% of SWP average water supply 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. There are fees and administrative costs 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.[36]

As shown in the third column of results in table 3.2, 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, 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 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, 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

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[36] 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.

becomes statistically insignificant relative to the baseline, but no appreciable change in the impact of groundwater depths on land values is noticed.

3.5.4. 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 degree days 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% 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% 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.

Table 3.2: Estimates from GSM Hedonic Regression[37]

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)

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

Table 3.2: 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)
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)
Oct precipitation	0.385***	0.367***	0.391***	0.355***
	(0.000)	(0.000)	(0.000)	(0.000)
Salinity of Groundwater (dS/m)	-0.107***	-0.096	-0.047	-0.016**
	(0.001)	(0.114)	(0.394)	(0.037)
Groundwater Depth (feet)	-0.056***	-0.065***	-0.057***	-0.056***
	(0.000)	(0.000)	(0.000)	(0.000)
State Water District	0.840***	0.901***	0.542**	0.795**
	(0.000)	(0.000)	(0.014)	(0.018)
Federal Water District	0.183**	0.198**	0.368***	0.436***
	(0.011)	(0.016)	(0.000)	(0.000)
Private Water District	0.130***	0.219***	0.115**	0.235***
	(0.004)	(0.000)	(0.051)	(0.001)
Mean_SWP	1.101***	0.067	1.021***	0.070
	(0.000)	(0.840)	(0.003)	(0.834)
Mean_CVP	0.122***	0.148***	0.074	0.087*
	(0.002)	(0.000)	(0.130)	(0.077)
Variance_SWP	-0.623***	-0.059	-0.590***	-0.072
	(0.000)	(0.743)	(0.001)	(0.695)
Variance_CVP	-0.012***	-0.003	-0.025	-0.018
	(0.000)	(0.885)	(0.307)	(0.466)
State_Other		0.517***		0.789***
		(0.007)		(0.007)
Fed_Other		0.112*		0.059
		(0.088)		(0.371)
Private_Other		0.087		0.006
		(0.162)		(0.928)
Private_State			-1.171**	-0.622**
			(0.035)	(0.014)
Private_Fed			-0.326**	-0.631**
			(0.023)	(0.000)

Table 3.2 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)
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
No. of Observations	1900	1900	1900	1900

3.6. 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). [38] The long run and net annual marginal values for water- and climate-related variables are reported in table 3.3.

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[38] 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.

3.6.1. 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, $1493 and $1821 increase in per-acre annual land values in scenario 1, yet only a $48, $843 and $1685 increase when 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.

3.6.2. Surface water supply variables

As shown in table 3.3, 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% 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 3.4 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/ac-ft, whereas an acre-foot of CVP water is valued at $314. As shown, Schlenker et al. suggest an estimated annual value of around $50/ac-ft, 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/ac-ft estimate for the most productive land and a $14/ac-ft estimate for their least productive land. There are many reasons which 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 $4056 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 ac-ft/ac versus 2.78 ac-ft/ac as shown in table 3.1, 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.

3.6.3. 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, Kan et al. (2002) in their programming approach that analyzes the salinity impacts on various crops in the Central Valley 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 is consistently statistically significant.[39] For comparison, Schlenker et al. (2007) find 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.

3.6.4. 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 access to water portfolios is included. For instance, the sales price of an acre of farmland in a state water district increases by $2768 annually in scenario 1 and by $2637 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 water district increases annually by $609 in scenario 1 and by $1459 in scenario 4, again, relative to a parcel which is not in a water district. Even for farms which are in private water districts, their land values are on average $445 higher in scenario 1 and $805 higher in scenario 4 compared to those farms not in water districts.

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[39] In this calculation, we assume a $20 per ac-ft 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) have been adjusted for inflation to 2004 dollars for comparison purposes.

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 $2604 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 $3925 ($236 in annualized value) relative to farms in private districts alone.

Similarly, farms in that have membership in private water districts as well as state districts which receives SWP deliveries in the bottom quartile of deliveries receive a premium of approximately $1963 ($138 in annualized value) above those that are in private districts alone. Finally, farms which are in state or federal districts which 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.

Table 3.3. 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 3.4. Comparison of the marginal monetary value of water with previous literature (2004 dollars)

	Scenario 4[40]	Schlenker et al. (2007)[41]	Mendelsohn and Dinar (2003)	Faux and Perry (1999)[42]
Annual Value of Water ($/ac-ft)[43]	SWP water[44]: 96 CVP water : 314	50	213	Most productive land: 69 Least productive land : 14

3.7 Conclusions

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

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[40] 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.

[41] 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.

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

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

[44] Value of SWP water is not statistically significant

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 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 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 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.

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.[45]

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[45] 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.

Chapter 4

Conclusions and Future Research

4.1. Objectives, Results and Policy Implications

This dissertation uses a spatial hedonic model to analyze the impacts on farm-land values from changes in biophysical, economic, and institutional factors with a particular focus on water. Water is treated as a differentiated product that varies not only by source and quantity, but also by reliability and quality. While there are natural occurring sources of water, e.g., precipitation, rivers, streams, groundwater systems, that affect farmland values, there are also sources that have been developed for irrigation which, as we investigated, offer water managers and growers alternatives water supply sources that may serve as substitutes or compliments to naturally occurring sources. The intention of this dissertation is to provide information on the benefits to growers of water management schemes that couple natural and developed sources of water, which can be referred to as a water portfolio. We also look at the impacts of lesser appreciated, or at least analyzed, water supply characteristics including those associated with reliability and quality. Finally, we show that attempts to define and value a water supply by a single characteristic, e.g., quantity or accessibility, is likely to be very uninformative when other characteristics of that particular supply are varying as well.

The primary motivation driving the research objectives of the second chapter of this dissertation are the issues of groundwater overdraft and salinity in Central Valley, which has consequent impacts on food supplies, employment and income within California and beyond. This study is based on approximately 700 parcels from five counties of Central Valley and takes into account a wide variety of variables including groundwater salinity, which has been overlooked by some of the previous studies in this literature (Torrel et al., 1990; Schlenker et al.2007; Hornbeck and Keskin, 2011). Furthermore, the analysis in this chapter also considers non-separability between groundwater depth and quality while accounting for spatial heterogeneity for both of these variables. Finally, the predicted model is used to develop an estimate of the damages associated with projected increases in groundwater salinity by the year 2030. From a methodological perspective, this study is an improvement over previous hedonic literature that provided limited attention to groundwater salinity and overlooked its interaction with groundwater depth in influencing farmland values.

The results of this chapter indicate that hedonic models of regions where groundwater quality is an issue likely suffer from omitted- variable bias if quality is not included. In addition to this, one of the main findings of this chapter is that the marginal value of changes in groundwater depth on land values is dependent upon the salinity of the water; similarly, the marginal damages associated with changes in salinity depend on the depth to the water table. These results have relevant policy implications for efficient salinity and drainage management strategies in Central Valley, California. For example, access to alternative sources of water supply, increases in surface water allocation or investment in salinity and drainage mitigation programs could be prioritized for the regions within Central Valley where there are higher damages from groundwater salinity and drainage issues.

Water supply issues in agriculture induced by climate change motivate the research objectives of Chapter 3. Significant number of studies looked into the impact of climate change on water supplies and agriculture and also a number of them investigated how agriculture can adapt to climate change with irrigation(Mendelsohn and Dinar, 2003; Schlenker et al. 2007). Most of the studies that tried to identify possible adaptation strategies to climate change in agriculture treated water supply as a homogenous source and overlooked some of its unique characteristics. The analysis in the third chapter of this dissertation differentiates between water supply sources according to their types (e.g. Private, State or Federal) and their unique characteristics (mean supply and variability). This is a methodological improvement over previous research that treated surface water supply as a single homogenous source, which could lead to biased estimates as each water supply source can have its unique characteristics. In addition to this, this study also investigates the benefits of having a diversified water portfolio in mitigating the negative impacts of salinity, water scarcity water supply variability and higher temperatures on farmland values. The findings of this chapter are unique and have relevant policy implications for water and agriculture in California and beyond.

4.2. General Conclusions and Future Research

The results of Chapter 2 and 3 in this dissertation imply that while we are analyzing water management strategies in agriculture we should consider a full range of water supply characteristics. Water is treated as a differentiated product and its value is determined by each of its unique characteristics including type of water supply, mean water supply, water supply variability and water quality. Other than this, this dissertation also highlights the importance of incorporating different types of adaptation techniques while trying to estimate the impact of climate change in agriculture. For instance, a water supply portfolio has been considered as a possible adaptation strategy in this dissertation.

One other major finding of this dissertation is that that groundwater quality and the spatial heterogeneity of both groundwater quality and depth plays a vital role in determining value of groundwater services in agriculture. Overall, the findings of this dissertation have relevant policy implications for water management strategies not only for California but also for any other semi-arid or arid regions facing similar water issues.

This dissertation could be extended to several potential research papers in future. One interesting extension of Chapter 2 could be to analyze the impact of groundwater export restrictions on farmland values. For instance, in California there are local ordinances restricting out of county exports for certain counties. In particular, communities in the source regions have raised concerns over the potential adverse effects of water sales on local groundwater users and the local economy (Hanak, 2003). The information on spatial heterogeneity of groundwater depth and salinity can be used in this analysis to investigate the degree to which groundwater export restrictions impact farmland values. The results of this analysis can have potential policy implications for water transfers restrictions in California water market.

Another potential extension of this dissertation could be an extension of Chapter 3 to analyze the role of water markets as a possible adaptation strategy to poor water supply conditions and climate change. Some studies have looked into effects of water markets in reducing the economic risk caused by water availability variations. These studies have mostly used programming approaches to analyze the impact of water market on the profit function of a water seller or grower (e.g., Calatrava and Garrido, 2005). However, limited effort has been made in the hedonic literature to analyze the role of water market on land values. As an extension of Chapter 3, the water market can be considered as a bigger water portfolio or an ultimate diversification strategy and its role for adaptation to water and climate variability in agriculture can be further explored through its impact on land values.

In addition, with the rich data set used in this dissertation, other issues for possible analyses include: (i) the role of agricultural land preservation (e.g. Williamson Act in California) in both agricultural and urban markets through its direct implications on land use and its indirect impact on water supplies, (ii) investigating how similar biophysical, development and climate variables influences the decision to diversify at the district level using a propensity score matching model, and/or (iii) the role of water institutions (e.g. water districts and/or water agencies) in agricultural and urban markets. The latter opportunity includes analyzing the economic and policy implications of couple of relevant issues including functioning of these institutions (e.g., whether they are easily accessible by customers, locations, management structure) and/or their water quality and quantity management strategies (e.g. waste water recycling, capture and reuse of storm water runoff and other water use efficiency programs).

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Appendix

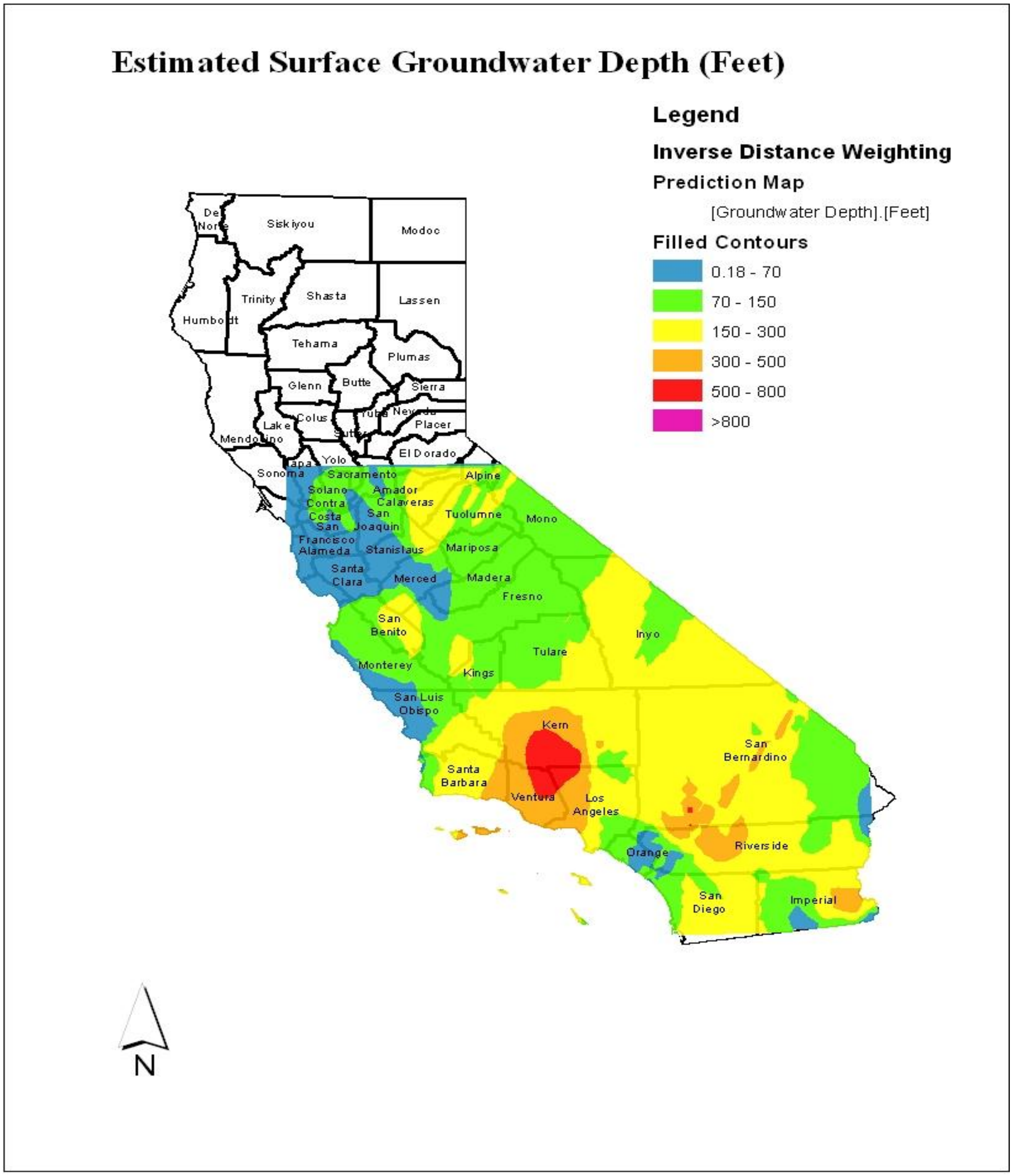

Figure A.1. Estimated surface for groundwater depth for more regions in California

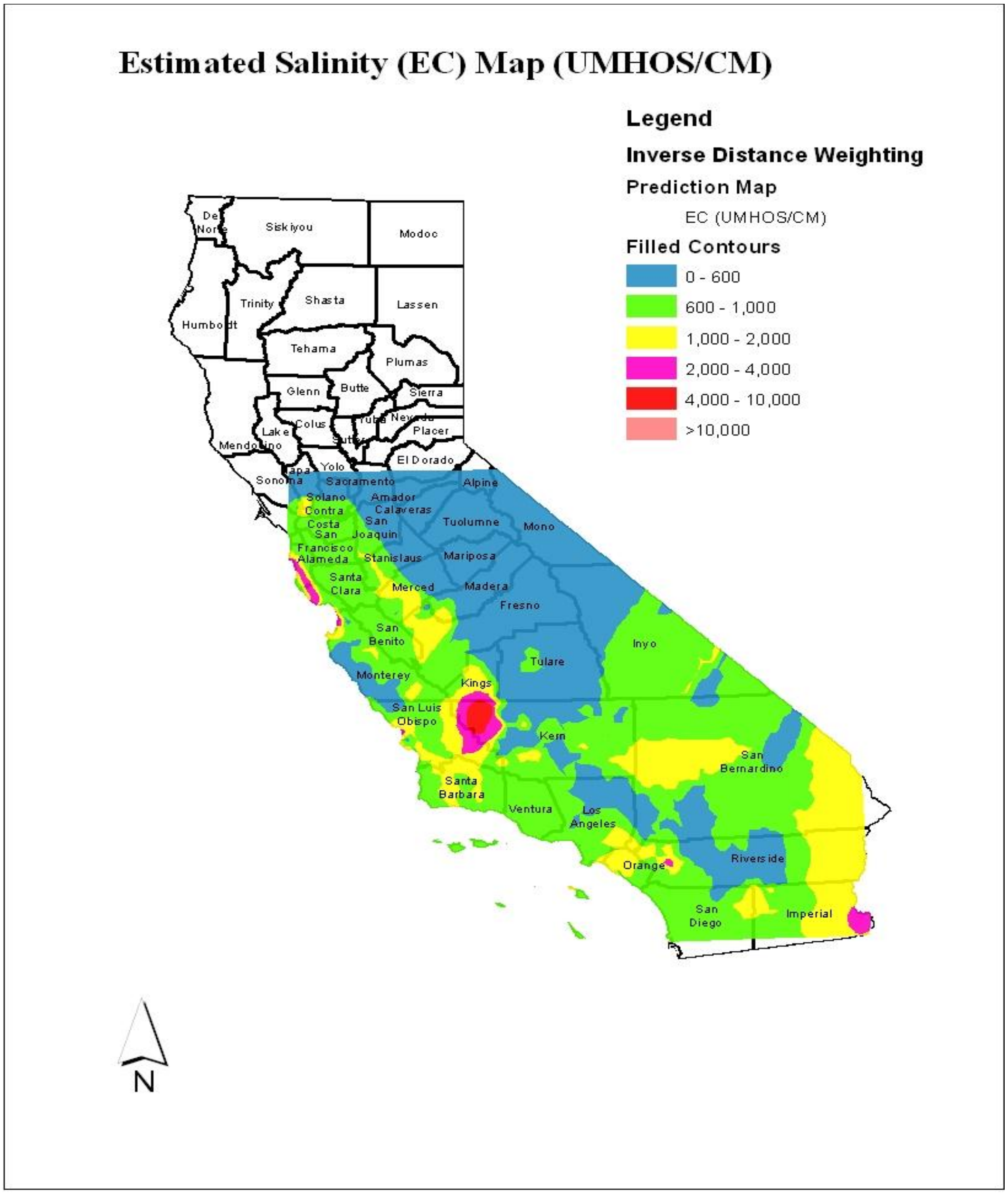

Figure A.2. Estimated surface for groundwater salinity for more regions in California

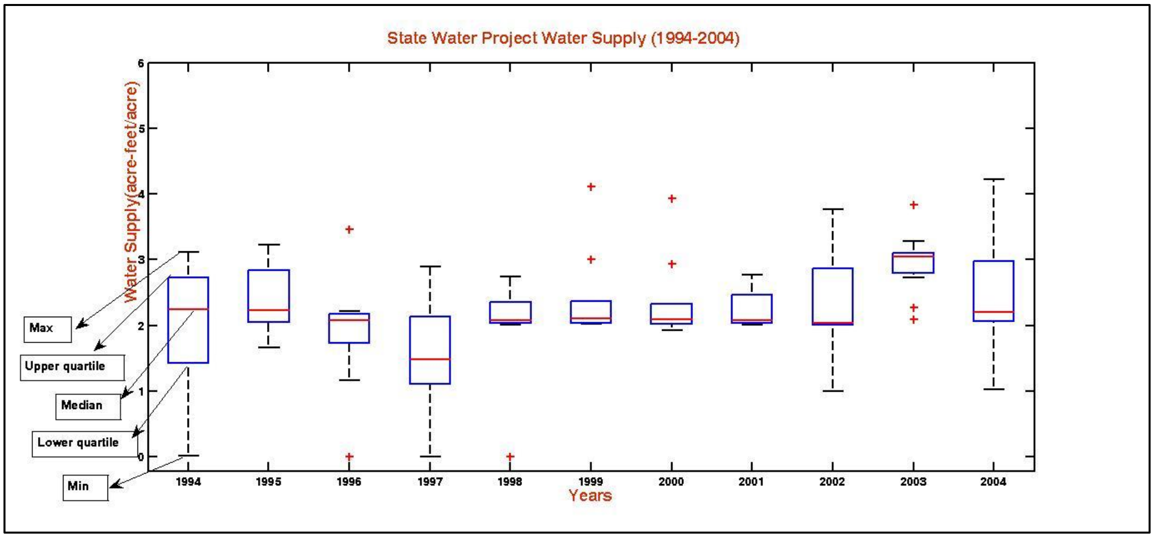

Figure A.3. Whisker Plots showing variability of SWP water supply

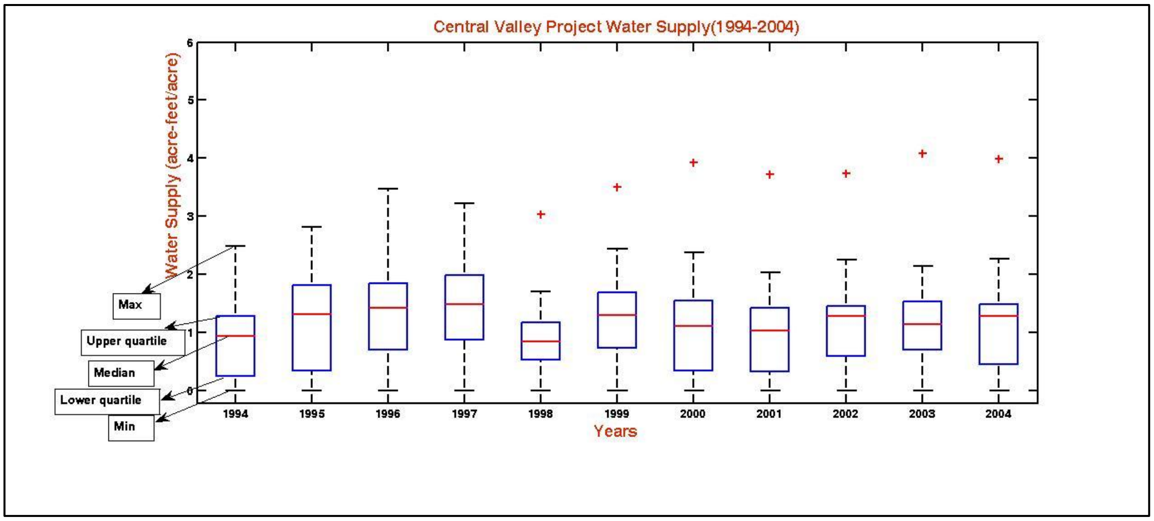

Figure A.4. Whisker Plots showing variability of CVP water supply